INVOTEK
Jurnal Inovasi Vokasional dan Teknologi
http://invotek.ppj.unp.ac.id/index.php/invotek
Vol. 22, No. 3, Oct 2022
ISSN: 1411 – 3411 (p)
ISSN: 2549 – 9815 (e)

Effect Of Layer Height, Infill Geometry, Nozzle Temperature, and Fan Speed On Tensile Strength Of 3D Printing PETG Specimens

Mahatma Junjung Mardlotila[1], Muhammad Trifiananto[1*], Dedi Dwi Laksana[1], Hari Arbiantara Basuki[1] , Muh. Nurkoyim Kustanto[1] , Intan Hardiatama[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, Jember University
Kalimantan Street No. 37, Jember, East Java, Indonesia
**Corresponding author: trifiananto@unej.ac.id* Doi :https://doi.org/10.24036/invotek.v22i3.1045

Abstract

This research is aimed to provide insight on the dependency of tensile strength on process parameters of the Fused Deposition Modeling (FDM). FDM is one of the most popular 3D printing manufacturing techniques. In the present study, a tensile test was performed to measure the tensile strength of PETG (Polyethylene terephthalate glycol) specimen with the combination of different layer height, infill geometry, nozzle temperature, and fan speed whereas other parameters are kept at a constant level. This study uses the ISO 527 1BA standard. Taguchi L16 (4^4) with 4 levels for each factor was used to determine the effect of each parameter. Each experiment repeated 3 times to minimize the occurrence of errors. layer height, infill geometry, nozzle temperature, and fan speed respectively effect of 13.4%, 63.6%, 19.0%, and 2.7%. Fan speed is considered a parameter that has no impact on tensile strength. The layer height and nozzle temperature parameter shows that the higher the value, the tensile strength of specimens tend to increase. Furthermore, infill geometry from the one with the highest to the lowest tensile strength value is gyroid, zig-zag, grid, and triangles. The combination of layer height of 0.24 mm, infill geometry gyroid, and nozzle temperature of 250 ˚C is the optimum combination of parameters which has the highest tensile strength of 34.76 N/mm^2.

Keywords: FDM, 3D printing, PETG, tensile strength

1. Introduction

The years 1750 to 1850 AD were a period of massive technological change in the agricultural, manufacturing, transportation, and mining sectors which became known as the industrial revolution [1]. Fused Deposition Modeling (FDM) is one of the most popular 3D printing manufacturing techniques[2]. FDM is a technique of extrusion of thermoplastic materials (polymers that can melt and reshape) in the form of filaments using a nozzle where the extruded products are placed layer by layer to form 3D objects [3] [4] . 3D printing can be used to manufacture workpieces with complex shapes and uses less material than the subtractive manufacturing method because there is no wasted material. Lately, 3D printing is not only used as a rapid prototyping method but also to make a final product in aviation, automotive, health, and fashion.

Plastic production began in the 1950s and continued to grow until reaching the annual manufacturing of 330 million metric tons (Mt) in 2016 [5]. Traditionally, PLA, tough PLA, PC, and ABS materials are common materials for Fused Deposition Modeling (FDM) modeling. Polyethylene terephthalate glycol or commonly called PETG is a polymer with the market name of polyester plastic but with the addition of glycol modification. As an alternative material, PETG has excellent chemical resistance, high impact resistance, low shrinkage, and good interlayer bonding [6]. PETG is gaining popularity in consumer and commercial applications, with FDM technology adjustable parts in the food industry (food safe plastic containers), and the medical sector can be created for medical use (rigid structures that withstand rigorous sterilization processes, implants) [7]. One of the products that can be printed using PETG filament is arm stabilizer for cameras. camera stabilizer must have good tensile

Received date 24/07/2022, Revised date 24/01/2023, Accepted date 17/02/2023

P-ISSN: 1411-3414
E-ISSN: 2549-9815

strength because it must withstand camera loads ranging from 2-5 kg depending on the camera used and other equipment.

Yadav et al. [8] conducted a tensile test study using PETG filaments and concluded that the maximum tensile strength achieved was 0.0405 kN/mm2 when fabricated with a layer height of 0.1 mm and an extrusion temperature of 225 °C. Srinivasan et al.[9] concluded that the higher the infill density, the higher the tensile strength. Infill density 100 % has a tensile strength value of 32.12 Mpa, while infill density 20 % has a tensile strength value of 17.38 Mpa. Srinivasan et al. [10] performed a tensile test using PETG and explained that the infill geometry grid has the highest tensile strength with a tensile strength value of 36.34 Mpa. Kumar et al. [11] also performed a tensile test using reinforced PETG carbon fiber and revealed that the maximum tensile strength w observed at 34,629 MPa with a print speed of 60 mm/s, a infill density of 80%, and a layer height of 0.3 mm.

