# Optimization of 3D Printing Process Parameters on Tensile Strength of ABS Filament Material Product using Taguchi Method

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Abstract: The world of the manufacturing industry continues to develop from time to time and one of the technologies that support the manufacturing industry in the era of the industrial revolution 4.0 is 3D printing technology. It is necessary to improve the quality of 3D printing products, especially in their mechanical properties, namely tensile strength. Low tensile strength can cause the product to experience mechanical failure such as yielding or fracture, it is necessary to combine the right and optimal process parameters in the 3D printing process. The test specimens were designed using Fusion 360 software according to the ASTM D638-14 type IV standard. The material used is ABS filament. The process parameters used are layer height 0.1 mm, 0.15 mm, 0.2 mm, infill pattern with grid, line, cross pattern and nozzle temperature 230°C, 240°C, 250°C. The Design of Experiment used the Taguchi method in the form of an orthogonal matrix $L_9(3^4)$ with three replications. From the experimental results, it is found that the most optimal combination of process parameters is layer height at level 3 with a value of 0.2 mm, infill pattern at level 2 with line pattern and nozzle temperature at level 1 with a value of 230°C.

## 1 INTRODUCTION

3D printing is one type of additive manufacturing, where a filament is processed layer by layer which is controlled by a computer and produces a three-dimensional product (Riza, Budiyantoro and Nugroho, 2020). 3D printing brings many benefits to engineering design, product development, and production processes (Nguyen, Huynh, Nguyen, Tran, 2020). The potential market for 3D printing globally in 2025 is predicted to reach US$ 230-550 billion spread across several manufacturing industry sectors, including consumer goods (US$ 100-300 billion), production of medical equipment and transportation (US$ 100-200 billion), and moulding production (US$ 30-50 billion). The presence of 3D printing technology has created new businesses in the creative industry sector, some examples of which are: Spuni, printing products for baby needs, such as tablespoons whose shape is adjusted to the shape of the baby's mouth. Technologia Humana 3D, prints a replica of the baby's fetus in three-dimensional form after doing an ultrasound for pregnant women. Make Eyewear, which can print the necessary glasses and supplies. Shapeways, printing models for prototypes ordered from around the world through online channels (Kusuma, 2016). The use of 3D printing has also increased (Nicholson, 2014) in other business environments such as the automotive industry and aerospace engineering. Spare parts, for example, are being manufactured in the automotive and aerospace industries leading to increased economies of scale. 3D printing is changing the way industrial production lines work, causing analysts to consider the advent of 3D printers as the second industrial revolution (Mpofu, Mawere and Mukosera, 2014). There are several technologies used in the rapid prototyping (RP) process, namely Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), 3-D Printing (3DM), and others (Nancharaiah, 2011). Fused Deposition Modeling (FDM) is a process of melting, extrusion, and deposition of thermoplastic filaments among various types of additive manufacturing (AM) techniques (Gebisa and Lemu, 2019).

More and more 3D printing products are made for various functions, it is necessary to improve the quality of these products, one of which is the mechanical properties in the form of tensile strength in 3D printing materials because low tensile strength can cause the product to experience yielding or



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fracture. Tensile testing is carried out to determine the amount of tensile strength that can be resisted by the material or product resulting from 3D printing.

The method that is often used for optimizing process parameters is the Taguchi method. The Taguchi method aims to optimize process parameters, improve product quality and reduce production costs so that a perfect/robust product is produced against the noise factor (Soejanto, 2008). The primary purpose of the experimental design technique is to understand the interactions among the parameters, which could help in the optimization of experimental parameters and provide a statistical model (Montgomery, 2014).

This research was conducted to obtain the optimal combination of process parameters on the FDM 3D printing machine, such as layer height, infill pattern, and nozzle temperature using ABS (Acrylonitrile Butadiene Styrene) filament material on tensile strength and will be analyzed using the Design of Experiment (DoE), namely the Taguchi method. Parameters that have the most influence on tensile strength will be identified.

