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The Influence of Printing Parameter Variations on the Dimensional Accuracy of 3D Nylon Carbon FDM Prints Using the Grey-Taguchi Method

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Abstract

The dimensional accuracy of the printed specimen in the process of forming a workpiece with carbon fiber material using the Creality K1 Max printer machine requires a combination of parameters in the printing process. The printing type using Fused Deposition Modeling (FDM) is a very popular type of printing process, in this process the filament of the raw material is heated to form the desired product. Nylon carbon was chosen because it has high strength and heat resistance, so it is quite potential for various types of applications. Dimensional accuracy is a major problem in the printing process using 3D printing, especially if the printed product will be assembled either in a mechanical system or a non-mechanical system. The results of the dimensional accuracy of the object printing process are greatly influenced by the selection of parameters used in the printing process. The printing parameter optimization process uses the Grey-Taguchi method, this method was chosen because this method combines multi-dimensional workpieces according to product quality. The specimen or workpiece uses the ASTM D638 standard. Dimensions are 165 length, 13 neck, 19 width, and 7 mm thick. Deviation or dimensional accuracy is based on the largest GRG value in the parameter composition. The research results obtained the following printing parameter factors: a layer thickness of 0.2 mm, a nozzle temperature of 280°C, and a printing speed of 60 mm/s, also layer thickness is the most influence parameter that increasing the dimensional accuracy.

Keywords: FDM; nylon carbon; dimensional accuracy; optimization; grey Taguchi

1 Introduction

The development of three-dimensional printing technology, also know as 3D printing, has brought significant changes in various fields including manufacturing, medicine, and automotive. Among these technologies, Fused Deposition Modeling (FDM) is a highly popular 3D printing technology due to its ease of use and relatively low cost in producing prototypes and functional components [1]. As FDM technology continues to evolve, the types of printable materials have also become more diverse, one of which is nylon carbon. Nylon carbon possesses high mechanical strength and is resistant to heat. Regardless of the raw material used, the quality of 3D prints heavily depends on printing parameters such as nozzle temperature, print speed, and layer thickness [2]. Variations in these parameters determine the mechanical properties and dimensional accuracy of the final product, which are two crucial aspects from an industrial application perspective [3], [4].

Previous research has shown that material made from nylon carbon has a great potential in 3D printing applications. Nylon carbon is lightweight material yet offers high strength [5]. Research on FDM parameter optimization is mostly limited to materials such as PLA and ABS. Studies on nylon carbon materials are still scarce. Findings indicate that nylon filament reinforced with carbon fiber has good potential for structural applications due to its stiffness and heat resistance, however it is affected by variations in printing parameters such as layer thickness and extrusion rate [6]. Another study showed a significant influence of parameters such as layer thickness and infill density on dimensional accuracy in PLA material, where a layer thickness of 0.2 mm resulted in the lowest dimensional deviation of ±0.15 mm [7]. Investigation the flexural strength of carbon-reinforced nylon composites produced using 3D printing technology. The targeted parameters were the effects of infill density and layer thickness on mechanical performance [8]. The results showed that a 100% infill density could withstand a maximum load of 127 N, while a 50% infill density could withstand a maximum load of

76.7 N. Study about the effect of increasing fill density on the tensile strength and elongation of carbon fiber filament materials [9]. The test specimens were produced using 3D printing with nylon carbon fiber and PLA carbon fiber filaments, both with a diameter of 1.75 mm. The specimens were experimentally tested using a Universal Testing Machine. Based on the experimental results, nylon carbon fiber filament showed elongation ranging from 16.970% to 26.681% and tensile strength between 19.244 MPa and 23.899 MPa, while PLA carbon fiber filament showed elongation ranging from 7.673% to 15.546% and tensile strength between 18.580 MPa and 24.552 MPa. It can be concluded that the fill density parameter affects the elongation and tensile strength of the material, and thus can be used as a setting parameter in 3D printing. With various results from studies that have been conducted, nylon carbon filament has the potential to be a reliable filament to be used in functional applications that require high strength, and this material also has the potential to be an alternative material for several types of metals and thermoset polymers because it has characteristics lightweight structure and mechanical capabilities [10].

Therefore, this study aims to analyze the influence of variations in FDM printing process parameters on the dimensional accuracy of specimens made of Nylon Carbon using 3 main parameters, namely layer thickness, nozzle temperature, and printing speed. The results of the experiment will be analyzed using the Grey-Taguchi method to obtain the optimal combination of parameters for dimensional accuracy. The Grey-Taguchi method is used to identify the optimal parameter combinations to produce products with the best performance. The results of this study are expected to contribute to academics and practitioners in the use of nylon carbon material as an alternative material intended for functional components which of course have high precision.