This study uses four parameters, namely layer height, infill geometry, nozzle temperature, and fan speed with each parameter having 4 levels to examine the effect of these parameters on tensile strength and find the best combination. Srinivasan et al. [10] studied 9 infills and found that grids and triangles produced the highest tensile strength. In this study examined gyroid and zigzag infills with infill grids and triangles as comparisons. The shape of the infill geometry is presented in Figure. 1. Yadav et al. [8] using a nozzle temperature range of 210-240 ˚C and concluded that the tensile strength increases with increasing temperature. In this study nozzle temperature of 220-250 ˚C was used to investigate if the trend still persist at 250 ˚C. Kumar et al. [11] investigate the effect of layer height with 3 levels and concluded that tensile strength still increase in 0.3 mm. This study use 4 level layer height namely 0.12, 0.16, 0.20, 0.24 mm. The effect of fan speed is investigated because research on the influence of fan speed has not been done much. Lee & Liu [12] examined the effect of fan speed with variations of 0-5 m/s on PLA material with the result that higher cooling speeds generated better geometric accuracy but lower mechanical strength.

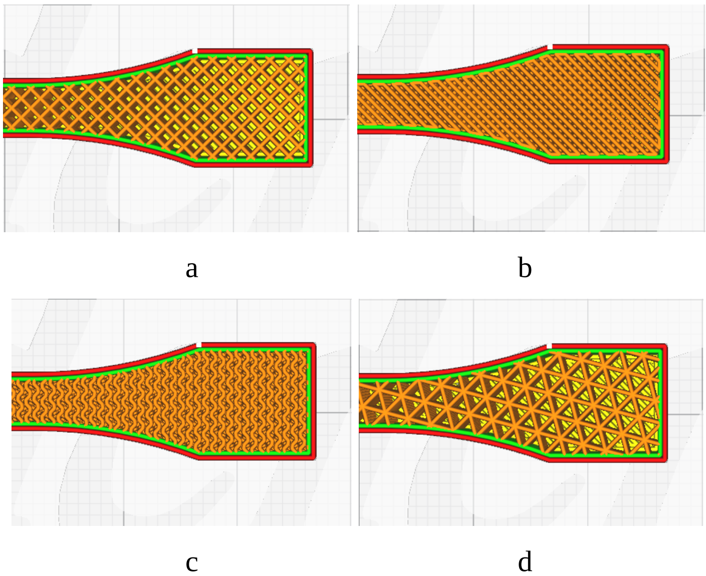

Figure. 1. a Grid, b. Zigzag, c. Gyroid, d. Triangles

According to Soejanto [13] the taguchi method is used to improve the characteristics, and manufacturing processes, and keep costs and resources used to a minimum. The taguchi method achieves this goal by making the workpiece and process resistant to noise parameters such as human resources, operational factors, etc. Therefore Taguchi OA L16 (4^4) was used to determine the influence of 3D printing parameters and the experimental data obtained were analyzed by signal-to-noise ratio analysis to obtain optimal FDM process parameters for the manufacture of specimens from PETG materials.

Research on the effect of layer height, infill geometry, nozzle temperature, and fan speed parameters on the tensile strength of PETG has not been widely carried out, so research is needed on this topic. In this study there were improvements from previous studies where in this study it had more parameters and parameter levels so that it could more clearly describe the effect of each parameter. This

P-ISSN: 1411-3414
E-ISSN: 2549-9815

study has two main objectives, namely to determine the effect of each parameter and to determine the combination of parameters that has the highest tensile strength.

2. Research Methodology

This study aims to test the tensile strength of 3D printing PETG specimens. The first step in this research is to design a 3D printing specimen using the Fusion 360 application. The design used complies with the ISO 527 type 1BA tensile test standard. Technical drawings of the ISO 527 type 1BA tensile test specimen as shown in Figure. 2. Taguchi Orthogonnal Array (OA) L16 (4^4) was processed using the Minitab application. The data obtained from the taguchi method is the parameter value used to set the 3D printing machine in the Cura application. The next step is to print the specimen using the Ender 3V2 3D printing machine. The specimen was tested with universal tensile strength HT-2402 with a capacity of 50 kN. After that, the last step is to process and analyze the data obtained from the results of tensile tests on the specimen with Minitab.

