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# Optimization of 3D Printing Parameter Process for Product Tensile Strength from PLA Materials Using the Taguchi Method

I Made Londen Batan[1]*, Arleta Listiyana Chandradewi[2], Arif Wahjudi[3] and Dinny Harnany[4]
[*1,2,3,4]Department of Mechanical Engineering, ITS, Sukolilo Surabaya 60111, Indonesia

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**Abstract**

Three-dimensional printing or 3D Printing is one of the revolutionary machines in addictive manufacturing techniques to create three-dimensional objects with complex structures. Until now, there are many techniques in 3D printing, one of which is Fused Deposition Modeling (FDM), which is widely used because of its ease and low operational costs. However, in the printing process, important things must receive attention, namely the process parameters, because this determines the printout's quality. This research analyzed the effect of process parameters such as infill rate, infill pattern, extrusion temperature, and layer thickness on the printed product's tensile strength. The Taguchi method with the Orthogonal Array $L_9$ ($3^4$) experimental design is used. Three tensile test specimens were printed for each variation using a Cubic Chiron 3D printer, so 27 specimens were printed. All specimens were tensile tested according to ASTM D638 standard. The results were analyzed based on the average and signal-to-ratio (SNR) values and their significance by analysis of variance (ANOVA). The analysis results show that the infill rate, infill pattern, and layer thickness significantly affect the tensile strength of the printing results. The optimal tensile strength value is 56.876 MPa, which occurs in the concentric pattern with an infill rate of 90% and a layer thickness of 0.2 mm. The confidence interval values were obtained from 55.477 MPa to 58.275 MPa from the confirmation test, meaning that the optimal predictive value was not significantly different from the confirmation test value.

**Keywords: Fused Deposition Modeling, 3D printing, parameters, tensile strength**

## 1. Introduction

Three-dimensional printing machines, often called 3D printing, are revolutionary machines in additive manufacturing techniques to create three-dimensional objects with unique and varied structures. These techniques until now include Fused Deposition Modeling (FDM), Polylactic Acid (PLA), Stereolithography Apparatus (SLA), Acrylonitrile Butadiene Styrene (ABS), Continuous Liquid Interface Production (CLIP), Digital Light Processing (DLP), and Selective Laser Sintering (SLS). In the late 1980s, S. Scott Crump developed FDM 3D printing, and was commercialized in the 1990s by Stratasys. FDM is a 3D printing method widely applied to object modeling because of its ease and low operational costs. It is environmentally friendly, almost resembling the original product's shape [1–4]. 3D printing is also beneficial for making prototypes of medical devices, especially equipment used for medical applications [5, 6].

The 3D Printing process has various parameters, such as layer thickness, printing density, infill pattern, extrusion temperature, printing orientation, and nozzle diameter. In addition to these parameters, the filament material used as filler has different mechanical and physical characteristics. This difference allows for different object results for each filament [7]. Various studies on the capabilities and process parameters of 3D printing with various types of filaments have been carried out, such as Lay Makara et al. compared the mechanical properties of PLA, ABS, and Nylon 6 materials which were fabricated using two machines, namely 3D printing and injection moulding. The results of this study show that with the same material, the mechanical properties of prints with injection machines and 3D printings are different. The tensile strength and impact of injection moulding results are higher than that of 3D printing [8]. A 3D Printing experiment was carried out with process parameters: printing angle, layer thickness, infill rate, and nozzle temperature. By using PLA as the filament material, the research results show that the layer thickness parameter affects the printing time and the object's accuracy and tensile strength [9]. In another way, an experiment was carried out on printing ABS material using 3D printing with the input parameters of infill pattern, infill density, and layer thickness. The results of the experimental tensile test showed that the product's tensile strength increased with an increase in the infill density printed sequentially from triangular, grid, and cubic patterns. In this research, the tensile strength

*Corresponding author. Email: londbatan@me.its.ac.id

has a maximum value when the layer thickness decreases and the infill pattern with the order of triangular, grid, and cubic patterns. For the last parameter, it shows that the maximum tensile strength is achieved when the infill density increases and the layer thickness decreases [10–13]. The other research to optimize the process parameters in 3D printing using the Taguchi method is conducted through the impact specimen. The process parameters are deposition speed, layer thickness, and infill density. Filament types as material are Acrylonitrile Butadiene styrene (ABS) and Polylactide (PLA). Thermoplastics are predominantly used in the process. The experimental result showed that from the S/N ratio graphs, the best combination of deposition speed of 40 mm/s, layer thickness of 0.4 mm, and infill density of 25% for minimum build time [14]. Furthermore, in 2021, an experiment was carried out regarding the effect of 3D printing parameters, especially layer thickness and printing speed, on the tensile strength value of products made of PLA material. The experimental results show that the thinner the layer thickness and the lower the printing speed, the higher the resulting tensile strength [15].