# 2 LITERATURE REVIEW

## 2.1 3D Printing

3D printing or additive manufacturing is a technique of printing products in three-dimensions form by adding computer material layer by layer which is controlled by a computer according to design made using CAD (Computer-Aided Design) software. 3D printing is the process of creating 3D solid objects from almost any shape from a digital model (Mpofu, Mawere and Mukosera, 2014). A typical 3D printer contains a nozzle printing that can handle one or more feed materials that can be moved in three dimensions (x, y, z). The section is made layer by layer, guided by 3D CAD models and stereolithography (Abeykoon, Sri-Amphorn and Fernando, 2020).

## 2.2 FDM (Fused Deposition Modeling)

Fused Deposition Modeling (FDM) is a technique that is usually used for 3D printing and additive manufacturing technology to print prototypes or products. Fused Deposition Modeling (FDM) technology uses a hot extruder where the filament or thermoplastic material is preheated in the extruder until it melts and is extruded through a nozzle and then moved to make layers to form the desired product (Rinanto and Sutopo, 2017).

## 2.3 ABS (Acrylonitrile Butadiene Styrene)

ABS is an engineering plastic whose portion butadiene is evenly distributed over a matrix acrylonitrile-styrene. ABS has excellent toughness, good dimensional stability, easy processing capability, chemical resistance, and low cost (Cabezas Arribas, 2017). ABS is impact resistant, has relatively high heat resistance, and is extruded at an ambient temperature of 210°C. When printing using ABS, a heated printing mat covered with polyimide tape regulated at about 110°C is almost necessary. Otherwise, the parts may warp when cold and may even break into larger molded materials. ABS is a widely used material by the 3D community printer individual, although the recent increase in the availability of PLA has changed that (J., 2012).

## 2.4 Tensile Strength

Tensile properties are often used as a determinant of properties and as an indication of polymer strength. Tensile properties measure the ability of a material to withstand separate tensile forces, and prolong deformation before breaking occurs. Tensile test results data such as tensile strength, elongation and modulus of elasticity can be used to select polymeric materials as specific applications from a large group (Divyathej, Varun and Rajeev, 2016).

## 2.5 Design of Experiment (DoE)

Design of Experiment is a joint evaluation of two or more factors (parameters) on their ability to influence the average or variability of the combined results of a certain product or process characteristics. To achieve this effectively and statistically, the levels of the control factors are varied, the results of certain combinations of tests are observed, and the complete result set is analyzed to determine which factors are influencing and the degree to which they are favourable and if the levels increase or decrease will result in further improvements (Soejanto, 2009).

## 2.6 Taguchi Method

Dr. Genichi Taguchi was the one who first introduced the quality engineering methodology in the 1960s, which until now is known as the Taguchi method (Soejanto, 2008). Taguchi design provides a robust and efficient method for designing processes that consistently perform optimally under a wide range of conditions. Strategically designed experiments should be used to determine the optimal design, exposing the process to various levels of design parameters (Semioshkina and Voigt, 2006). The target of the Taguchi method is to improve product quality, by looking for variables that affect quality, then separating them into control factors and uncontrollable factors (noise).

The calculation of degrees of freedom is carried out to calculate the minimum number of experiments that must be carried out to investigate the observed factors. The form of the orthogonal matrix equation in determining the number of experiments to be observed is as follows:

$$V_{0A} = (many\ factor)\ x\ (V_{fl}) \quad (1)$$

$$V_{fl} = (many\ level - 1\ ) \quad (2)$$

The equation of degrees of freedom to find out the total of degrees of freedom is as follows:

$$Total\ V_{fl} = (many\ experiment - 1) \quad (3)$$

Orthogonal matrices are used to analyze experimental data and are used to design efficient experiments to determine the minimum number of experiments that can provide as much information as possible on all the factors that affect the parameters. The general form of an orthogonal matrix is as follows: (Soejanto, 2008)

$$L_a(b^c) \quad (4)$$

With:
L = Latin square design
a = Many experiment / lines
b = Many level
c = Many factor / column

The calculation of the S/N ratio is used to determine the factors that have contributed to an experiment. There are several types of quality characteristics of the S/N ratio, which are as follows: (Soejanto, 2008)