2 Material and Methods

The workpiece specimen follows the ASTM D638 standard. The 3D model of the specimen was created using CAD software. The printed specimen design dimensions are shown in the Fig. 1. The use of the ASTM D638 specimen in this study is because this study continues to tensile testing in the next study, but before tensile test, dimensional accuracy is performed. The material used in this study is the latest eSUN 3D Filament: ePA Nylon Carbon Fiber Filament. The material specifications are shown in the following Table 1.

This study identifies the influence of printing parameters on the dimensional accuracy and tensile strength of nylon carbon filament specimens. The research varies three key parameters namely layer thickness (LT), nozzle temperature (NT), and printing speed (PS). The level selection of the three parameters is based on the recommendation of printing parameters based on the technical data sheet (TDS) which can be accessed through esun3d.com.

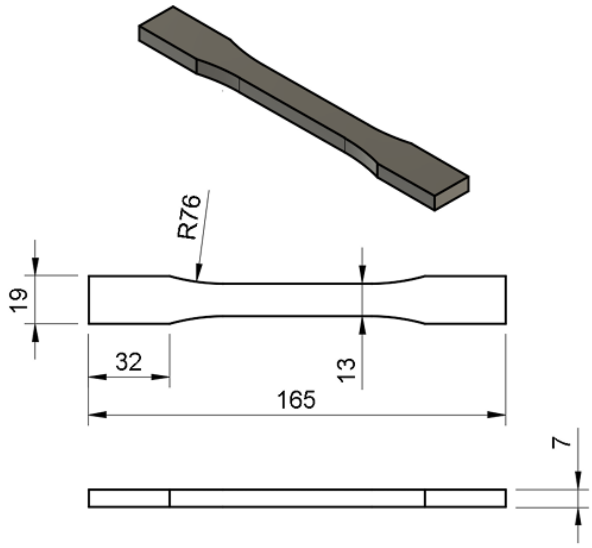


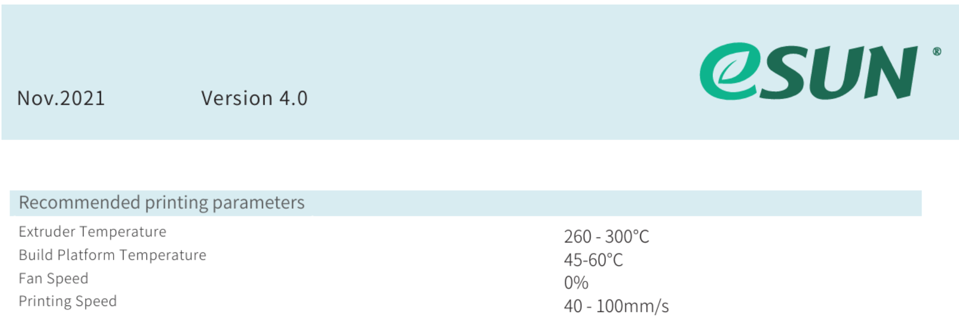
Figure 1. ASTM D638 Specimen

Table 1. Material Specifications eSUN ePA-CF

Filament diameter	1.75 mm
Extruder Temperatur	260 – 300 ^{0}C
Density	1.24 g/cm^3
Printing speed	40 -100 mm/s
Tensile Strength	140 Mpa
Elongation at Break	10.61 %

We can see in Fig. 2, which is a list of recommended printing parameters for ePA-CF or nylon carbon materials for the 3D printing process. Extruder temperature or commonly called nozzle temperature is in the range of 260 ºC - 300 ºC, while the printing speed is in the range of 40 – 100 mm/s. The layer thickness value is in range 0.1-0.2 mm, this value is commonly used for printing in fused deposition modeling machine. Therefore, the value in TDS is the basis for selecting the level of each parameter in this study.

Layer thickness is set at three levels: 0.1 mm, 0.16 mm, and 0.2 mm. Smaller layer thicknesses are expected to enhance interlayer bonding strength. Second, the nozzle temperature i.e., the temperature at the nozzle used to extrude the filament is varied at 260 °C, 280 °C, and 300 °C. Lastly, the printing speed defined as the movement speed of the nozzle during the printing process—is adjusted to three levels: 60 mm/s, 80 mm/s, and 100 mm/s. Higher printing speeds can accelerate the printing process but may reduce surface quality. The tabulation of printing parameter variations is shown in the following Table 2.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eSUN

Recommended printing parameters	
Extruder Temperature	260 - 300°C
Build Platform Temperature	45-60°C
Fan Speed	0%
Printing Speed	40 - 100mm/s

Figure 2. eSun ePA-CF TDS [11].