This research conducted an experimental study of the effect of 3D printing process parameters on tensile strength, particularly infill rate, infill pattern, extrusion temperature, and layer thickness. The material used is PLA, the data is analysed using the Taguchi method, and the results of the tensile strength test are confirmed so that the relationship between the parameters of the printing process and the tensile strength can be identified.

## 2. Experimental

A. Taguchi Method Experiment Design

This study will test four parameters, namely infill pattern, layer thickness, extrusion temperature, and infill rate, each in 3 levels. The types of infill patterns tested were Grid, Triangles, and Concentric types. The selected layer thicknesses were 0.10 mm, 0.20 mm, and 0.30 mm, respectively, at extrusion temperatures of 200°C, 210°C, and 220°C, at 30%, 60%, and 90% infill rate. The results of the printing of the variance of the object were tested for tensile, analyzed the results of the tensile strength, then the most optimal combination of parameters was selected, with the Taguchi Orthogonal Array $L_9$ $(3^4)$ experimental design as shown in table 1.

B. Specimen Printing

Based on the ASTM D638 standard, tensile test specimens as research objects are drawn in 3D CAD and stored in STL format (Stereolithography file format). The shape and size of the tensile test specimen can be seen in Figure 1 [16]. The next step is slicing and setting the variance of the parameters used in the printing process with the help of Ultimaker Cura 4.9.0 software. The slicing results are shown in Figures 2 and 3. Specimens were printed for each experiment, namely specimens A, B, and C. Design files of slicing results in g.code (G-code), ready to be inputted into the 3D printing. After setting the parameters in the software, the next step is the specimen printing process using the Chiron Cubic 3D Printing machine, while the filament material used is PLA. The dimensions of the specimens are measured, and in accordance with ASTM D638 Type IV, the dimensions of the tensile test specimens must comply with the provisions, such as a length of 115 mm with a maximum tolerance of 0.5 mm, gauge width of 6 mm with a maximum tolerance of 0.5 mm, and specimen thickness not exceeding from 4 mm. There were nine printing experiments carried out. In each experiment, three specimens were printed. For example, there were three specimens for number 1: 1A, 1B, and 1C. The overall result of the tensile test is 27 specimens, as shown in Figure 4.

C. Specimen Tensile Test

The specimen tensile test was carried out on the Hung Ta HT-2402 Tensile Test Machine, and the testing process can be seen in Figure 5, where Figure 5(a) shows the clamping of the specimen, and Figure 5(b) shows the specimen breaking after the tensile test.

**Table 1.** The Design Experiment of Orthogonal Array $L_9$ $(3^4)$

| EXP | Infill Rate (%) | Extrusion Temperature ($^{O}$C) | Layer Thickness (mm) | Infill Pattern |
|---|---|---|---|---|
| 1 | 30 | 200 | 0.1 | Grid |
| 2 | 30 | 210 | 0.2 | Triangles |
| 3 | 30 | 220 | 0.3 | Concentric |
| 4 | 60 | 200 | 0.1 | Concentric |
| 5 | 60 | 210 | 0.2 | Grid |
| 6 | 60 | 220 | 0.3 | Triangles |
| 7 | 90 | 200 | 0.1 | Triangles |
| 8 | 90 | 210 | 0.2 | Concentric |
| 9 | 90 | 220 | 0.3 | Grid |