1 Smaller is Better

The measurement of the characteristics of smaller is better, the ideal target is zero and the measurement when the value is lower, the quality will be better. Examples: roughness, number of failed products, defects, time efficiency, and others. The S/N value for the smaller is better characteristic type according to equation 5 is as follows:

$$S/N\ ratio = -10 \log \left[\sum_{i=1}^{n} \frac{{y_{i=1}}^2}{n}\right] \quad (5)$$

2 Larger is Better

The measurement of the characteristics of larger is better is that when the expected output is greater in value, the better the quality. Example: the number of production, the number of sales, tensile strength, and others. The S/N value for the larger is better characteristic type according to equation 6 is as follows:

$$S/N\ ratio = -10\ log \left[\frac{1}{n} \sum_{i=1}^{n} \frac{1}{{y_i}^2}\right] \quad (6)$$

3 Nominal is Better

The measurement of the nominal is better characteristic is usually assigned a certain nominal value by the user (user-defined). The closer to the nominal value that has been set, the better the quality will be. Example: dimensions, weight, and others. The value of S/N for the type of nominal is better characteristic according to equation 7 is as follows:

$$S/N\ ratio = -10 \log \left[\frac{\mu^2}{\sigma^2}\right] \quad (7)$$

With:
$\mu = \frac{1}{n}\left[\sum_{i=1}^{n} y_1\right]$
$\sigma^2 = \frac{1}{n}\left[\sum_{i=1}^{n} (y_1 - \mu)^2\right]$
n = Amount of data
$y_i$ = Observation response data to – i

The purpose of statistical Analysis of Variance (ANOVA) is to investigate which design parameters significantly affect the response variable of a test. ANOVA is used to analyze experimental data that occurs from the calculation of degrees of freedom (df), the number of squares (sum of square, SS), the middle square (mean of square, MS), and $F_{value}$ (Soejanto, 2009).

The confidence interval factor calculation was used for the treatment conditions at the time of the experiment. The confidence interval for optimal conditions can be calculated using the following equation:

$$CI_p = \pm \sqrt{\frac{F_{\alpha;d_{f1};d_{f2}} \times MS_e}{n_{eff}}} \quad (8)$$

$\mu_{prediction} - CI_p \leq \mu_{prediction} \leq \mu_{prediction} + CI_p$
$n_{eff}$ = Number of effective observations

$$= \frac{\text{total number of experiments}}{\text{1+the number of degrees of freedom for the average estimate}} \quad (9)$$

# 3 METODOLOGY AND IMPLEMENTATION

The test specimen is designed according to the ASTM D638-14 type IV standard using Autodesk Fusion 360 software and then the design file is exported in STL format so that the file can be opened and parameters set using the Ultimaker Cura software. This experiment was carried out by combining the levels of each predetermined process parameter, namely layer height, infill pattern, and nozzle temperature. The following are the levels for each process parameter used:

Table 1: Free Variables and Control Levels.

| Parameters | Layer Height (mm) | Infill Pattern | Nozzle Temperature (°C) |
|---|---|---|---|
| Level 1 | 0,1 | Grid | 230 |
| Level 2 | 0,15 | Line | 240 |
| Level 3 | 0,2 | Cross | 250 |

In the calculation of the degrees of freedom obtained a value of 6. The orthogonal array according to this experiment is $L_9(3^4)$. Furthermore, the calculation of the total degrees of freedom of the orthogonal array matrix using equation 3 obtained the total degrees of freedom is 8. By the standard orthogonal matrix, the value is greater than or equal to the calculation of the degrees of freedom of the experiment that has been applied, and then the experiment is declared feasible. Table 2 is an experimental design using Minitab19 software. The following is Table 2:

Table 2: Experiment Design.

| Experiment | Free Variables | | |
|---|---|---|---|
| | A | B | C |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

The study was conducted by printing test specimens of ABS filament material using an Ender 3 Pro brand 3D printer by a predetermined experimental design, namely the orthogonal array matrix nine times and replicated three times. Furthermore, the results of the specimen print were carried out with a tensile test using a Hung Ta brand tensile testing machine Type HT-2402 to get the maximum tensile strength value. The research data were calculated and analyze using the Taguchi method. $F_{value}$ is used for hypothesis testing by comparing $F_{value}$ for each factor with $F_{table}$. If $F_{value} > F_{table}$, then $H_0$ is rejected, and if $F_{value} < F_{table}$, then $H_0$ is accepted.