Table 2. Printing Parameter Variations

Parameter	1	2	3
Layer thickness (mm)	0.1	0.16	0.2
Nozzle temperature (^{O}C)	260	280	300
Printing speed (mm/s)	60	80	100

The specimens will be printed using the Creality K1 Max machine with a print size of 300 x 300 x 300 mm. Dual Gear Direct Drive Extruder Type with maximum nozzle temperature 300 ºC. The scenario of combining three printing parameters, each with three levels, for the specimen printing process was carried out using the full factorial method with an L_{27} Orthogonal Array (OA), as shown in the table 3

Table 3. Combination Printing Parameter

Run No.	**PARAMETER**		
	Layer thickness	Nozzle temperature	Printing speed
1	0.2	260	80
2	0.2	300	80
3	0.2	280	80
4	0.2	300	100
5	0.2	260	60
6	0.2	280	60
7	0.16	300	100
8	0.16	300	60
9	0.16	300	80
10	0.2	300	60
11	0.16	280	100
12	0.2	280	100
13	0.16	260	80
14	0.1	260	60
15	0.16	260	100
16	0.1	300	100
17	0.1	280	100
18	0.1	280	80
19	0.16	260	60
20	0.16	280	80
21	0.16	280	60
22	0.1	300	60
23	0.1	260	100
24	0.1	260	80
25	0.1	300	80
26	0.1	280	60
27	0.2	260	100

Dimensional accuracy tests will be performed using specimens that have been printed according to Figure 1. The dimensions measured are 4, namely length 165 mm, width 19 mm, neck 13 mm, and thickness 7 mm. Dimensional measurements of the specimen were carried out using an Insize digital caliper 1108-200 (8”/200 mm), with a measuring range of 0–200 mm and an accuracy of 0.01 mm.

As we can see in Fig. 3, it is the position of the printed specimen on the bed machine. Each size represents the direction of each axis on the machine. Length 165 mm represents the direction on the x-axis, the width is 19 mm and the neck is 13 mm represents the direction on the Y-axis, and the thickness of 7 mm represents the direction of the Z-axis. The measurement process is conducted after all specimens have been printed and the specimens have reached room temperature. Each dimension is measured at least three times per specimen, then the average value of the dimension is obtained. These results were then analyzed using Taguchi analysis, to obtain the S/N ratio value. These values are used to: 1) identify factors that significantly affect responses; 2) identify the combination of parameters that produce the most optimal responses; and 3) the value of the S/N ratio is a variable used in the calculation of multi-responses optimization using Grey Relational Analysis (GRA).

The Taguchi method is a statistical method that is commonly used to improve the quality of a product, optimize performance by varying the factors that affect the output [12]. In this study, we want to determine the effect of varied printing parameters on the dimensional accuracy of 3D printing results using nylon carbon material.

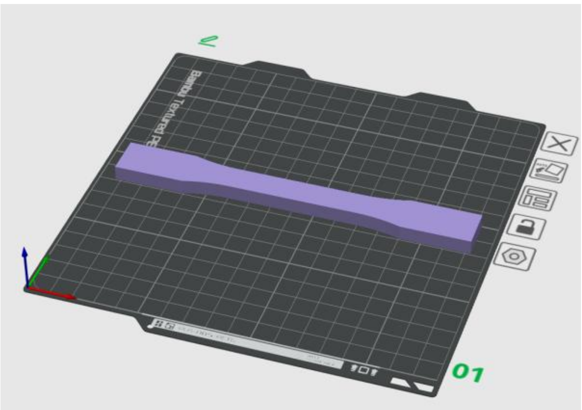

Figure 3. Specimen print position.

The output of the analysis is at least to know what parameters have the most influence on dimensional accuracy, as well as to find out the combination of printing parameters that produce the most optimal dimensional accuracy. The signal-to-noise (S/N) ratio was computed using the "smaller-the-better" criterion, since the objective of this study was to minimize dimensional deviation.

GRA will also be carried out which is an analysis method to measure the level of connectivity between factors [13]. This method is commonly used in the Taguchi method to optimize responses, especially if the trend in the S/N ratio is different for each factor studied, also the limitations of the Taguchi method are cannot optimize several responses simultaneously [14], [15].