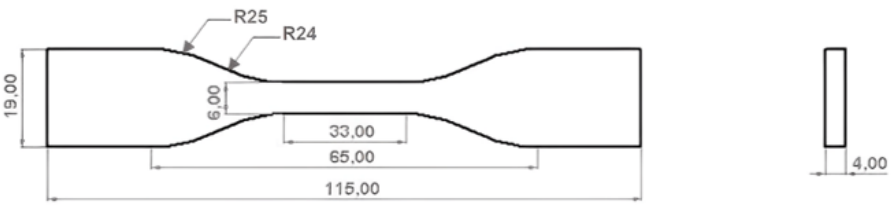



**Figure 1.** Dimensions of tensile test specimens according to ASTM D638

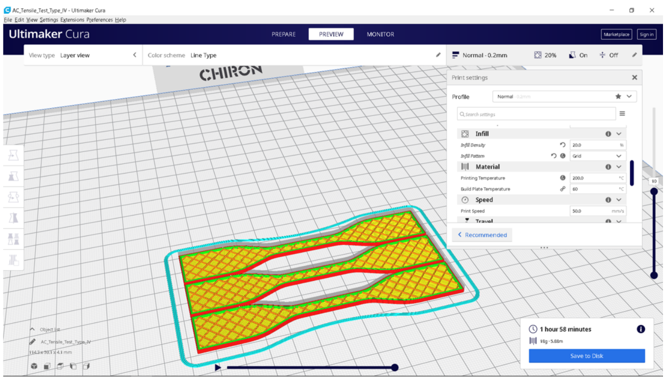



**Figure 2.** Display settings on the Ultimaker Cura 4.9.0 software

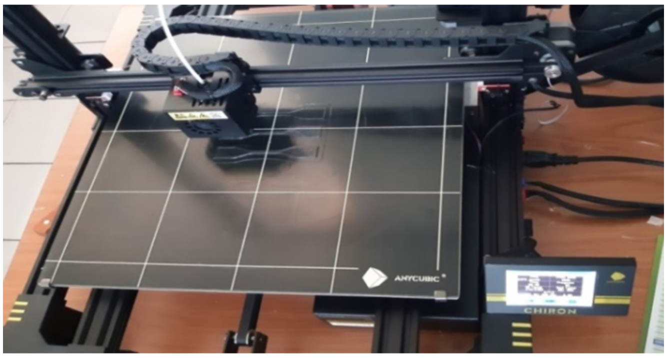


**Figure 3.** Process for printing test specimens

## 3. Results and Discussions

A. Specimen Tensile Test Result Data

As shown in Figure 4, this study focuses on optimizing the tensile strength values based on optimized printing process parameters. With the experimental design, as in Table 1, the results of the tensile test of the specimen in nine printing product experiments can be seen in Table 2. The results of these measurements were obtained from 27 specimens shown in Figure 4.

B. Calculation of Analysis of Variance

Analysis of variance (ANOVA) needs to be done to determine whether the selected parameters have a significant effect on the object's tensile strength. Analysis of variance was carried out in the study using the following hypotheses:

$H_0$: $\tau 1 = \tau 2 = \tau 3$
$H_1$: at least one of $\tau$i is different
$H_0$: $\beta 1 = \beta 2 = \beta 3$
$H_1$: at least one of $\beta$i is different
$H_0$: $\gamma 1 = \gamma 2 = \gamma 3$
$H_1$: at least one of $\gamma$i is different
$H_0$: $\delta 1 = \delta 2 = \delta 3$
$H_1$: at least one of $\delta$i is different

Information:
$\tau$i: parameter infill rate level i
$\beta$i: parameter temperature level i
$\gamma$i: layer thickness parameter of level i
$\delta$i: parameter infill pattern of level i

The analysis of variance used is the General Linear Model ANOVA. With the tensile test experimental data listed in Table 2, variance analysis was carried out using Minitab software, and the results can be seen in Table 3. The null hypothesis ($H_0$) states that no significant difference exists between the means of the groups being compared. The alternative hypothesis ($H_1$) states that there is a significant difference between the means of the groups being compared. In the context of Analysis of Variance (ANOVA), the determination of whether to accept or reject the null hypothesis is contingent upon a predefined significance level denoted as "alpha" ($\alpha$). This significance level serves as a critical threshold for evaluating the statistical test results. When the computed p-value, representing the probability of obtaining observed or more extreme results under the assumption that the null hypothesis is true, falls below the alpha level, it leads to the rejection of the null hypothesis. Consequently, this outcome signifies a statistically significant disparity among the means of the groups under scrutiny. Conversely, if the p-value exceeds the alpha threshold, it fails to reject the null hypothesis, signifying insufficient evidence to assert a significant difference in the means of the compared groups. Thus, the alpha level is a pivotal criterion in ANOVA for making informed statistical inferences regarding group mean differences.

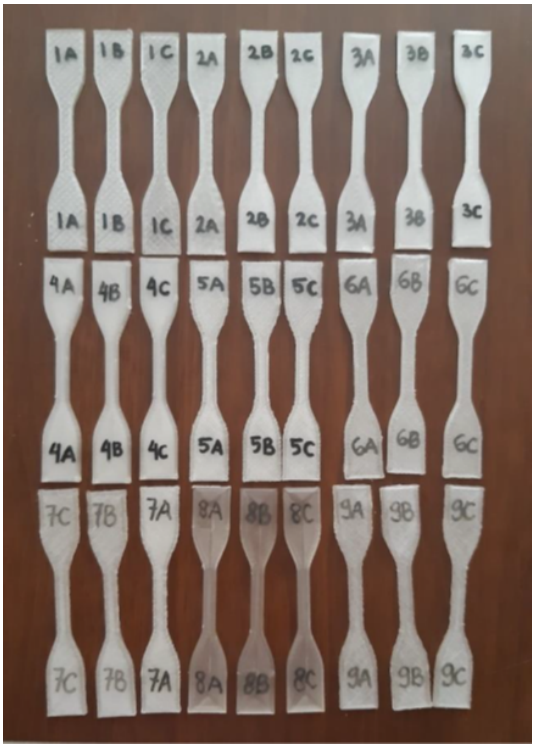
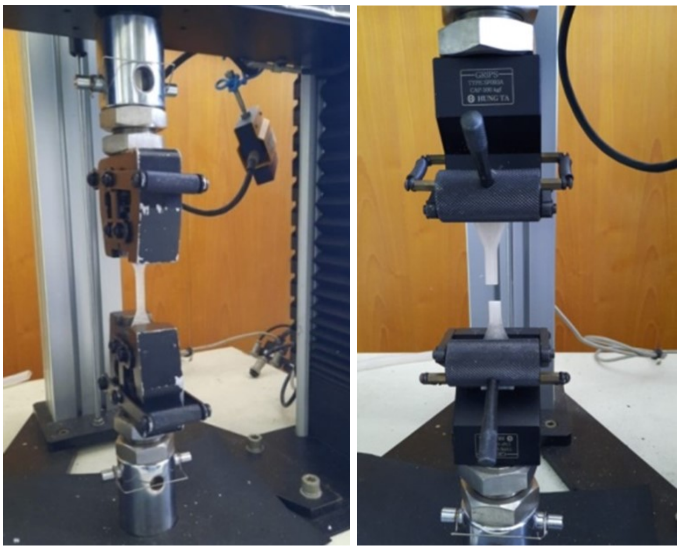