Table 1. Research variable

Control Variable	Independent Variable	Dependent Variable
PETG filament Esun	Layer height	Tensile strength
40 ˚C enclosure temperature	Infill geometry	
50% infill density	Nozzle temperature	
80 ˚C bed temperature	Fan speed	
50 mm/s printing speed		

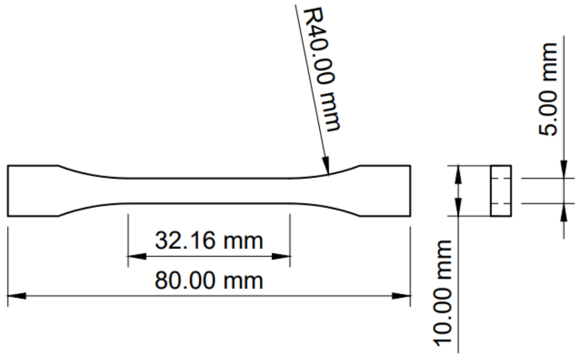

Figure. 2. Tensile test specimen

2.1. Research time and place

The specimens of tensile strength test printed in the Materials laboratory building, Faculty of Engineering, Jember University, while tested in the Physics Laboratory Building, Faculty of Mathematics and Natural Sciences, Jember University. This research was conducted on February-March 2022.

2.2. Tools and materials

The tools used in this research are Creality Ender 3 V2 3D printing machine, enclosure with temperature sensor, Cura 4.1.2 application, Minitab 20.3 application, and HT-2402 tensile test machine with a capacity of 50 kN. The material used for this research is PETG Esun filament in gray color. 3d printing machine in an enclosure with temperature sensor shown in Figure. 3.

P-ISSN: 1411-3414
E-ISSN: 2549-9815

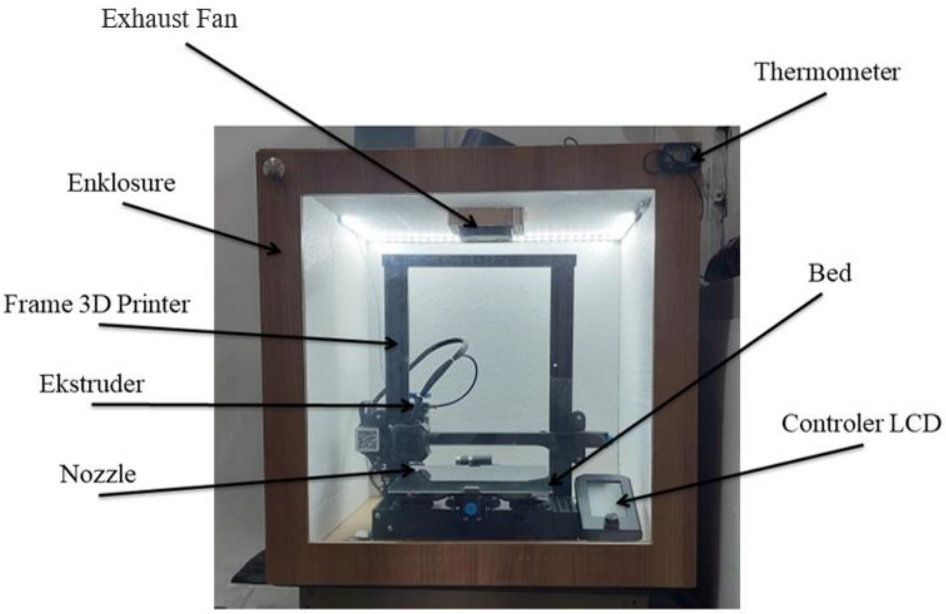

Figure. 3. Creality Ender 3 V2 with enclosure

2.3. Process parameter

The process parameters used in this study were layer height, infill geometry, nozzle temperature, and fan speed was varied to study the impact on tensile strength, whereas other parameters are kept at a constant level. The parameters process are tabulated and shown in Table 1. Research on the effect of layer height, infill geometry, nozzle temperature, and fan speed parameters on the tensile strength of PETG has never been conducted, so research on the topic is needed. The temperature used is in the range recommended by the Esun filament manufacturer [14], which ranges from 220-250 C. Infill density used 50% to reduce material usage.

