中國機械工程學刊第四十二卷第四期第 393~401 頁(民國一百一十年)
Journal of the Chinese Society of Mechanical Engineers, Vol.42, No.4, pp. 393~401 (2021)

Optimization of 3D Printing Process Parameters on Mechanical Behaviors and Printing Time of ABS, PLA, PET-G Products using Taguchi Method

Menderes KAM* and Ahmet İPEKÇİ**

Keywords： FDM, mechanical behaviors, printing time, Taguchi.

ABSTRACT

The effect of three important printing process parameters such as filament materials (ABS - Acrylonitrile Butadiene Styrene, PLA - Poly Lactic Acid, PET-G - Polyethylene Terephthalate Glycol), layer thickness (0.15, 0.2, and 0.25 mm), and raster angle (30, 45, and 60°) were investigated on mechanical behaviors and printing time of the prepared products. Taguchi method is applied to reduce the number of test, determined the optimum process parameters for high mechanical behaviors, low printing time, and product weight. Analytical methods such as Signal/Noise ratio, regression analysis, and variance analysis were used to evaluate the effects of three-dimensional (3D) printing parameters on mechanical behaviors and printing time. The results showed that the optimum 3D printing parameters for the strength were filament material of PET-G, layer thickness of 0.25 mm, and raster angle of 45º. The raster angle of 45° is the optimum mechanical behaviors at each individual layer when compared to other raster angles of 30° and 60°. Finally, statistical study was performed for prediction of mechanical behaviors and printing time of products.

Paper Received June, 2020. Revised October, 2020, Accepted November, 2020, Author for Correspondence: M. Kam

* *Assistant Professor, Department of Mechanical and Metal Technologies, Düzce University, Turkey 81620.*

** *Lecturer Ph.D, Department of Mechanical and Metal Technologies, Düzce University, Turkey 81620.*

INTRODUCTION

3D (three-dimensional) printing is used to print products to create a variety of materials using the desired properties. Although the usage area of this method is becoming widespread day by day, it is used in various sectors for different purposes (Murphy et al. 2018; El Magri et al. 2020; Çevik and Kam 2020). 3D printing process is one of the widely used material deposition method named FDM (Fused Deposition Modelling). It is the process of pouring the molten material from a hot nozzle to the glass surface or on a heated flat surface in the form of a thread with a cross sectional area. This process is widely used to create products with various filament materials; ABS - Acrylonitrile Butadiene Styrene, PLA - Poly Lactic Acid, PET-G - Polyethylene Terephthalate Glycol (Çevik and Kam 2020). The mechanical behaviors and printing time of the 3D printed products are affected by different printing process parameters. The application of 3D printing process may be limited due to raster angle in mechanical behaviors and printing time of the 3D printed products. Printing speed, occupancy rate, layer thickness, filling structure, nozzle temperature, nozzle width, cooling speed, and raster angle are the main printing process parameters affecting product quality, tensile strength, impact strength, printing time, and cost in additive manufacturing (Ramli et al. 2015; Wu et al. 2014; Çevik and Kam 2020).

Raster angle and occupancy rate affect the tensile and impact strength of products (Zhang et al. 2017; Abeykoon et al. 2020). The properties of 3D printed products were anisotropic and affected by the directional processing of layers. Further, occupancy rates and raster angles have an important effect on mechanical behaviors, (45°/−45°) given higher strength compared to the other raster angles (Fatimatuzahraa et al. 2011; Çevik and Kam 2020). Raster angles have important effects on fatigue life