**Figure 4.** The results of printing all specimens amounted to 27 specimens



**(a)** **(b)**

**Figure 5.** Specimens on a tensile testing machine (a) before pulling and (b) after breaking

**Table 2.** The result of the Tensile Strength Measurement

| EXP. | Infill Rate (%) | Extrusion Temperature ($^oC$) | Layer Thickness (mm) | Infill Pattern | Tensile Strength (N/mm2) | | |
|---|---|---|---|---|---|---|---|
| | | | | | A | B | C |
| 1 | 30 | 200 | 0.1 | Grid | 41.33 | 41.98 | 40.63 |
| 2 | 30 | 210 | 0.2 | Triangles | 44.71 | 43.60 | 45.42 |
| 3 | 30 | 220 | 0.3 | Concentric | 49.04 | 47.05 | 47.61 |
| 4 | 60 | 200 | 0.1 | Concentric | 51.17 | 51.70 | 52.42 |
| 5 | 60 | 210 | 0.2 | Grid | 48.32 | 47.41 | 47.94 |
| 6 | 60 | 220 | 0.3 | Triangles | 39.48 | 39.83 | 41.85 |
| 7 | 90 | 200 | 0.1 | Triangles | 51.37 | 49.19 | 50.90 |
| 8 | 90 | 210 | 0.2 | Concentric | 52.50 | 52.43 | 54.00 |
| 9 | 90 | 220 | 0.3 | Grid | 53.06 | 55.12 | 54.43 |

Based on the analysis results in Table 3, and with a significant level of 95% ($\alpha = 0.05$), it can be concluded that the infill rate, layer thickness, and infill pattern parameters have a P-value that is smaller than the $\alpha$ value, which is 0.00 (<0.05). Those parameters' P-value causes $H_0$ to be rejected so that this parameter significantly affects the tensile strength value. At the same time, the temperature parameter has a higher P-value than the $\alpha$ value, which is 0.108 (> 0.05). This P-value causes $H_0$ to fail to be rejected, so it is concluded that the temperature parameter has no significant effect on the tensile strength value, and then the temperature parameter is not optimized.

C. Process Optimization Analysis

To find out the optimal value for each parameter, the data that has been collected is then processed using two methods, namely the analysis of the experimental average (mean) and the analysis of the signal-to-noise ratio (SNR). This data processing is done using the software.

a) Calculation of Average Value Analysis

The average (mean) tensile strength $y_1$ consists of the sum of the responses in experiments 1, 2, and 3 from Table 2, and its value is calculated using equation 1. As an example of calculating the average tensile strength value in an experiment with the infill rate parameter for the 30% level is:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} y_i$$
$$\mu_{11} = \frac{(41.33 + 41.98 + ... + 47.61)}{9} = 44.60MPa \quad (1)$$

Where:
$\mu$: average value for certain parameters and levels
$n$: the amount of data tested
$y_i$: tensile strength value on the i-th specimen

**Table 3.** Experimental data

| Source | DF | Sq SS | Adj SS | Adj MS | F-value | P-value |
|---|---|---|---|---|---|---|
| Infill Rate | 2 | 307.542 | 307.542 | 153.771 | 177.02 | 0.000 |
| Temperature | 2 | 4.381 | 4.381 | 2.190 | 2.52 | 0.108 |
| Layer Thickness | 2 | 135.287 | 135.287 | 67.543 | 77.87 | 0.000 |
| Infill Pattern | 2 | 147.992 | 147.992 | 73.996 | 85.19 | 0.000 |
| Error | 18 | 15.636 | 15.636 | 0.869 | | |
| Total | 26 | 610.837 | | | | |
| S=0.932013 R-Sq=97.44% R-Sq (adj)=96.30% | | | | | | |

