Analysis of the Effect of 3D Printing Process Parameters on the Testing of Polylactic Acid (PLA) Specimens

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Abstract.
3D printing technology using the Fused Deposition Modeling (FDM) method has been widely adopted in manufacturing processes due to its ability to produce complex-shaped products at relatively low cost and with high production efficiency. However, the mechanical properties of printed products are significantly influenced by printing process parameters. This study aimed to analyze the effects of infill density, printing speed, and printing orientation on the mechanical properties of Polylactic Acid (PLA) specimens and to determine the optimal parameter combination using the Taguchi method. An experimental approach was employed using a Creality K1 3D printer and PLA filament. Tensile test specimens were manufactured according to the ASTM D638 standard, while compression test specimens were prepared based on the ASTM D695 standard. The experimental data were analyzed using the Taguchi method through the Signal-to-Noise (S/N) ratio to evaluate the influence of each process parameter and identify the optimal parameter combination. The results indicated that variations in the 3D printing process parameters significantly affected the mechanical properties of PLA specimens under both tensile and compression testing. Based on the Taguchi analysis, the optimal parameter combination consisted of an infill density of 0.1, a printing speed of 100 mm/s, and a horizontal printing orientation, which produced the best mechanical performance. Furthermore, the S/N ratio analysis revealed that printing orientation was the most influential parameter affecting the mechanical properties, followed by infill density, while printing speed had the least influence. Therefore, the Taguchi method proved to be an effective approach for determining the optimal process parameter combination to improve the mechanical quality of PLA specimens produced using the FDM 3D printing process.

Keywords: *3D Printing, Fused Deposition Modeling (FDM), Polylactic Acid (PLA), Taguchi method, infill density, printing speed, printing orientation, tensile test and compression test.*

I. INTRODUCTION

The development of additive manufacturing technology, commonly known as three-dimensional (3D) printing, has progressed significantly and has been widely implemented in various sectors, including industry and education. This technology enables products to be manufactured directly from digital models through a layer-by-layer material deposition process until a three-dimensional object is formed. Manufacturing technology is generally classified into two categories: conventional manufacturing and additive manufacturing. Conventional manufacturing is a production method that has long been used and remains the primary foundation of many industrial activities. It generally includes machining, casting, forming, and assembly processes, which require molds, specialized equipment, and high-capacity machinery. In contrast, additive manufacturing is a modern technology that produces components by depositing very thin layers of material based on a three-dimensional (3D) digital design created using Computer-Aided Design (CAD) software. This technology is recognized as one of the most advanced innovations in manufacturing, attracting considerable global attention from researchers and scientists seeking new technological breakthroughs. It offers advantages such as greater design flexibility, efficient material utilization, and the capability to produce complex geometries within a relatively short production time.

One of the most widely adopted additive manufacturing technologies is Fused Deposition Modeling (FDM). This technology is extensively used due to its ease of operation, relatively low investment and operating costs, and the availability of thermoplastic materials such as Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). According to Özen et al. (2021), FDM belongs to the material extrusion category, in which thermoplastic filament is heated to its melting temperature, extruded through a nozzle, and deposited layer by layer in a viscous state. The deposited material subsequently cools and solidifies, forming a three-dimensional component that conforms to the designed geometry.

Although the FDM printing process is relatively simple, the quality and mechanical properties of printed products are highly dependent on the selection of process parameters during printing. Parameters such as printing speed, infill density, printing orientation, layer thickness, and extruder temperature have significant effects on the mechanical strength and surface quality of printed components. Improper parameter settings may result in weak interlayer bonding, increased porosity, and non-uniform internal structures, ultimately reducing the quality and mechanical performance of the final product (Alsoufi & Elsayed, 2021).