- Test $F_{value}$ on layer height parameter
  - $H_0$ : there is no effect of layer height on tensile strength
  - $H_1$ : there is an effect of layer height on tensile strength
- Test $F_{value}$ on infill pattern parameter
  - $H_0$ : there is no effect of infill pattern on tensile strength
  - $H_1$ : there is an effect of infill pattern on tensile strength
- Test $F_{value}$ on nozzle temperature parameter
  - $H_0$ : there is no effect of nozzle temperature on tensile strength
  - $H_1$ : there is an effect of nozzle temperature on tensile strength

# 4 RESULT AND DISCUSSION

The maximum tensile test results data on each specimen can be seen in Table 3. After the specimen has fractured, the detailed tensile test results data (Test Report) will come out and can be viewed on the U.T.M. Testing Program software. Table 3 can be seen below.

Table 3: Experiment Results Data.

| Combinations | Ultimate Tensile Strength (N/mm²) | | |
|---|---|---|---|
| | Replication 1 | Replication 2 | Replication 3 |
| 1 | 16.11 | 16.36 | 16.53 |
| 2 | 16.55 | 16.98 | 16.49 |
| 3 | 13.29 | 13.53 | 13.30 |
| 4 | 17.25 | 17.30 | 17.50 |
| 5 | 17.60 | 17.91 | 17.53 |
| 6 | 15.25 | 15.97 | 15.59 |
| 7 | 19.00 | 19.32 | 19.04 |
| 8 | 19.53 | 20.01 | 19.62 |
| 9 | 16.97 | 17.12 | 17.02 |

## 4.1 Value for Means and S/N Ratios

Tensile strength has the characteristic of larger is better, the greater the value of the tensile strength, the better because the stronger it is. The following are the results of the calculation of the means and the S/N ratios. Table 4 can be seen below.

Table 4: Experiment Results Data.

| Combi nations | Free Variables | | | S/N Ratios | Means |
|---|---|---|---|---|---|
| | LH (mm) | IP | NT (°C) | | |
| 1 | 0.1 | Grid | 230 | 24.260 | 16.333 |
| 2 | 0.1 | Line | 240 | 24.438 | 16.673 |
| 3 | 0.1 | Cross | 250 | 22.524 | 13.373 |
| 4 | 0.15 | Grid | 240 | 24.785 | 17.350 |
| 5 | 0.15 | Line | 250 | 24.949 | 17.680 |
| 6 | 0.15 | Cross | 230 | 23.860 | 15.603 |
| 7 | 0.2 | Grid | 250 | 25.629 | 19.120 |
| 8 | 0.2 | Line | 230 | 25.897 | 19.720 |
| 9 | 0.2 | Cross | 240 | 24.628 | 17.037 |

## 4.2 ANOVA (Analysis of Variance)

The results of the calculation of the ANOVA tensile strength for means and S/N ratios can be seen in Tables 5 and 6. The calculations were carried out manually using Microsoft Excel and validated using Minitab19 software. The confidence interval used is = 0.05. Table 5 and 6 can be seen below.

Table 5: ANOVA Mean Results Data.

| Source | DF | SS | Contribution % | MS | $F_{value}$ |
|---|---|---|---|---|---|
| LH | 2 | 15.086 | 53.624 | 7.543 | 97.182 |
| IP | 2 | 12.520 | 44.504 | 6.260 | 80.655 |
| NT | 2 | 0.371 | 1.320 | 0.186 | 2.392 |
| Error | 2 | 0.155 | 0.552 | 0.078 | |
| Total | 8 | 28.132 | | | |

Based on Table 5, it can be seen that the layer height and infill pattern parameters have a significant effect, while nozzle temperature does not have a significant effect on the tensile strength response. The layer height parameter gives a contribution percentage of 53.624%, the infill pattern is 44.504% and the nozzle temperature is 1.320%.

