Optimization of Process Variables in 3D Printing on Dimensional Accuracy Using Nylon Filaments

Optimasi Variabel Proses Pada 3D Printing Terhadap Akurasi Dimensi Menggunakan Filamen Nylon

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Abstract—Manufacturing process over the past 50 years has led to very rapid and continuous progress in the manufacturing industry, one of the manufacturing processes that has progressed is 3D printing technology. The type of filament used in this research is nylon filament. This study aims to obtain optimal process parameters for dimensional accuracy. The method used in this study is the Taguchi L27 OA method. The process parameters used are nozzle temperature, bed temperature, layer thickness, flowrate, printing speed, overlap, infill density, infill speed, wall thickness. The results showed that the optimal process parameters are nozzle temperature (256°C), bed temperature (96°C), layer thickness (0.2 mm), flowrate (90%), printing speed (30 mm/s), overlap (10%).

Keywords: 3D printing; Accuracy; Dimensions; Nylon; Parameter;

Over the last 50 years, the manufacturing process has resulted in rapid and continuous progress in the manufacturing industry [1]. One of the progressive manufacturing processes is 3D printing technology, which is rapidly developing in the manufacturing industry [2]. 3D printing has numerous applications, one of which is the production of finished products such as mugs and bowls of various shapes. However, it has a flaw in the product printing process that is related to dimensional accuracy in this case. As a result, the final product is still not in accordance with the desired design because the product’s size has decreased or increased in comparison to the desired size. In connection with these shortcomings, it is necessary to have the right process parameters on a 3D printer to get a product or printout with good dimensional accuracy. [3].

Several studies on the process parameters of this 3D printer have been carried out by researchers. Research on the effect of process parameters on tensile strength and dimensional accuracy using nylon filament using the Taguchi L9 OA method shows that the most influential process parameter on dimensional accuracy is Layer thickness [4]. The best process parameters use a nozzle temperature of 90°C, bed temperature of 55°C, and a layer thickness of 0.2 mm [3]. Research on the effect of process parameters on dimensional accuracy using nylon filaments obtained the parameters that most affect the response to the dimensional accuracy of 3D printing nylon 6 products showing different results on the four dimensions, layer thickness parameter is the most influential factor on the response of LO and WO dimensions with the value of the percent contribution of 42.0802% and the value of the percent contribution of WO is 18.9439% while for the dimensions w and T the most influential parameters are generated by the nozzle temperature parameter with the contribution value of w of 60.1022% and the value of the contribution of T of 43.3853% [5].

Research on the effect of process parameters on dimensional accuracy using PLA filaments shows that to achieve good dimensional accuracy, a smaller layer thickness is needed, a lower extrusion temperature and infill percentage, and a hexagonal infill pattern [6]. Dimensional accuracy research using filament Eflex the most dominant parameter is layer thickness from parameter settings flowrate, layer thickness, nozzle temperature, printing speed, overlap, and fan speed [7].

According to the research, this study was carried out to optimize the 3D process parameters by focusing on nine process parameters, namely Nozzle
Temperature(°C), Bed Temperature(°C), Layer Thickness(mm), Wall Thickness (mm), Flowrate(%), Print Speed(mm/s), overlap(%), infill density(%), infill speed(mm/s) with Taguchi L27 OA method using nylon filament for dimensional accuracy. Using predetermined process parameters, this study aims to obtain the most optimal process parameters for dimensional accuracy of nylon nylon filament.

**METHOD**

This study uses nylon filament because it has the advantages of being strong and flexible, high impact resistance, does not cause unpleasant odors when printing, and has high abrasion resistance, so it will be very good if used for ready-to-use products. With the experimental method used to obtain the most optimal process parameters for dimensional accuracy. The stages of the research process are shown in the flow chart in Figure 1.

After the level values and process parameters are determined, the next step is to design the factorial of the Taguchi L27 OA (Orthogonal Array) method using analysis software. The results of the factorial design are presented in Table 2.

### Table 1 Level Value and Process Parameter

| Code | Factor                        | Level 1 | Level 2 | Level 3 |
|------|--------------------------------|---------|---------|---------|
| A    | Nozzle Temperature(°C)         | 256     | 258     | 260     |
| B    | Bed Temperature(°C)            | 95      | 98      | 100     |
| C    | Flowrate(%)                    | 90      | 95      | 100     |
| D    | Printing Speed(mm/s)           | 25      | 30      | 35      |
| E    | Layer Thickness(mm)            | 0.2     | 0.24    | 0.28    |
| F    | Wall Thickness (mm)            | 0.8     | 1.0     | 1.2     |
| G    | Overlap(%)                     | 5       | 10      | 15      |
| H    | Infill Density(%)              | 20      | 25      | 30      |
| I    | Infill Speed(mm/s)             | 20      | 25      | 30      |