Based on previous studies, although Fused Deposition Modeling (FDM) technology has been widely utilized, challenges remain regarding the consistency of product quality and mechanical properties, particularly for ASTM D638 tensile test specimens and PLA compression test specimens. Variations in mechanical properties and surface quality have been observed even when identical materials and specimen standards are used, indicating that the influence of printing process parameters has not yet been fully understood. Variations in infill density, printing speed, and printing orientation affect the internal structure of the material, which consequently influences tensile strength, hardness, and surface roughness. Furthermore, most previous studies have focused primarily on tensile testing, providing limited understanding of the overall mechanical performance and surface quality of printed products. Therefore, further research is required to investigate the influence of FDM process parameter variations on tensile strength, hardness, and surface roughness in an integrated manner.

A previous study related to this research by Viery Syahanifadhe et al. (2023), entitled *"Optimization of Parameters in the FDM (Fused Deposition Modeling) 3D Printing Process on the Quality of PLA (Polylactic Acid) Filament Products Using the Taguchi Multi-Response Signal-to-Noise Approach,"* applied the Taguchi method by evaluating tensile strength and surface roughness. The printing process was carried out using FDM technology by producing test specimens in accordance with the ASTM D638 standard. The specimens were printed using PLA material, which has a recommended printing temperature range of 165°C to 230°C, depending on the type and brand of PLA. Another study conducted by Gita Suryani Lubis et al. (2021), entitled *"Analysis of the Effect of Process Parameters on the Tensile Strength of Polylactic Acid 3D Printed Products,"* investigated the influence of FDM process parameter variations on the tensile strength of PLA material. The study employed an experimental method using a full factorial design, where specimens were fabricated using an Ender 3 Pro 3D printer and tested according to the ASTM D638 standard. However, the limitation of this study was that it focused solely on tensile properties without considering other mechanical properties such as compression strength, hardness, surface quality, or the influence of printing orientation.

Therefore, the objective of this study is to analyze the effect of 3D printing process parameters on the testing of Polylactic Acid (PLA) specimens by varying infill density, printing speed, and printing orientation. The evaluation is conducted through tensile testing to determine the mechanical strength of the material and assess the quality of the printed specimens. It is expected that the results of this study will provide a better understanding of the relationship between FDM process parameters and the characteristics of PLA materials, as well as serve as a reference for determining optimal printing parameters for laboratory, educational, and industrial applications.

II. METHODS

This study was conducted through direct experimental research adjusted to the research problems and objectives. Data were obtained from tensile and compression tests and were subsequently processed using descriptive analysis to determine the average values and the trends of changes in the test results for each variation of the Fused Deposition Modeling (FDM) 3D printing process parameters, namely infill density, printing speed, and printing orientation. The processed data were presented in the form of tables and graphs, followed by a comparative analysis among the parameter variations to evaluate their effects on the mechanical properties and surface quality of Polylactic Acid (PLA) specimens.

In addition, this study employed the Taguchi method as a Design of Experiment (DOE) approach to optimize the process parameters. The Taguchi method was implemented using an orthogonal array to determine efficient parameter combinations with a minimum number of experiments while still providing significant information. The analysis was carried out using the Signal-to-Noise (S/N) ratio to identify the parameters that have the greatest influence on the responses, such as tensile strength and compressive strength.

III. RESULTS AND DISCUSSION RESULTS

The experimental data in this study were obtained by combining several process parameters of the 3D printing machine. The process parameters considered to influence the tensile strength response were infill density (%), printing speed (mm/s), and printing orientation (°). The combinations of these three parameters were arranged using the Taguchi method. Subsequently, the tensile and compression test data were analyzed using the Taguchi Signal-to-Noise (S/N) ratio with the Larger-is-Better characteristic to determine the optimal combination of process parameters for achieving maximum tensile strength and compressive strength.

The 3D printing process was carried out using a Creality K1 printer. The printed specimens were fabricated according to the predetermined parameter combinations before being subjected to tensile and compression testing. Figure 1 illustrates the 3D printing process using the Creality K1 machine.

Ilustrasi proses 3D printing

3.2 Tensile Test Results

The tensile test was conducted to evaluate the mechanical properties of Polylactic Acid (PLA) specimens produced using the 3D printing process under tensile loading. The objective of this test was to obtain the material's mechanical characteristics, including maximum load, ultimate tensile strength (UTS), strain, and modulus of elasticity. The tests were performed using a Universal Testing Machine (UTM) in accordance with the ASTM D638 standard. Figure 2 shows the tensile testing process.