The first step in GRA method is to normalize the S/N Ratio value from each test result. The normalization value is calculated using equation 1, which is intended for the Small is Better criterion [15]. Sequentially, max $y_j(q)$ and min $y_j(q)$ are the largest and smallest values of $y_j(q)$ values studied.

$$y_{ij} = \frac{\max y_j - y_i}{\max y_j - \min y_j} \tag{1}$$

The next step is to calculate Deviation Sequence value, which involves finding the absolute difference between value of 1 and the previous normalized S/N Ratio data [15]. The deviation sequence calculation uses equation 2.

$$\Delta_{0ij} = y_{0j} - y_{ij} \tag{2}$$

which:

Δ_{0ij} : sequence deviation value in the experiment i and response j

y_{0j} : maximum value of normalized S/N Ratio (value 1)

y_{ij} : normalized value of S/N Ratio in experiment i and response j

After deviation sequence value is obtained, Grey Relational Coefficient (GRC) and Grey Relational Grade (GRG) values are calculated. GRC is calculated using equation 3, while GRG is the average of all-four GRC values for each response [14] (the importance level of each response is same). The distinguishing coefficient value uses 0.5, in accordance with the values commonly used in previous studies.

$$GRC\ y_{ij} = \frac{\Delta_{min} + \zeta . \Delta_{max}}{\Delta_{0ij} + \zeta . \Delta_{max}} \tag{3}$$

which:

Δ_{min} : minimum value of deviation sequence,

Δ_{max} : maximum value of deviation sequence,

ζ : distinguish coefficient, generally has a value of 0.5.

GRG value are then processed in non-weighted GRG value calculation to identify factors that influence all responses and confirm the best parameters based on the GRG values at each factor level [14].

3 Results and Discussions

The specimens that have been printed using all combination parameters are shown in Fig. 4. The specimens were examined using a dial-caliper to obtain the actual dimension of length, width, neck-width, and thickness (responses) data of each specimen. Each specimen was measured three times for each response, and the average value was recorded as the actual measurement data. Dimensional deviation was obtained by subtracting the nominal dimension value (the size in the design drawing) from the measured value. A smaller deviation value indicates better results, as it indicates a higher level of accuracy in the 3D printing process. The next step is to conduct a Taguchi analysis using the Small is better criterion. This criterion was chosen based on the research objective, which was to achieve the smallest dimensional deviation. The analysis yielded the S/N Ratio value, which is displayed along with the measurement results in Table 4 below.

n

Figure 4. 3D printed speciment

Table 4. Specimen measurement results and S/N Ratio

Run No.	Average measurement on dimensions				S/N Ratio value			
	length 165	width 19	neck 13	thickness 7	length 165	width 19	neck 13	thickness 7
1	165.02	19.27	13.26	7.16	-44.350	-25.925	-22.795	-17.5218
2	165.18	19.38	13.38	7.05	-44.359	-25.946	-22.803	-16.9761
3	165.13	19.35	13.32	7.07	-44.356	-25.940	-22.792	-17.0469
4	165.27	19.60	13.60	7.19	-44.364	-25.937	-22.794	-17.0048
5	165.26	19.57	13.57	7.19	-44.363	-25.937	-22.789	-17.0211
6	165.30	19.53	13.50	7.18	-44.365	-25.944	-22.803	-17.1063
7	165.59	19.78	13.80	7.52	-44.380	-25.945	-22.799	-17.1292
8	165.62	19.81	13.79	7.10	-44.382	-25.921	-22.774	-17.1493
9	165.56	19.77	13.78	7.48	-44.379	-25.946	-22.817	-17.055
10	165.32	19.51	13.51	7.02	-44.366	-25.948	-22.802	-17.0088
11	165.14	19.44	13.46	7.07	-44.356	-25.901	-22.751	-17.1386
12	165.12	19.45	13.43	7.11	-44.355	-25.942	-22.807	-17.0374
13	165.51	19.73	13.73	7.19	-44.376	-25.846	-22.667	-17.1319
14	165.36	19.57	13.57	7.17	-44.368	-25.696	-22.450	-17.101
15	165.36	19.59	13.62	7.19	-44.368	-25.831	-22.650	-17.1373
16	165.71	19.82	13.79	7.12	-44.387	-25.815	-22.598	-17.0007
17	165.68	19.83	13.81	7.17	-44.385	-25.805	-22.614	-16.9212
18	165.67	19.82	13.82	7.11	-44.385	-25.771	-22.581	-16.9911
19	165.17	19.53	13.49	7.08	-44.358	-25.814	-22.608	-17.1198
20	165.07	19.41	13.43	7.10	-44.353	-25.831	-22.650	-17.109
21	165.20	19.52	13.50	7.15	-44.360	-25.839	-22.683	-17.1399

22	165.62	19.83	13.80	7.19	-44.382	-25.760	-22.561	-17.0279
23	165.52	19.77	13.76	7.20	-44.377	-25.747	-22.528	-16.9624
24	165.65	19.83	13.83	7.12	-44.383	-25.732	-22.487	-16.9829
25	165.75	19.83	13.81	7.06	-44.389	-25.808	-22.609	-17.0834
26	165.72	19.81	13.80	7.08	-44.387	-25.780	-22.560	-17.0387
27	165.75	19.84	13.81	7.09	-44.388	-25.920	-22.782	-17.4742

The results of Taguchi analysis show that the model formed for Length (165) response has an R^2 value of 0.5534. Thus, the model formed is significantly able to explain 55.34% of overall results obtained. Layer Thickness factor has the largest contribution to Length (165) response, with a p-value of 0.001. Thus, Layer Thickness has an influence on Length (165) response of 44.06%. Evidence of Layer Thickness influence on Length (165) response is shown in Fig. 5. The model formed for Width (19) response has an R^2 value of 0.5711. This model is significantly able to explain 57.11% of overall results obtained. Layer Thickness factor has the largest contribution to Width (19) response, with a p-value of 0.001. Thus, Layer Thickness has an influence on Width (19) response of 44.69%, as shown in Fig. 6.