Table 6: ANOVA S/N Ratio Results Data.

| Source | DF | SS | Contribution % | MS | $F_{value}$ |
|---|---|---|---|---|---|
| LH | 2 | 4.055 | 51.478 | 2.027 | 39.455 |
| IP | 2 | 3.560 | 45.205 | 1.780 | 34.647 |
| NT | 2 | 0.159 | 2.013 | 0.079 | 1.543 |
| Error | 2 | 0.103 | 1.305 | 0.051 | |
| Total | 8 | 7.876 | | | |

Based on the Table 6, it can be seen that the layer height and infill pattern parameters have a significant effect, while nozzle temperature does not have a significant effect on the tensile strength response. $F_{table}$ for the S/N ratio for each factor is $F_{(0.05;2;2)}$ = 19.00. The layer height parameter gives a contribution percentage of 51.478%, the infill pattern is 45.205% and the nozzle temperature is 2.013%.

## 4.3 Optimal Parameters

Calculation of optimal parameters is used to determine the most optimal level of process parameters on the tensile strength response. The greater the averages value of each level, the greater its contribution to the tensile strength response variable. The following are the results of calculating the optimal parameters for the mean and S/N ratio which can be seen in tables 7 and 8.

Table 7: Optimal Parameters for Mean.

| Level | Layer Height | Infill Pattern | Nozzle Temperature |
|---|---|---|---|
| 1 | 15.460 | 17.601 | 17.219 |
| 2 | 16.878 | 18.024 | 17.020 |
| 3 | 18.626 | 15.338 | 16.724 |
| Delta | 3.166 | 2.687 | 0.494 |
| Rank | 1 | 2 | 3 |

Table 7 shows that the optimal parameters for the mean to tensile strength response are layer height at level 3 with a value of 0.2 mm, infill pattern at level 2 with line pattern, and nozzle temperature at level 1 with a value of 230°C. Figure 1 is the main effects plot for means according to the minitab19 software.

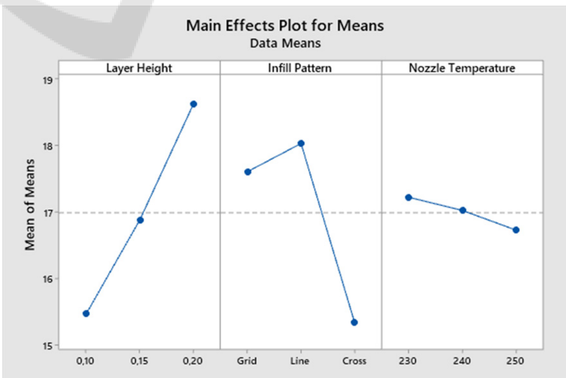


Figure 1: Main Effects Plot for Mean.

From the means graphs, the best combination of layer height of 0.2 mm, infill pattern of line pattern, and nozzle temperature of 230°C for high tensile strength.

Table 8: Optimal Parameters for S/N Ratio.

| Level | Layer Height | Infill Pattern | Nozzle Temperature |
|---|---|---|---|
| 1 | 23.741 | 24.892 | 24.672 |
| 2 | 24.531 | 25.094 | 24.617 |
| 3 | 25.384 | 23.670 | 24.367 |
| Delta | 1.644 | 1.424 | 0.305 |
| Rank | 1 | 2 | 3 |

Table 8 shows that the optimal parameters for the S/N ratio to the tensile strength response are layer height at level 3 with a value of 0.2 mm, infill pattern at level 2 with line pattern and nozzle temperature at level 1 with a value of 230°C. Figure 2 is a main effect plot for S/N ratio according to the minitab19 software.