Tensile Test

Each specimen was tested until fracture to obtain data representing the material's ability to withstand tensile loading. The experimental results were then used as the basis for analyzing the influence of variations in the 3D printing process parameters in the subsequent stage of the study. The tensile test results for each specimen are presented in Table

Summary of Tensile Test Results

No	Infill Density (%)	Print Speed (mm/s)	Orientasi (°)	Tegangan Tarik (MPa)	*Ultimate Tensile Strength*, UTS (MPa)	Regangan (%)	Modulus Elastisitas (MPa)
1	0,1	100	horizontal	25,44	25,53	1,4	18,17
2	0,2	100	horizontal	25,61	26,32	1,3	19,7
3	0,3	100	horizontal	26,93	27,37	1,3	20,71
4	0,1	110	horizontal	26,75	27,28	1,3	20,57
5	0,2	110	horizontal	24,65	25,44	1,2	20,54
6	0,3	110	horizontal	25,70	26,05	1,3	19,76
7	0,1	120	horizontal	24,47	25,09	1,3	18,82
8	0,2	120	horizontal	26,23	26,49	1,4	18,73
9	0,3	120	horizontal	25,61	25,79	1.3	19,7
10	0,1	100	vertikal	15,96	15,96	1,0	15,96
11	0,2	100	vertikal	13,95	14,47	0,8	17,43
12	0,3	100	vertikal	13,86	14,04	0,9	15,4
13	0,1	110	vertikal	7,4	8,3	0,7	10,57
14	0,2	110	vertikal	7,3	8,3	0,6	12,16
15	0,3	110	vertikal	6,8	8,2	0,5	13,6
16	0,1	120	vertikal	15,35	15,35	1,0	15,35
17	0,2	120	vertikal	10,70	13,07	0,8	13,37
18	0,3	120	vertikal	14,47	14,56	0,9	16,07

3.3 **Compression Test Results**

The compression test was conducted to evaluate the ability of Polylactic Acid (PLA) specimens produced by the 3D printing process to withstand compressive loading. The objective of this test was to obtain the mechanical properties of the material, including maximum compressive load, compressive strength, and compressive strain. The tests were performed using a Universal Testing Machine (UTM) in accordance with the ASTM D695 standard. Figure 3 shows the compression testing process.

Compression Test

Each specimen was subjected to a gradually increasing compressive load until deformation or failure occurred. The experimental data were used to evaluate the material's ability to withstand compressive loading for each specimen variation. The compression test results for each specimen are presented in Table

Summary of Compression Test Results

No	Infill Density (%)	Print Speed (mm/s)	Orientasi (°)	Tegangan Tekan (MPa)	Beban Maksimum (kN)	Regangan (%)	Modulus Elastisitas (MPa)
1	0,1	100	horizontal	40	12,9	5,12	7,81
2	0,2	100	horizontal	41,85	13,5	6,1	6,86
3	0,3	100	horizontal	41,54	13,4	6,30	6,59
4	0,1	110	horizontal	41,23	13,3	6,22	6,62
5	0,2	110	horizontal	40,92	13,2	6,14	6,66
6	0,3	110	horizontal	40,61	13,1	6,06	6,70
7	0,1	120	horizontal	40,30	13,0	5,98	6,65
8	0,2	120	horizontal	39,99	12,9	5,91	6,76
9	0,3	120	horizontal	39,68	12,8	5,83	6,80
10	0,1	100	vertikal	39,37	12,7	5,75	6,84
11	0,2	100	vertikal	33,48	10,8	5,71	5,86
12	0,3	100	vertikal	32,86	10,6	5,63	5,83
13	0,1	110	vertikal	32,24	10,4	5,59	5,76
14	0,2	110	vertikal	31,62	10,2	5,51	5,73
15	0,3	110	vertikal	31,00	10,0	5,43	5,70
16	0,1	120	vertikal	30,38	9,8	5,35	5,67
17	0,2	120	vertikal	29,76	9,6	5,28	5,63
18	0,3	120	vertikal	34,7	11,2	7,09	4,89