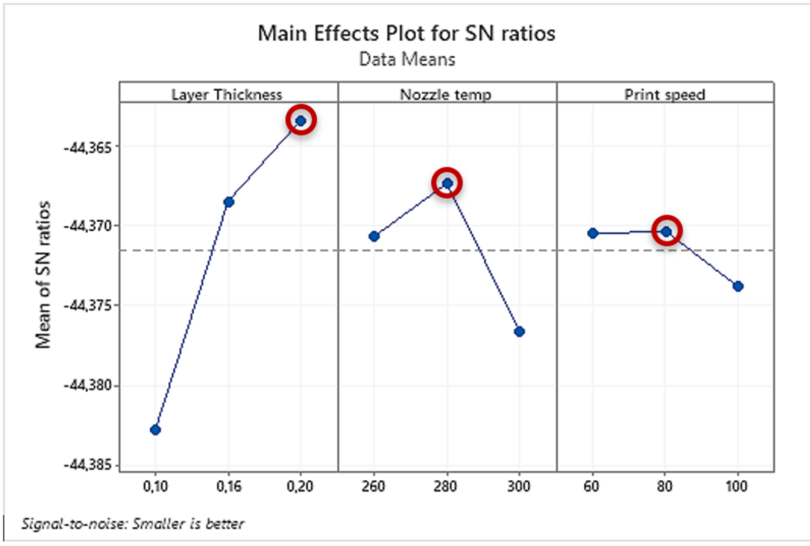

Figure 5. Main effect plot (S/N Ratio) for Length (165) response

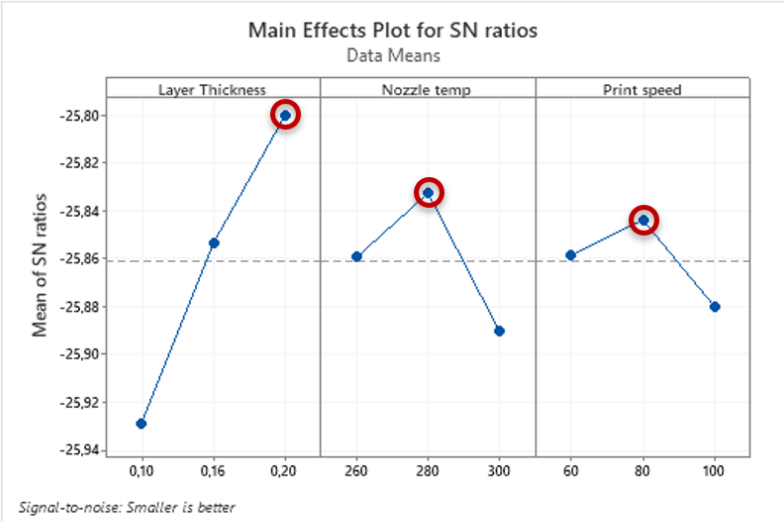

Figure 6. Main effect plot (S/N Ratio) for Width (19) response

For Neck-width (13) response, the formed model has an R^2 value of 0.5817, which means that this model is significantly able to explain 58.17% of overall results obtained. Similar to previous responses, Layer Thickness factor is the most influential factor on this response. In Neck-width (13) response, Layer Thickness factor has an influence of 45.02% with a p-value of 0.001. This large influence is shown in Main Effect Plot for Neck-width (13) response in Figure 7. Meanwhile, the formed model for Thickness (7) response only has an R^2 value of 0.2524 or only explains 25.24% of overall response value obtained. In this model, there is no factor that dominantly influences to Thickness (7) response. This can be seen in Fig. 8, which shows that all factors contribute a relatively balanced influence on Thickness (7) response.