Table 2. Parameter Process

Parameters	Level
layer height	0.12 ; 0.16 ; 0.20 ; 0.24 mm
infill geometry	grid, zigzag, gyroid, and triangles
nozzle temperature	220, 230, 240, 250
fan speed	0, 0.2, 0.5, 0.8 m/s
enclosure temperature	40 ˚C
infill density	50 %
bed temperature	80 ˚C
printing speed	50 mm/s

2.4. Taguchi orthogonal array

Taguchi OA L16 (4^4) was used to minimize the number of experiments from 256 to only 16 experiments. each experiment was repeated 3 times to reduce error. the taguchi L16 OA table is obtained from the Minitab application. OA table contains each combination of parameter levels for each experiment as shown in Table 2.

Table 3. Taguchi OA

Eksperiment	Layer height (mm)	Infill geometry	Nozzle temperature (˚C)	Fan speed (m/s)
1	0.12	Grid	220	0
2	0.12	Zigzag	230	0.2
3	0.12	Gyroid	240	0.5
4	0.12	Triangles	250	0,8

P-ISSN: 1411-3414
E-ISSN: 2549-9815

Eksperiment	Layer height (mm)	Infill geometry	Nozzle temperature (˚C)	Fan speed (m/s)
5	0.16	Grid	230	0.5
6	0.16	Zigzag	220	0.8
7	0.16	Gyroid	250	0
8	0.16	Triangles	240	0.2
9	0.2	Grid	240	0.8
10	0.2	Zigzag	250	0.5
11	0.2	Gyroid	220	0.2
12	0.2	Triangles	230	0
13	0.24	Grid	250	0.2
14	0.24	Zigzag	240	0
15	0.24	Gyroid	230	0.8
16	0.24	Triangles	220	0.5

3. Result and Discussion

Tests were performed using the ISO 527 1BA standard, with a tensile speed of 15mm/minute. The specimens that have been subjected to tensile tests are shown in Figure. 4. Tensile strength experimental data are shown in Table 3. From these tests, the 10th experiment had the highest average tensile strength of 25.00 N/mm^2, while the 12th experiment had the lowest average tensile strength of 19.76 N/mm^2.

Each experiment was repeated three times which was used to calculate the signal-to-noise ratio or SNR. SNR is used to determine the parameters that affect the response which in this study is the tensile strength. Minitab application is used to analyze experimental data. Furthermore, the parameters are sorted from the most influential to the least influential and written in the main effect graph and response table.

Figure. 4. 3D print specimens after testing

Table 4. Tensile strength value of each specimens

Eksperiment	Tensile Strength (N/mm^2) 1	2	3	means (N/mm^2)	Standart Deviation
1	20.73	20.45	20.87	20.68	0.2139
2	21.64	22.37	21.44	21.82	0.4895
3	23.89	22.88	23.62	23.46	0.5229
4	19.98	20.96	21.38	20.77	0.7184
5	21.09	21.21	21.07	21.12	0.0757

P-ISSN: 1411-3414
E-ISSN: 2549-9815

Eksperiment	Tensile Strength (N/mm^2)			means	Standart
	1	2	3	(N/mm^2)	Deviation
6	22.05	22.93	21.77	22.25	0.6053
7	23.87	24.28	24.44	24.20	0.2940
8	20.18	21.00	21.38	20.85	0.6133
9	21.65	21.54	21.58	21.59	0.0557
10	24.58	25.12	25.30	25.00	0.3747
11	23.41	21.56	22.74	22.57	0.9366
12	19.97	19.73	19.57	19.76	0.2013
13	22.94	22.90	23.07	22.97	0.0889
14	24.85	24.64	24.87	24.79	0.1274
15	23.68	23.90	23.71	23.76	0.1193
16	21.40	20.93	21.62	21.32	0.3525

The tensile strength response of the specimen was analyzed using the large is better SNR method or the higher the response value, the better. The quality characteristic of large is better SNR is continuous and does not have a negative value. In this stage, the selection of the level that minimizes interference is carried out by selecting the level that has the highest SNR value.

The influence of layer height, infill geometry, nozzle temperature, and fan speed is reported in Figure. 5. From the Figure. 5, it can be seen that each parameter has a different response to tensile strength. The optimum parameter level can be seen from the process parameter level by looking at the largest noise value. In the SNR response for tensile strength the most optimum parameter level is layer height 0.24 mm, infill geometry gyroid, nozzle temperature 250 ˚C, fan speed 0.5 m/s^2.