3.4 Taguchi Method (Design of Experiment)

In this study, the Taguchi method was employed as a Design of Experiment (DOE) approach to develop a systematic, structured, and efficient experimental design. This method was selected because it reduces the number of experimental runs compared with the full factorial design, thereby improving the efficiency of time, cost, and material usage without compromising the quality of the information obtained. The experimental design was arranged using the L9 (3^3) Orthogonal Array (OA), which consists of three factors: infill density, printing speed, and printing orientation, with each factor having three levels. These combinations of factors and levels served as the basis for fabricating Polylactic Acid (PLA) specimens using the Fused Deposition Modeling (FDM) process for both tensile and compression testing.

The experimental results were analyzed using the mean response and the Signal-to-Noise (S/N) ratio with the Larger-is-Better quality characteristic, as the objective of this study was to maximize the tensile and compressive strengths of the printed specimens. The S/N ratio analysis was used to evaluate the influence of each process parameter on the measured responses and to determine the optimal parameter-level combination that provides the best mechanical performance. A higher S/N ratio indicates better response quality and lower sensitivity to process variation or noise during printing. Therefore, the parameter combination with the highest S/N ratio can be considered the optimal setting for producing PLA specimens with superior mechanical properties.

3.5 Signal-to-Noise Ratio Calculation

The Signal-to-Noise (S/N) ratio analysis in the Taguchi method is used to identify the factors that have the greatest influence on improving the response quality while minimizing process variation. The S/N ratio transforms the experimental data into a single value that represents both the stability and quality of the response. The selection of the S/N ratio equation depends on the quality characteristic of the response under investigation.

In this study, the response variable was **tensile strength**, which falls under the **Larger-is-Better** quality characteristic because higher tensile strength indicates better product quality. Accordingly, the S/N ratio was calculated using the following equation:

S/N Ratio Formula (Larger-is-Better)

$$\boxed{S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)}$$

where:

- **S/N** = Signal-to-Noise Ratio (dB)
- **n** = number of replications
- **(y_i)** = experimental result of the *i*-th replication

Since each experimental run in this study had **only one replication**, the equation becomes:

$$S/N = -10\log_{10}\left(\frac{1}{y^2}\right)$$

which can be simplified to:

$$S/N = 20\log_{10}(y)$$

where:

- **(y)** = measured test result (MPa)

The quality characteristic adopted in this study is Larger-is-Better, as the objective is to obtain the highest possible tensile strength and compressive strength of the PLA specimens. After completing the mechanical tests, the experimental data were analyzed using the Signal-to-Noise (S/N) ratio. Because each experiment was conducted with a single replication, the S/N ratio for every experimental combination was calculated using the Larger-is-Better equation.

3.6 Signal-to-Noise (S/N) Ratio Calculation for the Tensile Test

The Signal-to-Noise (S/N) ratio for the tensile test was calculated using the Larger-is-Better quality characteristic because the objective of this study was to obtain the highest possible tensile strength. Since each experimental run consisted of one replication, the S/N ratio was calculated using the simplified equation

- Replikasi 1 = 25,53 MPa

$$S/N = 20\log_{10}(25{,}53)$$
$$S/N = 20(1{,}4071)$$
$$S/N = 28{,}14\ dB$$

Tabel Results of the S/N Ratio Calculation for the Tensile Test

Parameter				**Nilai Kekuatan Tarik**	
No	**Infill Density (%)**	**Print Speed (mm/s)**	**Orientasi (°)**	***Ultimate Tensile Strength,* UTS (MPa)**	**S/N** (dB)
1	0,1	100	horizontal	25,53	28,14
2	0,2	100	horizontal	26,32	28,41
3	0,3	100	horizontal	27,37	28,75
4	0,1	110	horizontal	27,28	28,72