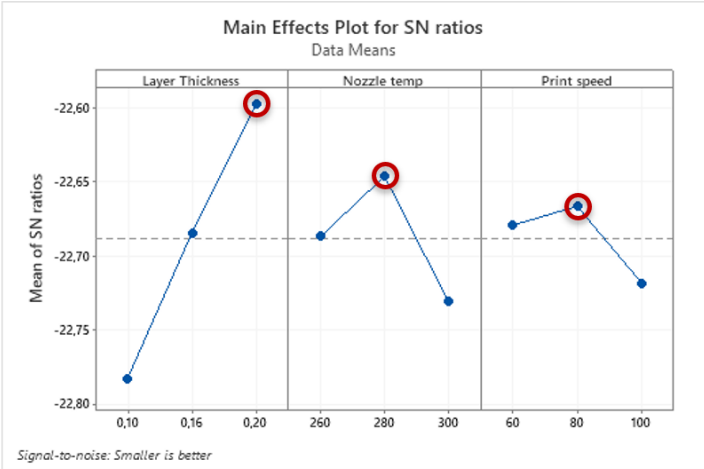

Figure 7. Main effect plot (S/N Ratio) for Neck-width (13) response

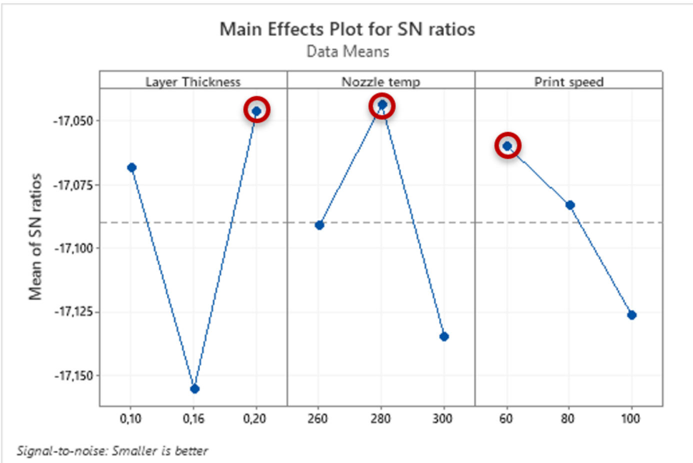

Figure 8. Main effect plot (S/N Ratio) for Thickness (7) response

From all-four Main Effect Plot images above, the best combination of process parameters for each response can also be identified. Length (165), Width (19), and Neck-width (13) responses have the least dimensional deviations in the process parameters of Layer Thickness 0.2 mm, Nozzle Temperature 280°C, dan Printing Speed 80 mm/s. While Thickness (7) response has least dimensional deviations in process parameters Layer Thickness 0.2 mm, Nozzle Temperature 280°C, dan Printing Speed 60 mm/s. The Taguchi method cannot optimize several responses simultaneously [14], so an additional procedure is needed that can optimize all-four responses in a balance.

GRA is implemented to optimize the multi-response Length (165), Width (19), and Neck-width (13), and Thickness (7) simultaneously. GRA begins by calculating the normalization value using equation 1 and deviation sequence using equation 2. The normalization value is calculated using the S/N Ratio value that has been obtained in the previous Taguchi analysis. The results of normalization and deviation sequence calculation are shown in Table 5 below.

Table 5. Normalized value and deviation sequences

Run no.	Normalized value from S/N Ratio				Deviation sequence			
	Length 165	**Width 19**	**Width-neck 13**	**Thick 7**	**Length 165**	**Width 19**	**Width-neck 13**	**Thick 7**
1	0.000	0.000	0.000	0.287	1.00	1.00	1.00	0.71
2	0.220	0.195	0.214	0.062	0.78	0.80	0.79	0.94
3	0.151	0.142	0.107	0.103	0.85	0.86	0.89	0.90
4	0.343	0.582	0.602	0.348	0.66	0.42	0.40	0.65
5	0.329	0.530	0.549	0.348	0.67	0.47	0.45	0.65
6	0.384	0.460	0.426	0.328	0.62	0.54	0.57	0.67
7	0.781	0.896	0.948	1.000	0.22	0.10	0.05	0.00
8	0.822	0.948	0.931	0.165	0.18	0.05	0.07	0.84
9	0.740	0.879	0.914	0.922	0.26	0.12	0.09	0.08
10	0.411	0.425	0.444	0.000	0.59	0.58	0.56	1.00
11	0.165	0.301	0.356	0.103	0.84	0.70	0.64	0.90
12	0.137	0.319	0.303	0.185	0.86	0.68	0.70	0.81
13	0.672	0.809	0.828	0.348	0.33	0.19	0.17	0.65
14	0.466	0.530	0.549	0.307	0.53	0.47	0.45	0.69
15	0.466	0.565	0.636	0.348	0.53	0.44	0.36	0.65
16	0.945	0.965	0.931	0.206	0.05	0.03	0.07	0.79
17	0.904	0.983	0.966	0.307	0.10	0.02	0.03	0.69
18	0.891	0.965	0.983	0.185	0.11	0.03	0.02	0.81
19	0.206	0.460	0.409	0.124	0.79	0.54	0.59	0.88
20	0.069	0.248	0.303	0.165	0.93	0.75	0.70	0.84
21	0.247	0.442	0.426	0.267	0.75	0.56	0.57	0.73
22	0.822	0.983	0.948	0.348	0.18	0.02	0.05	0.65
23	0.685	0.879	0.879	0.368	0.31	0.12	0.12	0.63
24	0.863	0.983	1.000	0.206	0.14	0.02	0.00	0.79
25	1.000	0.983	0.966	0.083	0.00	0.02	0.03	0.92
26	0.959	0.948	0.948	0.124	0.04	0.05	0.05	0.88
27	1.000	1.000	0.966	0.144	0.00	0.00	0.03	0.86