The layer height parameter shows that the higher the layer height value, the higher the tensile strength of the specimen. This happens because the higher the layer height value, the less the interlayer bond, while the interlayer bond has a lower strength than the intralayer bond. The order of infill geometry from the one with the lowest to the highest tensile strength value is triangles, grid, zig-zag, and gyroid. At the nozzle temperature parameter, the tensile strength of the specimen tends to increase as the nozzle temperature increases. While the fan speed parameter has the highest tensile strength value at a speed of 0.5 m/s^2.

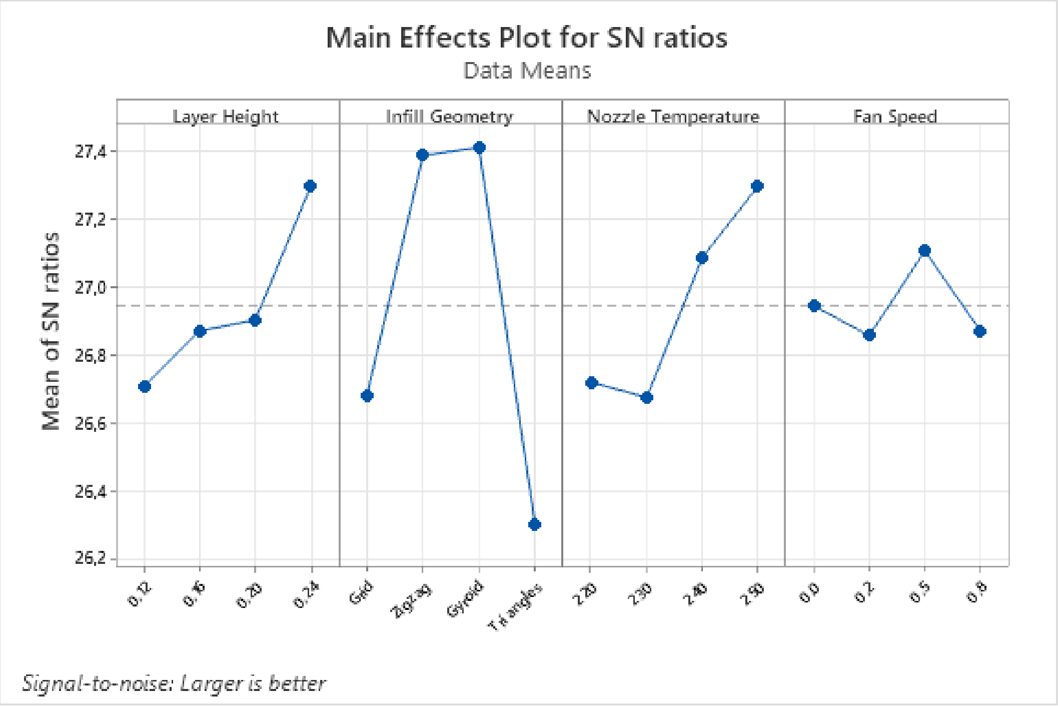

Figure. 5. Main effects of signall to noise ratios

P-ISSN: 1411-3414
E-ISSN: 2549-9815

Research by Srinivasan, Nirmal Kumar, et al. [10] in 2020 showed that infill geometry grids have the highest tensile strength, followed by infill geometry triangles. In this study, the authors found that infill geometry gyroids have higher tensile strength than grids and triangles. The gyroid parameter is an infill geometry introduced by Cura in 2021.

Yadav et al. [8] suggested that the higher the nozzle temperature, the higher the tensile strength of the specimen. Research Yadav et al. [8] using a nozzle temperature range of 210-240 ˚C. in this study used a nozzle temperature of 220-250 ˚C and found that the tensile strength still increased at a nozzle temperature of 250 ˚C.

The level of influence of the process parameters on the response is described in the response table. The response table shows the level of influence by looking at the delta or the value of the largest difference between parameter levels. The response table based on the SNR value shows different results for different parameters. Table. 5 shows that infill geometry has the highest influence with a delta value of 1.11 while fan speed has the lowest effect with a delta of 0.25.