5	0,2	110	horizontal	25,44	28,11
6	0,3	110	horizontal	26,05	28,32
7	0,1	120	horizontal	25,09	27,99
8	0,2	120	horizontal	26,49	28,46
9	0,3	120	horizontal	25,79	28,23
10	0,1	100	vertikal	15,96	24,06
11	0,2	100	vertikal	14,47	23,21
12	0,3	100	vertikal	14,04	22,95
13	0,1	110	vertikal	8,3	18,38
14	0,2	110	vertikal	8,3	18,38
15	0,3	110	vertikal	6,8	18,28
16	0,1	120	vertikal	15,35	23,72
17	0,2	120	vertikal	10,70	22,33
18	0,3	120	vertikal	14,47	23,26

The S/N ratio values for each process parameter were determined from Table . The Signal-to-Noise (S/N) ratio was calculated using Minitab software based on the Taguchi method with the Larger-is-Better quality characteristic. The processed data, consisting of the S/N response values for each level of the process parameters, are presented in Table.

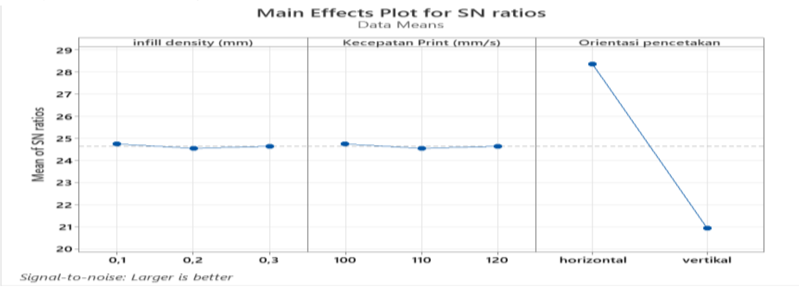
Table S/N Response Table for the Tensile Test

Response Table for Signal to Noise Ratios

Larger is better

Level	infill density (mm)	Kecepatan Print (mm/s)	Orientasi pencetakan
1	24.74	24.74	28.34
2	24.54	24.54	20.94
3	24.64	24.64	
Delta	0.20	0.20	7.40
Rank	2.5	2.5	1

Based on Table , the printing orientation parameter has the greatest influence on tensile strength, with a Delta value of 7.40, ranking first among all factors. In contrast, infill density and printing speed both have the same Delta value of 0.20, indicating that their effects on tensile strength are relatively small. Therefore, the order of influence of the process parameters on tensile strength is printing orientation, followed by infill density and printing speed.



grafik Main Effects Plot dan Response uji tarik

Based on the Main Effects Plot and the S/N Response Table, the optimal parameter combination was determined by selecting the level with the highest average S/N ratio for each factor. For infill density, the highest S/N ratio was obtained at Level 1 (0.1) with a value of 24.74 dB. Similarly, for printing speed, the highest S/N ratio was achieved at Level 1 (100 mm/s) with a value of 24.74 dB. For printing orientation, the highest S/N ratio was obtained at Level 1 (horizontal) with a value of 28.34 dB.

Therefore, the recommended parameter combination for achieving the maximum tensile strength is an infill density of 0.1, a printing speed of 100 mm/s, and a horizontal printing orientation.

3.7 Compression Test

In the compression test, the data obtained from the Universal Testing Machine (UTM) were initially recorded as the maximum load (kN). Therefore, these data were first converted into compressive stress (MPa) using the original cross-sectional area of the specimen in accordance with the ASTM D695 standard. The calculated compressive stress values were then used as the primary data for the Signal-to-Noise (S/N) ratio calculation based on the Taguchi method with the Larger-is-Better quality characteristic. Compressive stress was selected because it accounts for the specimen's cross-sectional area, allowing the test results from different specimens to be compared more accurately and consistently.