The calculation is continued by calculating the Grey Relational Coefficient (GRC) and Grey Relational Grade (GRG) using equation 3. GRG values are obtained from the average GRC value (all responses) in each treatment parameter. This shows that the weight of the importance of each response is equal or balanced. The results of the GRC and GRG calculations are shown in Table 6.

The results of non-weighted GRG calculation are shown in Table 7. The smallest non-weighted value for each parameter indicates the level that provides Small is Better response characteristic [15]. Delta value indicates the difference between the largest and smallest non-weighted values. A large Delta value indicates that the parameter has a large influence on all four responses, and vice versa.

Table 6. Grey Relational Coefficient and Grey Relational Grade

Run no.	GRC				GRG
	Length 165	**Width 19**	**Width-neck 13**	**Thick 7**	
1	0.33	0.33	0.33	0.41	0.3531
2	0.39	0.38	0.39	0.35	0.3776
3	0.37	0.37	0.36	0.36	0.3640
4	0.43	0.54	0.56	0.43	0.4919
5	0.43	0.52	0.53	0.43	0.4756
6	0.45	0.48	0.47	0.43	0.4552
7	0.70	0.83	0.91	1.00	0.8575
8	0.74	0.91	0.88	0.37	0.7243
9	0.66	0.80	0.85	0.87	0.7954
10	0.46	0.46	0.47	0.33	0.4328
11	0.37	0.42	0.44	0.36	0.3966
12	0.37	0.42	0.42	0.38	0.3970
13	0.60	0.72	0.74	0.43	0.6263
14	0.48	0.52	0.53	0.42	0.4860
15	0.48	0.53	0.58	0.43	0.5079
16	0.90	0.94	0.88	0.39	0.7755
17	0.84	0.97	0.94	0.42	0.7902
18	0.82	0.94	0.97	0.38	0.7757
19	0.39	0.48	0.46	0.36	0.4221
20	0.35	0.40	0.42	0.37	0.3852
21	0.40	0.47	0.47	0.41	0.4357
22	0.74	0.97	0.91	0.43	0.7612
23	0.61	0.80	0.81	0.44	0.6665

24	0.79	0.97	1.00	0.39	0.7845
25	1.00	0.97	0.94	0.35	0.8137
26	0.92	0.91	0.91	0.36	0.7750
27	1.00	1.00	0.94	0.37	0.8261

Table 7. Non-weighted GRG

Level code	Parameter		
	Layer Thickness	Noozle Temp.	Printing Speed
1	0.7365	0.5720	**0.5520***
2	0.5723	**0.5305***	0.5862
3	**0.4637***	0.6700	0.6344
Delta	0.273	0.139	0.082
Rank	**1**	**2**	**3**
Best Parameter	Layer Thickness 0.20 mm, Nozzle Temperature 280°C, Printing Speed 60 mm/s		

Based on optimization results using a combination of Taguchi and GRA, it can be seen that the 3D printing process parameters with optimal and simultaneous response results of Length (165), Width (19), Neck-width (13), and Thickness (7) are: Layer Thickness 0.20 mm, Nozzle Temperature 280°C, and Printing Speed 60 mm/s. Based on GRA calculations, it is also known that the Layer Thickness factor is factor that has the most significant influence on all-four responses, as evidenced by the largest Delta value. This is in line with the results of the ANOVA analysis for each response.

4 Conclusions

This research successfully implemented experiments by utilizing the Taguchi analysis method and optimizing the response of Length (165), Width (19), Neck Width (13), and Thickness (7) simultaneously using the Gray Relational Analysis method. The results of the study showed that the process of printing objects with ASTM D-638 shapes and dimensions, using Creality K1 Max brand 3D printing, with process parameters of 0.2 mm layer thickness, 280°C nozzle temperature, and 60 mm/s printing speed with carbon nylon material is the best printing process parameter that produces the most optimal dimensional accuracy response. Meanwhile, the layer thickness factor is a factor that contributes significantly to dimensional accuracy.