Table 5. Response of process parameters

Level	Layer Height	Infill Geometry	Nozzle Temperature	Fan Speed
1	26.71	26.68	26.72	26.95
2	26.87	27.39	26.67	26.86
3	26.90	27.41	27.09	27.11
4	27.30	26.30	27.30	26.87
Delta	0.59	1.11	0.62	0.25
Rank	3	1	2	4

The analysis of variance table presented in Table. 6. The contribution of each process parameter to the tensile strength response can be seen by dividing the Seq SS parameter by the total Seq SS. After calculating, it was found that Infill geometry has the largest contribution, namely 63.6 %, followed by nozzle temperature at 19.0 %, layer height at 13.4 %, and fan speed only having an effect of 2.7 %.

Table 6. Analysis of variance of process parameters

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Layer Height	3	0.75855	0.75855	0.25285	12.54	0.033
Infill Geometry	3	3.60717	3.60717	1.20239	59.62	0.004
Nozzle Temperature	3	1.0574	1.05754	0.35858	17.78	0.021
Fan Speed	3	0.15822	0.15822	0.05274	2.62	0.225
Residual Error	3	0.06050	0.06050	0.02017		
Total	15	5.66019				

From the analysis of variance table, it can also be seen that each parameter has various p values. $p < 0.05$ is considered to affect the tensile strength response, whereas if $p > 0.05$ the parameter is not considered to affect the tensile strength response. This is also in line with the calculation of the % contribution where the % contribution of the fan speed parameter has a low contribution of 2.7 % so the fan speed parameter is considered to not affect the tensile strength response.

In Figure. 5 it can be seen that the combination of parameters of 0.24 mm layer height, infill geometry gyroid, and nozzle temperature of 250 ˚C is the most optimum combination of parameters, but in the 16 experiments that have been carried out, there is no combination of these parameters. So the authors conducted a confirmation test to ensure that the combination produces the highest tensile strength value.

Confirmation test results shown in Figure. 6. In the graph, it can be seen that the combination of parameters of 0.24 mm layer height, infill geometry gyroid, and nozzle temperature of 250 ˚C produces an average tensile strength of 34.76 N/mm^2. The comparison between experiment 10 and the confirmation test is shown in Figure 7. Experiment 10 has the highest tensile test value from the teguchi method with parameters layer height 0.2, Infill geometry Zigzag, nozzle temperature 250C and fan speed 0.5 m/s . Figure. 7 shows the confirmation test is higher than experiment 10.