Calculation for Experiment 1

Compression test result:

- Replikasi 1 $= 40{,}00$ MPa

$$S/N = 20log_{10}(40{,}00)$$
$$S/N = 20(1{,}6021)$$
$$S/N = 32{,}04\ dB$$

Table Results of the S/N Ratio Calculation for the Compression Test

Parameter				**Nilai Kekuatan Tekan (compression)**	
No	**Infill Density (%)**	**Print Speed (mm/s)**	**Orientasi (°)**	**Tegangan Tekan (MPa)**	**S/N** (dB)
1	0,1	100	horizontal	40	32,04
2	0,2	100	horizontal	41,85	32,43
3	0,3	100	horizontal	41,54	32,37
4	0,1	110	horizontal	41,23	32,30
5	0,2	110	horizontal	40,92	32,24
6	0,3	110	horizontal	40,61	32,17
7	0,1	120	horizontal	40,30	32,11
8	0,2	120	horizontal	39,99	32,04
9	0,3	120	horizontal	39,68	31,97
10	0,1	100	vertikal	39,37	31,90
11	0,2	100	vertikal	33,48	30,50
12	0,3	100	vertikal	32,86	30,33
13	0,1	110	vertikal	32,24	30,17
14	0,2	110	vertikal	31,62	30,00
15	0,3	110	vertikal	31,00	29,83
16	0,1	120	vertikal	30,38	29,65

17	0,2	120	vertikal	29,76	29,47
18	0,3	120	vertikal	34,7	30,81

The S/N ratio values for each process parameter were determined from Table . The Signal-to-Noise (S/N) ratio responses were calculated using Minitab software based on the Taguchi method with the Larger-is-Better quality characteristic. The processed data, consisting of the S/N response values for each level of the process parameters, are presented in Table

Based on Table , printing orientation has the greatest influence on the compressive strength of the

Response Table for Signal to Noise Ratios

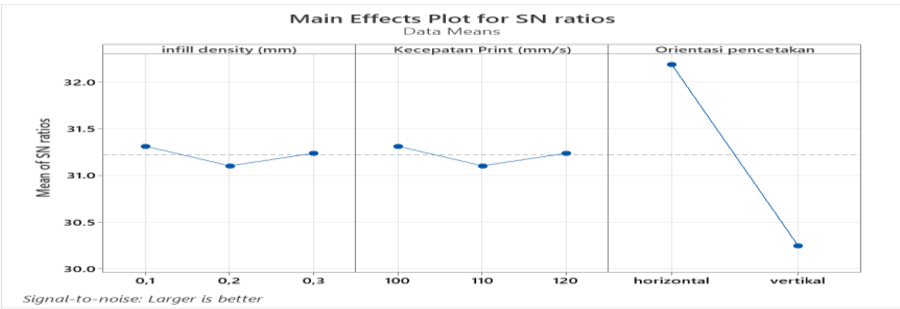
Larger is better

Level	infill density (mm)	Kecepatan Print (mm/s)	Orientasi pencetakan
1	31.31	31.31	32.18
2	31.10	31.10	30.25
3	31.24	31.24	
Delta	0.21	0.21	1.94
Rank	2.5	2.5	1

PLA specimens. This is indicated by the Delta value of 1.94, which is the highest among all process parameters. The order of influence of the process parameters on compressive strength is printing orientation (Rank 1), followed by infill density and printing speed, both of which have the same Delta value of 0.21. Therefore, these two parameters exhibit relatively similar effects on compressive strength (Rank 2.5).

Based on Table , a Main Effects Plot for the S/N Ratio can be generated to illustrate the S/N ratio values at each level of the process parameters. The resulting graph is presented in Figure

Grafik Main Effects Plot for SN Response uji tekan (compression)



Based on the analysis of the Main Effects Plot and S/N Response Table, the optimal parameter combination for achieving the highest compressive strength was obtained as infill density of 0.1, printing speed of 100 mm/s, and horizontal printing orientation. Furthermore, printing orientation was identified as the most influential parameter affecting compressive strength, with a Delta value of 1.94, while infill density and printing speed had relatively smaller effects, with each having a Delta value of 0.21.

Therefore, the recommended optimal parameter combination for producing the maximum compressive strength is an infill density of 0.1, a printing speed of 100 mm/s, and a horizontal printing orientation.