### Table 2 Taguchi L27 OA Factorial Design

| No  | A   | B   | C   | D   | E   | F   | G   | H   | I   |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | 256 | 90  | 0.20| 90  | 30  | 5   | 20  | 25  | 0.8 |
| 2   | 256 | 90  | 0.20| 90  | 35  | 10  | 25  | 30  | 1.0 |
| 3   | 256 | 90  | 0.20| 90  | 40  | 15  | 30  | 35  | 1.2 |
| 4   | 256 | 95  | 0.24| 95  | 30  | 5   | 20  | 30  | 1.0 |
| 5   | 256 | 95  | 0.24| 95  | 40  | 15  | 30  | 35  | 1.2 |
| 6   | 256 | 95  | 0.24| 95  | 40  | 15  | 30  | 35  | 0.8 |
| 7   | 256 | 100 | 0.28| 100 | 30  | 5   | 20  | 35  | 1.2 |
| 8   | 256 | 100 | 0.28| 100 | 35  | 10  | 25  | 35  | 0.8 |
| 9   | 256 | 100 | 0.28| 100 | 40  | 15  | 30  | 30  | 1.0 |
| 10  | 258 | 90  | 0.24| 90  | 30  | 10  | 30  | 25  | 1.0 |
| 11  | 258 | 90  | 0.24| 100 | 35  | 15  | 20  | 30  | 1.2 |
| 12  | 258 | 90  | 0.24| 100 | 40  | 5   | 25  | 35  | 0.8 |
| 13  | 258 | 95  | 0.28| 90  | 30  | 10  | 30  | 30  | 1.2 |
| 14  | 258 | 95  | 0.28| 90  | 35  | 15  | 20  | 35  | 0.8 |
| 15  | 258 | 95  | 0.28| 90  | 40  | 5   | 25  | 25  | 1.0 |
| 16  | 258 | 100 | 0.20| 90  | 30  | 10  | 30  | 35  | 0.8 |
| 17  | 258 | 100 | 0.20| 90  | 35  | 15  | 20  | 25  | 1.0 |
| 18  | 258 | 100 | 0.20| 95  | 40  | 5   | 25  | 30  | 1.2 |
| 19  | 260 | 90  | 0.28| 90  | 35  | 15  | 25  | 25  | 1.2 |
| 20  | 260 | 90  | 0.28| 95  | 35  | 5   | 30  | 30  | 0.8 |
| 21  | 260 | 90  | 0.28| 95  | 40  | 10  | 20  | 35  | 1.0 |
| 22  | 260 | 95  | 0.20| 100 | 30  | 15  | 25  | 30  | 0.8 |
| 23  | 260 | 95  | 0.20| 100 | 35  | 5   | 30  | 35  | 1.0 |
| 24  | 260 | 95  | 0.20| 100 | 40  | 10  | 20  | 25  | 1.2 |
| 25  | 260 | 100 | 0.24| 90  | 30  | 15  | 25  | 35  | 1.0 |
| 26  | 260 | 100 | 0.24| 90  | 35  | 5   | 30  | 25  | 1.2 |
| 27  | 260 | 100 | 0.24| 90  | 40  | 10  | 20  | 30  | 0.8 |
In Table 2 it is used for the G-code manufacturing process and then used for printing dimensional accuracy test specimens. This specimen will be printed with three replications for each specimen.

1.2 Preparation of Tools and Materials
The tools used in this research are the Anycubic 4max 3D Printing machine which is used to print test specimens, the Asus brand laptop which is used to run the software that will be used in the research, the slicing software to get the G-code, dry box filament is used to dry the filament during the experiment, the printing process, a micrometer with an accuracy of 0.001 mm was used to measure the test specimen, and the material used was nylon filament with a diameter of 1.75mm and black.

1.3 Object of research
The object of research carried out on a 3D printer is a specimen with object dimensions 10mm x 10mm as shown in Figure 2. Specimen Design using CAD software in STL format then processed in slicing software to get G-code which will be saved to the SD card and then inserted into the 3D printer.

1.4 Product Dimension Measurement
Printed specimens are measured to determine the dimensional accuracy of the finished product. Measurement of the dimensions of this specimen using a micrometer with an accuracy of 0.001 mm. The dimensions measured are the Outside Diameter of the Specimen with measurements at three different points.

2. RESULTS AND DISCUSSION
The results of printing specimens with three replications in each specimen using the Taguchi L27 OA factorial design method in Table 2 will be shown in Figure 3.