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References

[1] R. B. Kristiawan, F. Imaduddin, D. Ariawan, Ubaidillah, and Z. Arifin, "A review on the fused deposition modeling (FDM) 3D printing: Filament processing, materials, and printing parameters," Jan. 01, 2021, *De Gruyter Open Ltd*. doi: 10.1515/eng-2021-0063.

[2] A. Widyo Nugroho, D. Tohidin, and C. Budiyantoro, "Analisis pengaruh parameter proses terhadap kuat tarik produk 3D Printing dari bahan Polyvinyl Alcohol (PVA)," *Jurnal Program Studi Teknik Mesin UM Metro*, vol. 9, no. 2, pp. 154–161, 2020, Accessed: Jan. 30, 2025. [Online]. Available: http://ojs.ummetro.ac.id/index.php/turbo

[3] Pristiansyah, Hasdiansah, and Sugiyarto, "Optimasi Parameter Proses 3D Printing FDM Terhadap Akurasi Dimensi Menggunakan Filament Eflex," *Jurnal Teknologi Manufaktur*, vol. 11, no. 01, 2019.

[4] H. Bakhtiari, A. Nouri, and M. Tolouei-Rad, "Impact of 3D printing parameters on static and fatigue properties of polylactic acid (PLA) bone scaffolds," *Int. J. Fatigue*, vol. 186, Sep. 2024, doi: 10.1016/j.ijfatigue.2024.108420.

[5] P. K. Thanikonda, J. K. Rao, and D. K. Vaka, "3D Printed Composite Materials: Innovations In Additive Manufacturing And Mechanical Performance," *Educational Administration: Theory and Practice*, 2024, doi: 10.53555/kuey.v30i10.8075.

[6] I. Farina, N. Singh, F. Colangelo, R. Luciano, G. Bonazzi, and F. Fraternali, "High-Performance Nylon-6 Sustainable Filaments for Additive Manufacturing," *Materials*, vol. 12, no. 23, p. 3955, Nov. 2019, doi: 10.3390/ma12233955.

[7] A. Dey and N. Yodo, "A systematic survey of FDM process parameter optimization and their influence on part characteristics," Sep. 01, 2019, *MDPI Multidisciplinary Digital Publishing Institute*. doi: 10.3390/jmmp3030064.

[8] V. Kumar, D. Veeman, M. Vellaisamy, and V. Singh, "Evaluation of flexural strength of 3D-Printed nylon with carbon reinforcement: An experimental validation using ANN," *Polymer (Guildf).*, vol. 316, Jan. 2025, doi: 10.1016/j.polymer.2024.127854.

[9] B. D. Prihadianto, S. Darmo, D. A. Hasan, and D. N. Ananda, "Analisis Kekuatan Tarik dan Regangan Filamen Carbon Fiber Hasil 3D Print dengan Variasi Fill Density," *Infotekmesin*, vol. 14, no. 2, pp. 390–396, Jul. 2023, doi: 10.35970/infotekmesin.v14i2.1936.

[10] I. M. Alarifi, "A performance evaluation study of 3d printed nylon/glass fiber and nylon/carbon fiber composite materials," *Journal of Materials Research and Technology*, vol. 21, pp. 884–892, Nov. 2022, doi: 10.1016/j.jmrt.2022.09.085.

[11] Ltd. Shenzhen Esun Industrial Co., "ePA-CF Technical Data Sheet," 2021, *Esun, Shenzen*. [Online]. Available: www.esun3d.net

[12] M. B. Wicaksono and F. K. A. Nugraha, "Optimization of 3D Printing Parameters Using the Taguchi Method to Improve Dimensional Precision Martinus," *J. Teknol.*, vol. 12, no. 2, pp. 70–75, 2022, doi: 10.35134/jitekin.v12i2.76.

[13] B. L. Jian, C. C. Wang, H. T. Yau, L. W. Wu, and A. H. Tian, "Optimization of lathe cutting parameters using taguchi method and grey relational analysis," *Sensors and Materials*, vol. 32, no. 3, pp. 843–858, 2020, doi: 10.18494/SAM.2020.2674.

[14] K. Ismartaya, B. Bawono, and P. W. Anggoro, "Hardness and Toughness Investigation of ASSAB 705 Steel by Various Tempering Temperatures," *Key Eng. Mater.*, vol. 951, pp. 11–20, 2023, doi: 10.4028/p-qhlFk6.

[15] M. I. Qazi, R. Akhtar, M. Abas, Q. S. Khalid, A. R. Babar, and C. I. Pruncu, "An integrated approach of GRA coupled with principal component analysis for multi-optimization of shielded metal arc welding (SMAW) process," *Materials*, vol. 13, no. 16, 2020, doi: 10.3390/MA13163457.

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