IV. DISCUSSION

Specimen Fabrication and Testing Stages

1. Preparation of Equipment and Materials

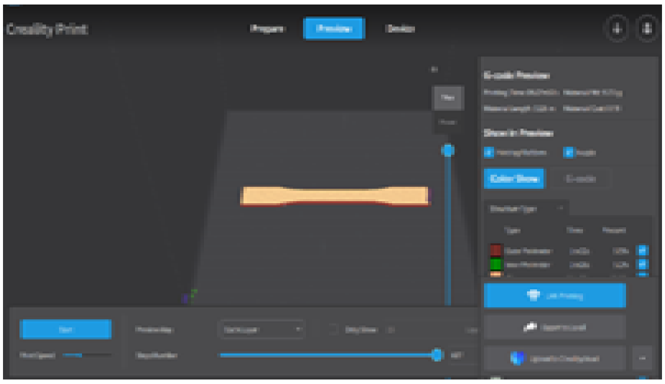
The preparation of equipment and materials is the initial stage conducted to ensure that all research processes can be carried out properly. The material used in this study was Polylactic Acid (PLA) filament with a diameter of 1.75 mm, while the specimen fabrication process was performed using a Fused Deposition Modeling (FDM)-based 3D printer.

2. Specimen Model Design

The specimen model design stage was carried out after all equipment and materials were prepared. In this stage, the specimens were designed using Computer-Aided Design (CAD) software based on the testing standards applied in this research. Two types of specimens were used in this study, namely tensile test specimens based on the ASTM D638 standard and compression test specimens based on the ASTM D695 standard.

3. **Slicing Process**

After the specimen model was completed and saved in STL (Stereolithography) format, the file was imported into slicing software and configured using Creality Print before the printing process. In this stage, the three-dimensional model was converted into a series of instructions in the form of G-code, which can be interpreted and executed by the 3D printer. The slicing process also involved setting the printing parameters according to the experimental design, including infill density, printing speed, and printing orientation.



4. **Printing Process (3D Printing)**

After the slicing process was completed, the G-code file was transferred to the 3D printer to begin the specimen fabrication process using the Fused Deposition Modeling (FDM) method. In this process, Polylactic Acid (PLA) filament was fed through the extruder into the nozzle, where it was heated until melted and then extruded along the predetermined path defined in the G-code file. The material was deposited gradually in a layer-by-layer manner, where after completing one layer, the nozzle moved upward according to the specified layer height value until the entire specimen was successfully fabricated according to the designed model.

5. Cooling and Specimen Removal

After the printing process was completed, the specimens were allowed to cool for several minutes until their temperature decreased and reached room temperature. This cooling stage aimed to ensure that the PLA material had fully solidified, maintaining the stability of the specimen shape and dimensions.

V. CONCLUSION

Based on the optimization process and analysis results obtained from this study entitled "Analysis of the Effect of 3D Printing Process Parameters on the Testing of Polylactic Acid (PLA) Specimens", the following conclusions can be drawn:

1. The variations of 3D printing process parameters, namely infill density, printing speed, and printing orientation, were proven to influence the mechanical properties of PLA specimens in tensile testing. Based on the Taguchi method analysis, the optimal process parameter combination that produced the best mechanical characteristics was obtained with an infill density of 0.1, printing speed of 100 mm/s, and horizontal printing orientation. This parameter combination was able to produce the highest tensile strength value.
2. The results of the Signal-to-Noise (S/N) Ratio analysis showed that printing orientation was the most dominant parameter affecting the compression test results, followed by infill density, while printing speed had the smallest influence. The optimal condition was obtained using a combination of infill density of 0.1, printing speed of 100 mm/s, and horizontal printing orientation. Therefore, this combination is recommended as the most effective process parameter setting for producing PLA specimens with improved mechanical properties.
3. The application of the Taguchi method successfully determined the optimal combination of process parameters to improve the quality of printed specimens. By applying the optimal parameters obtained from the analysis, the printing process was able to produce PLA specimens with higher tensile strength and compressive strength compared with other parameter combinations. Thus, the objective of this research to obtain optimal 3D printing process parameters has been achieved.

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