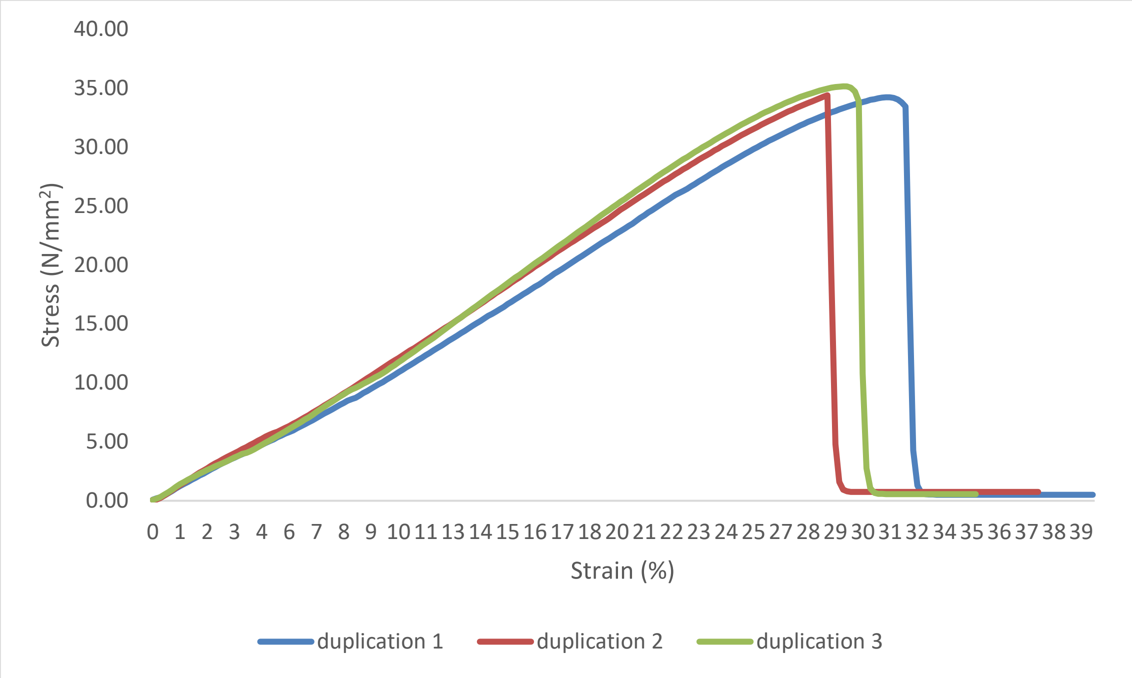

Figure. 6. Confirmation test

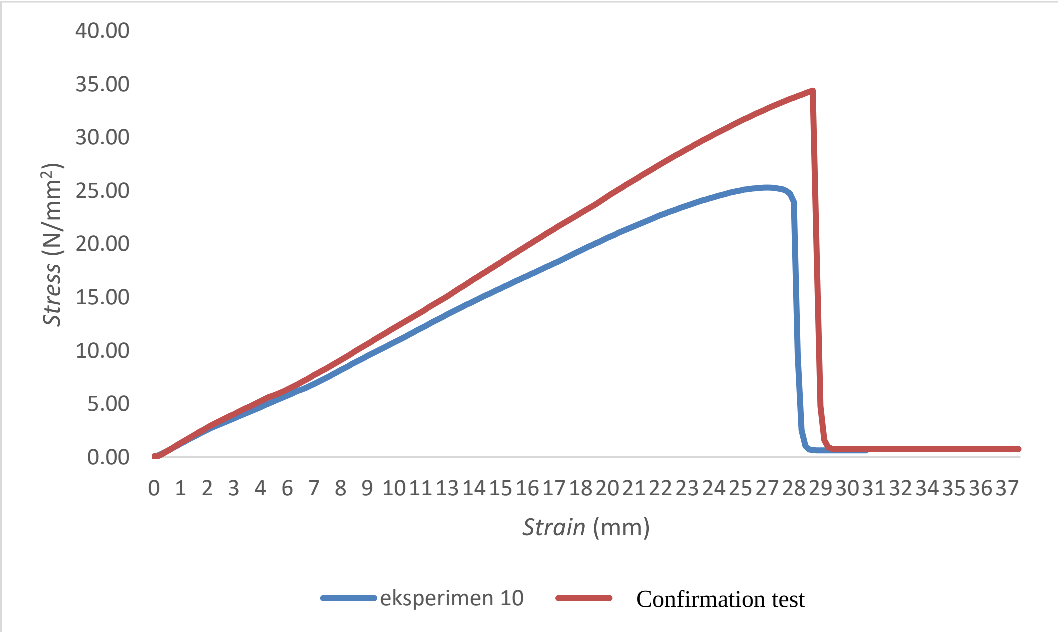

Figure. 7. Comparation Experiment 10 and Confirmation test

Guessasma et al. [15] in their research used PETG filament 210 °C - 250 °C, and the results showed that the PETG filament must be printed at a temperature of over 230 °C; it was found that the higher the temperature, the higher the tensile strength. Bembenek et.al. [16] conducted tensile tests on PETG material with nozzle temperature parameters of 230 ^{0}C; 25% infill; triangle geometry; and layer height variations of 0.12, 0.20, and 0.28 mm XY orientation . The result is that the higher the layer height, the higher the tensile strength of UTS in the range of 13,223-16,449 MPA.

4. Conclusion

Based on the research conducted, the layer height parameter affects tensile strength by 13.4%. The higher the layer height, the higher the tensile strength of the specimen, where the optimum level

P-ISSN: 1411-3414
E-ISSN: 2549-9815

value is 0.24 mm. The infill geometry gyroid has the highest tensile strength response, followed by zigzags, grids, and triangles. Infill geometry has the highest influence on the tensile strength of the specimen with a contribution of 63.6 %. Nozzle temperature has a contribution to the tensile strength response of 19.0 %. The nozzle temperature parameter tends that the higher the nozzle temperature the higher the tensile strength, with the optimum level value at a temperature of 250 ˚C. fan speed has the lowest effect, which is 2.7%, thus the fan speed parameter is not considered a factor that affects the response of the tensile strength of the specimen. The combination of layer height 0.24 mm, infill geometry gyroid, nozzle temperature 250 ˚C is the optimum combination of parameters which has the highest tensile strength of 34.76 N/mm2.