**Table 4.** Calculation results of the average tensile strength (MPa)

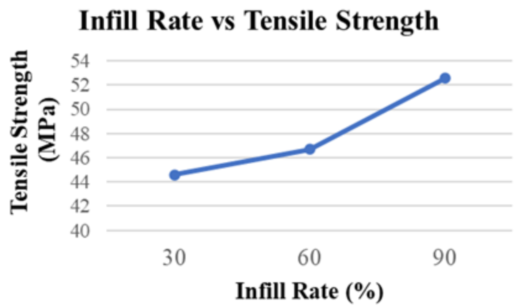
| Level | Infill Rate | Layer Thickness | Infill Pattern |
|---|---|---|---|
| 1 | 44.60 | 44.89 | 47.81 |
| 2 | 46.68 | 50.19 | 45.15 |
| 3 | 52.57 | 48.76 | 50.88 |

In the same way, the calculation of the average (mean) tensile strength value for each parameter is carried out, and the results are shown in Table 4.

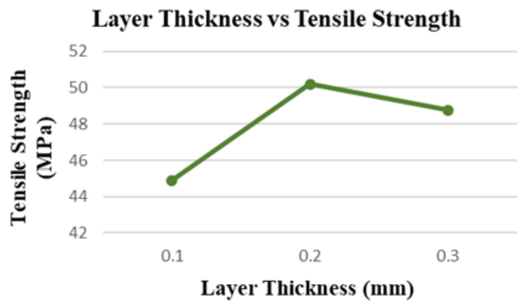
With the experimental design as in Table 1, the average tensile strength results for each level are shown in the graph, as shown in Figure 6. Table 4 and the graph in Figure 6 show that each specimen in each variation has a different tensile strength. For the infill rate parameter with a level of 30%, the average value is 44.60 MPa, the 60% level is 46.68 MPa, and the 90% level is 52.57 MPa. Based on the graph, it can be seen that the greater the infill rate on the specimen, the greater the tensile strength value. The infill rate parameter with the highest tensile strength value is the 90% level. The greater the infill rate, the denser the specimen will be in the 3D printing. In other words, the greater the specimen's filling (higher density), the greater its strength against external forces, and vice versa.

For the layer thickness parameter with a level of 0.1 mm, an average value was obtained of 44.89 MPa. For a level of 0.2 mm, it was 50.19 MPa; for a level of 0.3 mm, it was 48.76 MPa. In the layer thickness parameter graph, the highest average tensile strength value is at 0.2 mm thickness. In principle, thickness will affect the tensile stress of a specimen. Test results show that PLA material is brittle [5, 7, 12]. Based on Hooke's law, strain depends on the increase in length and the initial length of the specimen. Experimental tests show that a thickness of 0.2 mm provides the highest tensile stress value, meaning that the tensile stress occurs at the highest before the specimen breaks, namely at a thickness of 0.2 mm.

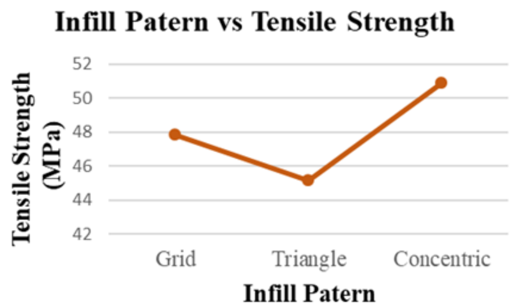
Finally, for the infill pattern parameter with the grid level, an average value of 47.81 MPa was obtained. The triangle level obtained 45.15 MPa, while the concentric level obtained 50.88 MPa. The concentric level is the infill pattern parameter with the highest average tensile strength value. Concentric has the greatest tensile strength value because this grid allows the load to be distributed evenly. Even load distribution reduces the possibility of weak points susceptible to cracking (failure). In addition, this shape also has many paths (branches) along its concentric grid, which causes the structure to be relatively rigid. In contrast to the grid and concentric pattern, the triangle pattern is not solid. There are cavities in the triangle pattern, so the tensile stress in this pattern is the smallest. Printing the triangle shape takes the longest time compared to other pattern shapes [2].




(a)




(b)

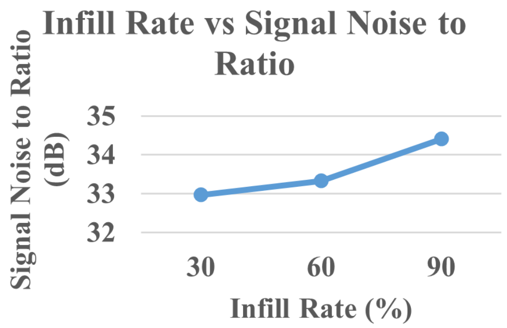



(c)