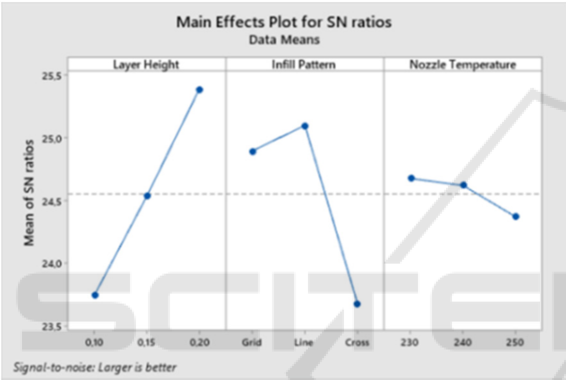


Figure 2: Main Effect Plot for S/N Ratio.

From the S/N ratios graphs, the best combination of layer height of 0.2 mm, infill pattern of line pattern and nozzle temperature of 230°C for high tensile strength.

## 4.4 Confidence Interval

The following is the Optimal Condition Confidence Interval Prediction for Mean Value.

1 Optimal Condition Prediction

$$\mu_{prediction} = \bar{y} + (\overline{A_3} - \bar{y}) + (\overline{B_2} - \bar{y}) + (\overline{C_1} - \bar{y})$$

$$\mu_{prediction} = 16.988 + (18.626 - 16.988) + (18.024 - 16.988) + (17.219 - 16.988) = 19.893$$

2 Confidence Interval

$$n_{eff} = \frac{9 \times 3}{1+2+2+2} = 3.8571$$

$$CI_p = \pm\sqrt{\frac{F_{0.05;1;2} \times 0.078}{3.8571}} = \pm 0.6103$$

Optimal confidence interval for mean value

$$\mu_{prediction} - CI_p \leq \mu_{prediction} \leq \mu_{prediction} + CI_p$$

$$19.893 - 0.6103 \leq \mu_{prediction} \leq 19.893 + 0.6103$$

$$\mathbf{19.28} \leq \boldsymbol{\mu_{prediction}} \leq \mathbf{20.504}$$

The Following is Optimal Condition Confidence Interval Prediction for S/N Ratio Value.

1 Optimal Condition Prediction

$$\mu_{prediction} = \bar{y} + (\overline{A_3} - \bar{y}) + (\overline{B_2} - \bar{y}) + (\overline{C_1} - \bar{y})$$

$$\mu_{prediction} = 24.552 + (25.384 - 24.552) + (25.094 - 24.552) + (24.672 - 24.552) = 26.047$$

2 Confidence Interval

$$n_{eff} = \frac{9 \times 3}{1+2+2+2} = 3.8571$$

$$CI_p = \pm\sqrt{\frac{F_{0.05;1;2} \times 0.0514}{3.8571}} = \pm 0.4966$$

Optimal confidence interval for S/N Ratio value

$$\mu_{prediction} - CI_p \leq \mu_{prediction} \leq \mu_{prediction} + CI_p$$

$$26.047 - 0.4966 \leq \mu_{prediction} \leq 26.047 + 0.4966$$

$$\mathbf{25.550} \leq \boldsymbol{\mu_{prediction}} \leq \mathbf{26.543}$$

Based on the results of the calculation of the confidence interval, the minimum confidence value is 19.283 and the maximum confidence value is 20.504 for the means, while for the S/N ratios, the minimum confidence value is 25.550 and the maximum confidence value is 26.543.

# 5 CONCLUSION

The Taguchi method can be used to find the optimal combination of process parameters for one response variable. Optimization aims to improve product quality from better machining.

From the results of the study, it can be seen that the 3D printing process parameters that affect the tensile strength of ABS filament material products are layer height and infill pattern with the results of the hypothesis that $F_{value}$ is greater than $F_{table}$, while the nozzle temperature parameter does not have a significant effect on the tensile strength response variable with the results of the hypothesis $F_{value}$ less than $F_{table}$. The optimal combination of process parameters to produce a product with the highest tensile strength is layer height at level 3 with a value of 0.2 mm, infill pattern at level 2 with a line pattern, nozzle temperature at level 1 with a value of 230°C.

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