![Figure 3 Printed Specimens](image)

Table 3 Results of Measurement of the Outside Diameter of the Specimen

| EXP. No. | Preliminary data | Replication 1 | Replication 2 | Average |
|----------|-----------------|---------------|---------------|---------|
| 1        | 9,806           | 9,834         | 9,834         | 9,834   |
| 2        | 9,793           | 9,799         | 9,799         | 9,799   |
| 3        | 9,742           | 9,813         | 9,813         | 9,813   |
| 4        | 9,922           | 9,887         | 9,887         | 9,887   |
| 5        | 9,928           | 9,871         | 9,871         | 9,871   |
| 6        | 9,952           | 9,893         | 9,893         | 9,893   |
| 7        | 9,981           | 9,929         | 9,929         | 9,929   |
| 8        | 9,984           | 9,914         | 9,914         | 9,914   |
| 9        | 9,953           | 9,924         | 9,924         | 9,924   |
| 10       | 9,958           | 9,967         | 9,967         | 9,967   |
| 11       | 9,971           | 9,968         | 9,968         | 9,968   |
| 12       | 9,982           | 9,962         | 9,962         | 9,962   |
| 13       | 9,985           | 9,991         | 9,991         | 9,991   |
| 14       | 9,986           | 9,982         | 9,982         | 9,982   |
| 15       | 9,911           | 9,985         | 9,985         | 9,985   |
| 16       | 9,965           | 9,977         | 9,977         | 9,977   |
| 17       | 9,975           | 9,967         | 9,967         | 9,967   |
| 18       | 9,966           | 9,976         | 9,976         | 9,976   |
| 19       | 9,976           | 9,986         | 9,986         | 9,986   |
| 20       | 9,985           | 9,972         | 9,972         | 9,972   |
| 21       | 9,943           | 9,970         | 9,970         | 9,970   |
| 22       | 9,944           | 9,978         | 9,978         | 9,978   |
| 23       | 9,927           | 9,972         | 9,972         | 9,972   |
| 24       | 9,950           | 9,969         | 9,969         | 9,969   |
The Taguchi method is used to process measurement data in order to obtain optimal process parameters that affect the dimensional accuracy test results. The data is processed using analysis software in which the values in Table 3 are entered, and the measurement data is entered into the analysis software to obtain the Mean Plot and S/N Ratio results with "smaller is better" quality because the smaller the deviation, the better the dimensional accuracy.

Figure 4 and Table 4 show the results of the analysis software calculation on the accuracy of the dimensions of the outside diameter of the specimen, while Figure 5 and Table 5 show the S/N Ratio.

Table 4 Results Mean Plot Outside Diameter of Specimen

| Response Table for Mean | Factor | Level 1 | Level 2 | Level 3 | Delta | Rank |
|-------------------------|--------|---------|---------|---------|-------|------|
| A                       | 9,987  | 9,974   | 9,974   |         |       | 1    |
| B                       | 9,966  | 9,956   | 9,956   |         |       | 2    |
| C                       | 9,979  | 9,967   | 9,967   |         |       | 3    |

Figure 4 Graph of the Mean Plot Outer Diameter of the Specimen

Table 5 S/N Ratio Outside Diameter of Specimen

| Response Table for Signal to Noise Ratios | Factor | Level 1 | Level 2 | Level 3 | Delta | Rank |
|------------------------------------------|--------|---------|---------|---------|-------|------|
| A                                        | -19.89 | -19.98  | -19.98  |         | 0.09  | 1    |
| B                                        | -19.93 | -19.95  | -19.96  |         | 0.03  | 3    |
| C                                        | -19.93 | -19.95  | -19.97  |         | 0.04  | 2    |
| D                                        | -19.93 | -19.95  | -19.96  |         | 0.03  | 4    |
| E                                        | -19.95 | -19.94  | -19.95  |         | 0.01  | 5    |
| F                                        | -19.95 | -19.94  | -19.95  |         | 0.01  | 6    |
| G                                        | -19.95 | -19.95  | -19.95  |         | 0.00  | 8    |
| H                                        | -19.95 | -19.95  | -19.95  |         | 0.00  | 9    |
| I                                        | -19.95 | -19.95  | -19.95  |         | 0.00  | 7    |

Figure 5 Graph of S/N Ratio of Specimen Outside Diameter

3. CONCLUSION

Based on the results of the measurement of the outer diameter of the printed object specimen in Table 3 and the results of the analysis software data processing, it can be concluded that the optimal process parameter values for the accuracy of the dimensions of the outer diameter of the specimen are nozzle temperature (256°C), bad temperature (96°C), layer thickness (0.2mm), infill density (25%), and Infill speed (30mm/s).
and Infill speed(30mm/s), and wall thickness (1.0mm ).

For further research, it can be added or used more process parameters and levels, because the more parameters or levels used, the optimal parameter values for dimensional accuracy found, the better.

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