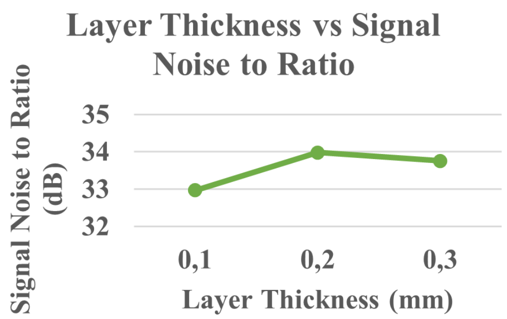
**Figure 6.** Tensile strength average graph of (a) infill rate, (b) layer thickness, and (c) infill pattern from calculation results

**Table 5.** Calculation results of the average value of SNR (dB)

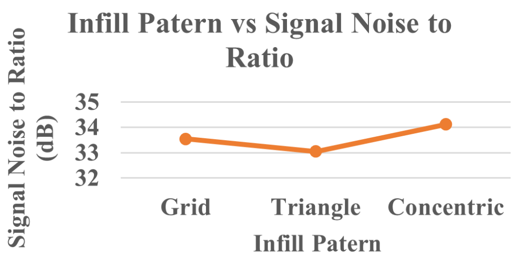
| Level | Infill Rate | Layer Thickness | Infill Pattern |
|---|---|---|---|
| 1 | 32.97 | 32.97 | 33.54 |
| 2 | 33.33 | 33.98 | 33.05 |
| 3 | 34.41 | 33.76 | 34.12 |




(a)




(b)




(c)

**Figure 7.** The signal noise to ratio (SNR) graph on (a) infill rate, (b) layer thickness, and (c) infill pattern

b) Signal Noise to Ratio (SNR) Value Analysis

Apart from being able to calculate the experimental average value, the data obtained can also be processed in the form of a signal-to-noise ratio (SNR) to look for factors that influence variations in 3D Printing parameters. Due to the response being the tensile strength value, the signal-to-noise ratio for the characteristics used is greater (larger is better). Equation 2 is an example of calculating the signal-to-noise ratio value in the experiment with the infill rate parameter for the 30% level with $y_1$ consisting of the sum of the responses in experiments 1, 2, and 3.

$$SNR_{11} = -10\log_{10}\left(\frac{1}{n}\sum_{i=i}^{n} y_i^2\right)$$
$$SNR_{11} = -10\log_{10}\left(\frac{(41.33 + 41.98 + ... + 47.61)^2}{9}\right)$$
$$SNR_{11} = -10\log_{10}\left(\frac{(401.37)^2}{9}\right) = 33.97dB \quad (2)$$

Where:
$\mu$: average value for certain parameters and levels
$n$: the amount of data tested
$y_i$: tensile strength value on the i-th specimen

Table 5 and Figure 7 are the results of calculating the signal-to-noise ratio (SNR) for each parameter variation and its level.

From Table 5 and the graph in Figure 7, the infill rate parameter with a level of 30% obtained an SNR value of 32.97 dB, 60% of 33.33 dB, and 90% of 34.41 dB. Based on the graph, the infill rate parameter with the highest SNR value is the 90% level. For the layer thickness parameter with a level of 0.1 mm, an SNR value of 32.97 dB was obtained; for a level of 0.2 mm, it was 33.98 dB, and for a level of 0.3 mm, it was 33.76 dB. The highest SNR value is at the 0.2 mm level in the layer thickness parameter graph. Finally, for the infill pattern parameter with the grid level, the SNR value is 33.54 dB, the triangle level is 33.05 dB, and the concentric level is 34.12 dB. The concentric level is the infill pattern parameter with the highest SNR value.

D. Confirmation Test

a) Optimal Prediction Value Confidence Interval Calculation

Based on the optimization process analysis results, it was found that the parameter variations that produced the most optimal results were an infill rate of 90%, a layer thickness of 0.2 mm, and a Concentric infill pattern. This parameter was not tested again because the extrusion temperature was not significant. The average of each variation and the total average tensile strength value that has been done before must first be calculated to determine the optimal predictive value for these parameters. Table 6 shows the calculation of this study's average tensile strength values of 3D printing results.

1) Optimal Predictive Value

Optimal predictive value ($\mu_{prediction}$) can be calculated using equation 3 as follows.

**Table 6.** The results of calculating the average value of each specimen variance

| EXP | Infill Rate (%) | Layer Thickness (mm) | Infill Pattern | Tensile Strength (N/mm2) | | | Average |
|---|---|---|---|---|---|---|---|
| | | | | A | B | C | |
| 1 | 30 | 0.1 | Grid | 41.33 | 41.98 | 40.63 | 41.313 |
| 2 | 30 | 0.2 | Triangles | 44.71 | 43.60 | 45.42 | 44.577 |
| 3 | 30 | 0.3 | Concentric | 49.04 | 47.05 | 47.61 | 47.900 |
| 4 | 60 | 0.1 | Concentric | 51.17 | 51.70 | 52.42 | 51.763 |
| 5 | 60 | 0.2 | Grid | 48.32 | 47.41 | 47.94 | 47.890 |
| 6 | 60 | 0.3 | Triangles | 39.48 | 39.83 | 41.85 | 40.387 |
| 7 | 90 | 0.1 | Triangles | 51.37 | 49.19 | 50.90 | 50.487 |
| 8 | 90 | 0.2 | Concentric | 52.50 | 52.43 | 54.00 | 52.977 |
| 9 | 90 | 0.3 | Grid | 53.06 | 55.12 | 54.43 | 54.203 |
| | | | | Total Average (X2) | | | 47.948 |

