Surface finish machining optimization for 3D print

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Abstract. The machining process has been conducted to get better surface results of a 3D print product. However, until now, there has been no optimization of parameters for the procedure. This study aims to obtain the optimal level of surface roughness in the machining process. A total of 27 experiments with the full factorial method were conducted (3 levels for three parameters). In this study, parameters to obtain surface roughness on the x and y-axes are different. On the x-axis, optimal surface roughness is achieved with 40 m / minute cutting speed parameters, 400 mm / minute feed rate, and 0.4 mm depth of cut. Meanwhile, on the y-axis, optimal surface roughness is obtained with 80 m / minute cutting speed parameters, 250 mm / minute feed rate, and 0.4 mm depth of cut.

1. Introduction

3D print technology has been widely used in various industries, such as health, food, automotive, aerospace [1–4]. This technology has many advantages compared to normal machining processes. Its ability to model complex shapes in a short time is one of its benefits.

The use of 3D print machines in the developing world of industry is also accompanied by an increase in quality requirements. One aspect of quality needed is the level of surface roughness [5]. All this time, to get a good surface result, the thickness of the layer must be minimal. However, there is a trade-off for the cost and time. The thinner the layer, the more expensive and more prolonged the process [6,7].

In order to reduce production costs by using 3D print, it can be conducted by post-processing [6,8–10], both manually and machinery. However, this process must be done carefully so as not to change the dimensions of the workpiece. The manual process with human power even has more deficiencies at the level of accuracy.

Post-Processing techniques that are often used are using CNC machines. With the help of CNC, the accuracy of the smoothing results can be obtained. [8,10,11]. Besides, the process does not require a long time. However, until now, there has been no optimization of parameters at the machine to obtain the required surface roughness. This study aims to achieve optimal surface roughness through parameter settings on CNC.

2. Methods

2.1. Material

This study uses a 3D print machine type FDM type GF-C01 produced by PT Centra Teknologi Indonesia (Figure 1). The GF C-01 3D print machine has a work area of 20 cm x 20 cm with a height...
of 20 cm. The device has an accuracy of 0.05 mm to 0.25 mm. The filament used is Polylactic Acid (PLA) with a diameter of 1.75 mm. The printing temperature is 200 °C, with a flow rate of 100%.

The workpiece in this study was made three sides with a height of 10 mm, 12 mm, and 10 mm (Figure 2). The printing process of the workpiece uses the default parameters of the printer with little modification. The top and layer thickness, which was initially 0.8 mm, was changed to 1 mm. This change in parameters is conducted so that the test object is not deformed during machining surfaces.

2.2. Experimental design
In this study, a full factorial method was [12–14]. This method uses all samples to retrieve the data so that an actual result is obtained. However, this method takes a long time because every data must be considered.

The process parameters used in this study are Cutting Speed, Feed Rate, and Depth of Cut. This parameter value is obtained from the results of a pilot study that has been done before. The level of each parameter can be seen in Table 1. Thus, in this experiment, there were three parameters with each of the three levels so that there are $3^3$ (or 27 times) experiment using the full factorial method.

| Parameter       | Level       |
|-----------------|-------------|
|                 | 1           | 2           | 3           |
| Cutting Speed   | 40 m/minute | 60 m/minute | 80 m/minute |
| Feed Rate       | 100 mm/minute | 250 mm/minute | 400 mm/minute |
| Depth of Cut    | 0.2 mm     | 0.3 mm     | 0.4 mm     |

2.3. Machining process
The machining process is carried out using a 3-axis CNC machine. The tool used is a 3 mm diameter endmill with four flutes. The machining process begins with the installation of the workpiece in CNC. After that, setting zero is done by turning the tool and touching it on the x, y, and z sides of the CNC machine. Then the finishing process is conducted on the three sides of the workpiece. An illustration of the workpiece smoothing process can be seen in Figure 3.
2.4. Surface roughness test

The surface roughness testing process is carried out with ISO 1997 standard using Mitutoyo SJ-210. This machine has a range of surface roughness ranging from -200 μm to +140 μm. Data retrieval is done on the x and y-axes, five times each for each experiment. The results are then averaged to get the level of surface roughness on the x and y-axes. The testing process is carried out on glass that has a flat surface so that the data obtained is valid. Illustration of the testing process can be seen in Figure 4.