References

[1] R. Nur and M. A. Suyuti, *Pengantar Sistem Manufaktur*. Deepublish, 2017.

[2] P. Pristiansyah, H. Hasdiansah, and S. Sugiyarto, "Optimasi Parameter Proses 3D Printing FDM Terhadap Akurasi Dimensi Menggunakan Filament Eflex," *Manutech J. Teknol. Manufaktur*, vol. 11, no. 01, 2019, doi: 10.33504/manutech.v11i01.98.

[3] P. WANG, B. ZOU, S. DING, L. LI, and C. HUANG, "Effects of FDM-3D printing parameters on mechanical properties and microstructure of CF/PEEK and GF/PEEK," *Chinese J. Aeronaut.*, vol. 34, no. 9, 2021, doi: 10.1016/j.cja.2020.05.040.

[4] A. A. Ansari and M. Kamil, "Effect of print speed and extrusion temperature on properties of 3D printed PLA using fused deposition modeling process," in *Materials Today: Proceedings*, 2021, vol. 45, doi: 10.1016/j.matpr.2021.02.137.

[5] "History of plastics • Plastics Europe." https://plasticseurope.org/plastics-explained/history-of-plastics/ (accessed Feb. 13, 2023).

[6] K. Durgashyam, M. Indra Reddy, A. Balakrishna, and K. Satyanarayana, "Experimental investigation on mechanical properties of PETG material processed by fused deposition modeling method," in *Materials Today: Proceedings*, 2019, vol. 18, doi: 10.1016/j.matpr.2019.06.082.

[7] T. Panneerselvam, S. Raghuraman, and N. Vamsi Krishnan, "Investigating Mechanical Properties of 3D-Printed Polyethylene Terephthalate Glycol Material Under Fused Deposition Modeling," *J. Inst. Eng. Ser. C*, vol. 102, no. 2, 2021, doi: 10.1007/s40032-020-00646-8.

[8] D. Yadav, D. Chhabra, R. K. Gupta, A. Phogat, and A. Ahlawat, "Modeling and analysis of significant process parameters of FDM 3D printer using ANFIS," in *Materials Today: Proceedings*, 2020, vol. 21, doi: 10.1016/j.matpr.2019.11.227.

[9] R. Srinivasan, W. Ruban, A. Deepanraj, R. Bhuvanesh, and T. Bhuvanesh, "Effect on infill density on mechanical properties of PETG part fabricated by fused deposition modelling," in *Materials Today: Proceedings*, 2020, vol. 27, doi: 10.1016/j.matpr.2020.03.797.

[10] R. Srinivasan, K. Nirmal Kumar, A. Jenish Ibrahim, K. V. Anandu, and R. Gurudhevan, "Impact of fused deposition process parameter (infill pattern) on the strength of PETG part," in *Materials Today: Proceedings*, 2020, vol. 27, doi: 10.1016/j.matpr.2020.03.777.

[11] M. A. Kumar, M. S. Khan, and S. B. Mishra, "Effect of fused deposition machine parameters on tensile strength of printed carbon fiber reinforced pla thermoplastics," in *Materials Today: Proceedings*, 2020, vol. 27, doi: 10.1016/j.matpr.2020.03.033.

[12] C. Y. Lee and C. Y. Liu, "The influence of forced-air cooling on a 3D printed PLA part manufactured by fused filament fabrication," *Addit. Manuf.*, vol. 25, pp. 196–203, Jan. 2019, doi: 10.1016/J.ADDMA.2018.11.012.

[13] I. Soejanto, *Desain eksperimen dengan metode Taguchi*. Yogyakarta : Graha Ilmu, 2009.

[14] Esun, "Best PETG Filament 2022 3D Printer PETG Materials eSUN3D." https://www.esun3d.com/petg-product/ (accessed Sep. 16, 2022).

P-ISSN: 1411-3414
E-ISSN: 2549-9815

[15] S. Guessasma, S. Belhabib, and H. Nouri, "Printability and tensile performance of 3D printed polyethylene terephthalate glycol using fused deposition modelling," *Polymers (Basel).*, vol. 11, no. 7, 2019, doi: 10.3390/polym11071220.

[16] M. Bembenek, Ł. Kowalski, and A. Kosoń-Schab, "Research on the Influence of Processing Parameters on the Specific Tensile Strength of FDM Additive Manufactured PET-G and PLA Materials," *Polymers*, vol. 14, no. 12. 2022, doi: 10.3390/polym14122446.