$$
\begin{aligned}
\mu_{prediction} &= \mu + (IR3 - \mu) + (KL2 - \mu) + (IP3 - \mu) \\
\mu_{prediction} &= 47.948 + (52.57 - 47.94) + (50.19 - 47.94) \\
&\quad + (50.88 - 47.94) \\
\mu_{prediction} &= 47.984 + 4.63 + 2.25 + 2.94 \\
\mu_{prediction} &= 57.768 MPa
\end{aligned} \tag{3}
$$

where:

IR3 : average value of tensile strength for the infill rate parameter with a level of 90%
KL2 : the average value of the tensile strength for the layer thickness parameter with a level of 0.2 mm
IP3 : average tensile strength value for infill pattern parameters with Concentric level

2) Optimal Value Confidence Interval

The confidence interval of the average predicted value can be calculated by substituting equations 4 and 5 into equation 6 as follows.
With:

$$
\begin{aligned}
n_{eff} &= \frac{n}{v_\mu + v_{IR} + v_{KL} + v_{IP}} \\
n_{eff} &= \frac{9 \times 3}{1+2+2+2} = 3.8
\end{aligned} \tag{4}
$$

$$
\begin{aligned}
Ve &= \frac{SSerror}{DOFerror} = \frac{SSe + S_T}{ve + v_T} \\
Ve &= \frac{15.636 + 4.381}{18+2}
\end{aligned} \tag{5}
$$

**Table 7.** Confirmation test results data

| **EXP** | **Tensile Strength Confirm (N/mm2)** |
|---|---|
| K1 | 57.86 |
| K2 | 55.26 |
| K3 | 57.45 |
| K4 | 56.34 |
| K5 | 57.47 |
| $\mu$confirm | 56.876 |

where:

$n_eff$ : the total number of experiments divided by the number of degrees of freedom
$v_\mu$ : average number of degrees of freedom
$v_I R$ : number of degrees of freedom infill rate
$v_K L$ : number of degrees of freedom layer thickness
$v_I P$ : number of degrees of freedom infill pattern
$Ve$ : pooled error variance
$SSe$ : sum square of error
$S_T$ : sum square of temperature
$ve$ : number of error degrees of freedom
$v_T$ : number of temperature degrees of freedom

and the F table value of $\alpha$ = 0.05, v1 = 1, v2 = n-1 = 25 is 0.4225, then the optimal value confidence interval can be calculated as follows:

$$
\begin{aligned}
Cl_o &= \sqrt{F_{\alpha,v1,v2} \times Ve \times \left[\frac{1}{n_{eff}}\right]} \\
Cl_o &= \sqrt{0.4225 \times 1.00085 \times \left[\frac{1}{3.8}\right]} \\
Cl_o &= 0.333 MPa
\end{aligned} \tag{6}
$$

where:

$CI_o$ : Optimal value confidence interval
$F_(\alpha, v1, v2)$ : F ratio table
$V_e$ : pooled error variance
$n_eff$ : the total number of experiments divided by the number of degrees of freedom
$\alpha$ : risk, confidence level = 1 – risk
$v_1$ : degrees of freedom for the mean and its value is always 1 for the confidence interval
$v_2$ : degrees of freedom for pooled error variance
$n$ : number of observations
$r$ : number of repetitions or replications ($r \neq 0$)

Then the optimal value confidence interval limits are calculated as in equations 7 and 8.

**Table 8.** Comparison of confidence intervals for optimal conditions and confirmation experiments [21]

| Condition | Comparison | Information | Decision |
|---|---|---|---|
| **A** | | Optimal | Accepted |
| | | Confirmation | |
| **B** | | Optimal | Accepted |
| | | Confirmation | |
| **C** | | Optimal | Rejected |
| | | Confirmation | |