3. Result and Analysis

From the results of surface roughness testing, data can be seen in Table 2. From these data, the smallest surface roughness on the x-axis is found in experiment 9 with optimal cutting speed parameters of 40 m / minute, 400 mm / minute feed rate, and 0.4 mm depth of cut. Meanwhile, on the y-axis, the smallest surface roughness is found in experiment 24 with optimal cutting speed 80 m / minute, 250 mm / minute feed rate, and 0.4 mm depth of cut. Both have similarities which are found at a depth of cut of 0.4 mm. The next step is to find out the effect of each optimal parameter on the x and y-axis on surface roughness (Ra).

| No | Cutting Speed (m/minute) | Feed Rate (mm/minute) | Depth of Cut (mm) | Surface roughness (μm) |
|----|------------------------|-----------------------|------------------|------------------------|
|    |                        |                       |                  | X                      |
| 1  | 40                     | 100                   | 0.2              | 6.133                  |
| 2  | 40                     | 100                   | 0.3              | 8.131                  |
| 3  | 40                     | 100                   | 0.4              | 9.945                  |
| 4  | 40                     | 250                   | 0.2              | 10.061                 |
| 5  | 40                     | 250                   | 0.3              | 18.645                 |
| 6  | 40                     | 250                   | 0.4              | 5.016                  |
| 7  | 40                     | 400                   | 0.2              | 3.328                  |
| 8  | 40                     | 400                   | 0.3              | 16.388                 |
| 9  | 40                     | 400                   | 0.4              | 2.313                  |
| 10 | 60                     | 100                   | 0.2              | 11.759                 |
| 11 | 60                     | 100                   | 0.3              | 8.861                  |
| 12 | 60                     | 100                   | 0.4              | 5.774                  |
| 13 | 60                     | 250                   | 0.2              | 21.283                 |
| 14 | 60                     | 250                   | 0.3              | 12.649                 |
| 15 | 60                     | 250                   | 0.4              | 3.196                  |
| 16 | 60                     | 400                   | 0.2              | 8.751                  |
| 17 | 60                     | 400                   | 0.3              | 18.837                 |
| 18 | 60                     | 400                   | 0.4              | 9.173                  |
A comparison of surface roughness and cutting speed is carried out on the optimal parameters for each x and y-axis. A comparison is made using graphs that can be seen in Figure 5. From the figure, it can be seen that the smallest surface roughness on the x-axis is obtained at the cutting speed of 40 m/minute, while for the y-axis at cutting speeds of 80 m/minute.

On the x-axis with a cutting speed of 40 m/minute, the workpiece surface does not melt, so the value of the roughness surface is small. When cutting speed is 60 m/minute surface roughness increases and then decreases at a speed of 80 m/minute. It is because when cutting speed is 60 m/minute, the surface of the workpiece melts, but the tool is not able to lift the melt. This melt then attaches to the surface of the workpiece and increases the value of surface roughness. Meanwhile, at cutting speeds of 80 m/minute, the melt can be lifted so that the surface roughness is not too large.

3.1. Surface roughness vs. Cutting speed

On the y-axis, the value of surface roughness decreases with increasing speed. It is because the melt on the surface of the workpiece falls due to the force of gravity. The tool does not need to lift the melt from the surface of the workpiece. So the results obtained will get better along with the increase in cutting speed.
3.2. Surface roughness vs. Feed Rate

A comparison of surface roughness and feed rate at optimal parameters for each x and y-axis can be seen in Figure 6. From the figure, it can be seen that the smallest surface roughness on the x-axis is obtained at a feed rate of 400 mm/minute, while for the y-axis the feed rate is 250 mm/minute. We need further research on the causes of this.

![Figure 6. Comparison of surface roughness and feed rate](image)

On the x-axis, the higher the cutting speed, the smaller the value of the surface roughness will be. When the feed rate value is low, friction will occur more often, causing heat and melting the surface. It causes surface roughness to be high. On the y-axis, the value of surface roughness is not too different for each feed rate value. The amount of the feed rate at a speed of 250 mm/minute has decreased and then increased slightly at a feed rate of 400 mm/minute.

3.3. Surface roughness vs. Depth of Cut

A comparison of surface roughness and depth of cut at optimal parameters for each x and y-axis can be seen in Figure 7. From the picture, it can be seen that the smallest surface roughness on the x and y-axis is obtained at a depth of cut of 0.4 mm.

On the x-axis, the value of surface roughness at the 0.3 mm depth of cut has increased. It happens because of the printing parameters with the GF C-01 3D print engine that uses a 0.2 mm layer height and nozzles with a diameter of 0.4 mm. At the 0.3 mm depth of cut, the feeding process will leave half the layer or 0.1 mm. The rest of the feed is partially lifted, and some of it will stick to the surface so that it will increase the value of Ra on the surface. On the y-axis, the amount of surface roughness at 0.4 mm depth of cut has decreased dramatically. It happens because the feeding process takes place without leaving any residual ingestion as occurs on the x-axis.
4. Conclusion

Based on the results of this study, the optimal parameter values for surface smoothing on the x-axis are obtained at 40 m / minute cutting speed, 400 mm / minute feed rate, and 0.4 mm depth of cut. While the optimal parameters on the y-axis are cutting speed 80 m / minute, feed rate 250 mm / minute, and depth of cut 0.4 mm. Each parameter has a different influence on the level of surface roughness. In doing surface machining on the 3d print results, it is necessary to pay attention to the machine parameters and also the printing process, because it can affect the machining process. In addition, the research carried out is only based on PLA material, for other materials, further research is needed.

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