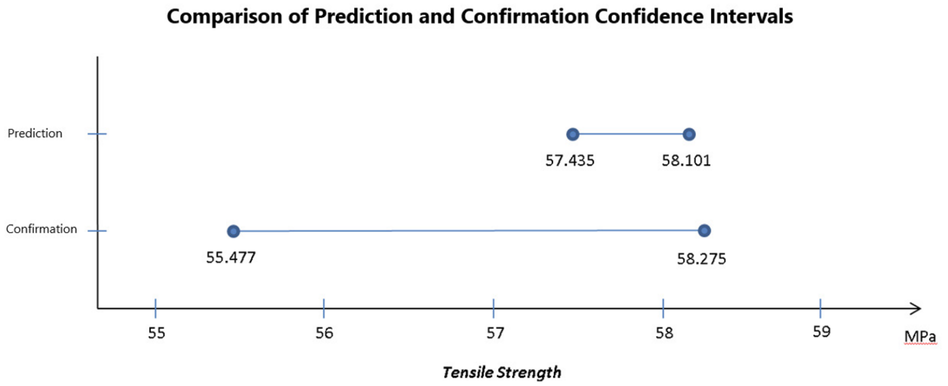



**Figure 8.** Graph of comparison of the optimal value and confirmation confidence intervals

$$Bottom\,limit = \mu_{prediction} - Cl_o = 57.768 - 0.333 \\ = 57.435MPa \tag{7}$$

$$Upper\,limit = \mu_{prediction} + Cl_o = 57.768 + 0.333 \\ = 58.101MPa \tag{8}$$

Then the confidence interval for the optimal predictive value is $57.435 \leq \mu_{prediction} \leq 58.101$.

b) Confirmation Test Results and Confidence Interval Calculation Confirmation Test Values

After calculating the confidence interval or the optimal value prediction confidence interval, confirmation testing will then be carried out. This test is carried out aiming to find out whether the optimal value analysis is acceptable or not. The confirmation test consisted of 5 new specimens (K1 until K5) with an infill rate parameter of 90%, a layer thickness of 0.2 mm, and a Concentric infill pattern in accordance with the predicted optimal value parameter analysis. The results of the confirmation tensile test can be seen in Table 7.

Based on the results of the tensile test of the confirmation test specimens in Table 7, the average result is 56,876 MPa. Then, the confidence interval of the confirmation test value can be calculated by equation 9.

$$\begin{aligned} Cl_c &= \sqrt{F_{\alpha,v1,v2} \times Ve \times \left[\frac{1}{n_{eff}} + \frac{1}{r}\right]} \\ Cl_c &= \sqrt{0.4225 \times 1.00085 \times \left[\frac{1}{3.8} + \frac{1}{5}\right]} \\ Cl_c &= 1.399MPa \end{aligned} \tag{9}$$

where:

- $CI_o$ : confirmation test value confidence interval
- $F(\alpha, v1, v2)$ : F ratio table
- $V_e$ : pooled error variance
- $n_eff$ : the total number of experiments divided by the number of degrees of freedom
- $\alpha$ : risk, confidence level = 1 – risk
- $v_1$ : degrees of freedom for the mean and its value is always 1 for the confidence interval
- $v_2$ : degrees of freedom for pooled error variance
- $n$ : number of observations
- $r$ : number of repetitions or replications ($r \neq 0$)

Then the limit of the confidence interval for the confirmation test value is calculated as in equations 10 and 11.

$$Bottom\,limit = \mu_{confirm} - Cl_c = 56.876 - 1.399 \\ = 55.477MPa \tag{10}$$

$$Upper\,limit = \mu_{confirm} + Cl_c = 56.876 + 1.399 \\ = 58.275MPa \tag{11}$$

Then, the confidence interval for the confirmation test value is $55.477 \leq \mu_{confirm} \leq 58.275$.

c) Confidence Interval Analysis of Optimal Predictive Value and Confirmation Test

After determining the optimal factor level, it is necessary to know the average predicted value expected at optimum conditions and compare it with confirmation experiments. If the response predictions and confirmation experiments are close enough to each other, it can be concluded that the design meets the requirements of the Taguchi experiment. In contrast, the purpose of using confidence intervals is to make estimates of factor levels and predict the average process at optimal conditions. The optimal condition confidence interval values are then graphically compared with the confirmation experiment confidence intervals. Table 8 contains three conditions comparing confidence intervals for optimal conditions and confirmation experiments. Figure 8 is a graph of the comparison of confidence intervals for the average values of confirmation experiments with optimal conditions.

In Figure 8, the optimal tensile strength values range from 57.435 MPa to 58.101 MPa. Meanwhile, the confirmation values range from 55.477 MPa to 58.275 MPa. Considering the confidence interval because the optimal value interval line is on the confirmation test value interval line, it can be concluded that the optimal predicted value is not significantly different from the confirmation test value. This condition also corresponds to condition A in Table 8.

## 4. Conclusions

Based on the Analysis of Variance, it is known that the infill rate, layer thickness, and infill pattern parameters have a significant effect on the tensile strength value, while the extrusion temperature parameter does not have a significant effect. The optimal tensile strength value occurs in the concentric infill pattern with an infill rate of 90% and a layer thickness of 0.2 mm. After the confirmation test was carried out with the combination of these parameters, the average tensile strength was 56.876 MPa, while the confirmation test values were at intervals of 55.477 MPa to 58.275 MPa. Considering the confidence interval, it can be concluded that the optimal predictive value is not significantly different from the confirmation test value.

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