(Ziemian et al. 2015; Çevik and Kam 2020; Kannan et al. 2020). The numbers of occupancy rates have direct effect on mechanical behaviors. The occupancy rates are directly proportional to the strength (Mahmood et al. 2017). Researchers obtained the most optimum values for strength of produced parts and 0° of raster angle printed stronger products (Onwubolu and Rayegani, 2014). They made tests using different filling structures to show that the mechanical properties will differ based on filling structures (Samykano et al. 2019; Abeykoon et al. 2020). Literature studies have been focused on tensile strength of 3D products (Lee et al. 2007; Sood et al. 2009) printing methods, engineering applications (Fantini et al. 2008), different printing process (Vaezi et al. 2013), and development (Lanzotti et al. 2015). It was emphasized that FDM method shows success in the production of complex surfaced geometry (Fantini et al. 2008; Vaezi et al. 2013; Lanzotti et al. 2015). Tensile and izod impact tests are the most important methods used to determine the mechanical behaviors of 3D printing products (Kam et al. 2021). Tensile tests for plastic materials are commonly applied according to ISO 527 standards (Kam et al. 2020, Kam et al. 2021). 3D printers are commonly print products using various filament materials (ABS, PLA, and PET-G) (Kreemer et al. 2014; Çevik and Kam 2020; Kam et al. 2020; Kam et al. 2021). These filament materials were selected in many applications because of its chemical resistance, impact resistance, thermal properties, and mechanical behaviors (strength, elongation, hardness, toughness, and izod impact strength) (Abeykoon et al. 2020; Çevik and Kam 2020). Researchers studied to determine the tensile strength and elasticity modulus of printed products with 3D printer (Wong and Pfahnl, 2014). In another study, they investigated the effect of printing parameters on mechanical behaviors of products with ABS filament (Thompson et al. 2016). It has been known in works that the raster angle which is one of the printing parameters, affects mechanical behaviors of the products (Adam and Zimmer 2015; Çevik and Kam 2020). In a study conducted with the FDM method, the effect of different raster angles (0, 30, 45, 60 and 90°) on the mechanical behaviors was investigated tensile strength of the printed products from ABS (Dorigato et al. 2017). Manufacturing processes are developing rapidly for manufacturing more sensitive products. Ratio of waste material in traditional production methods is very high. The works about 3D printing systems include varied process parameters (Lee et al. 2007) printing methods, reverse engineering practice (Fantini et al. 2008), development of production (Vaezi et al. 2013), medical investigations (Adam, and Zimmer, 2015), have been studied by FDM method (Turner et al. 2014; Dorigato et al. 2017; Çevik and Kam 2020). Many works on mechanical behaviors of products printed by 3D printing process and FDM method have been conducted in the literature (Popescu et al. 2018; Kam et al. 2020; Çevik and Kam, 2020; Kam et al. 2021). In this study, it was aimed to optimization of the effects of 3D printing parameters on mechanical behaviors and printing time of products printed with these filament materials using a 3D printer. This study is primarily focused on the effects of mechanical behaviors of 3D products subjected to the influence of three factors; filament materials (ABS, PLA, and PET-G), layer thickness (0.15, 0.2, and 0.25 mm), and raster angle (30, 45, and 60°). These parameters are the most important main factors affecting mechanical behavior, product quality, printing time, and printing cost as 3D printing process parameters. Therefore, these parameters were selected for this experimental and statistical study.

MATERIAL AND METHOD

Printing process parameters and filament materials

This study aims to investigate the effect of three important parameters such as filament materials, layer thickness (0.15, 0.2, and 0.25 mm), raster angles (30, 45, and 60°) on mechanical behaviors and printing time of printed products using ABS, PLA, and PET-G filament materials in FDM method. Products for experiments were designed using the SolidWorks program. After the G code was created, it was printed on a 3D model platform. 3D Printing process parameters of the products were determined as shown in Table 1.

Table 1. Constant parameters of the printing process.

3D printing process parameters	Values
Nozzle diameter (mm)	0.40
Extruder temperature (°C)	240
Bed temperature (°C)	80
Occupancy rates (%)	50
Extrusion width (mm)	0.35
Printing speed (mm/min)	4200
Speed in free (mm/min)	4800
Room temperature (°C)	24 ± 1
Filling structures	Rectilinear

Filament materials (ABS, PLA, and PET-G) were used. The properties of filament materials were presented in Table 2. Figure 1 presents process of printing products using a 3D Printer.

Table 2. The Properties of filament materials (Lanzotti et al. 2015; Kam et al. 2017; Çevik and Kam 2020).

Properties	Filament Materials		
	ABS	PLA	PET-G
Filament color	White	Red	Natural
Filament diameter (mm)	1.75	1.75	1.75
Density (g / cm³)	1.04	1.24	1.27
Strength (MPa)	51	45.6	50
Elastic modulus (MPa)	2750	3600	2140
Percentage elongation (%)	30	17.5	20
Melting point (ºC)	235	210	135
Heat deflection temperature (ºC)	94	60	70

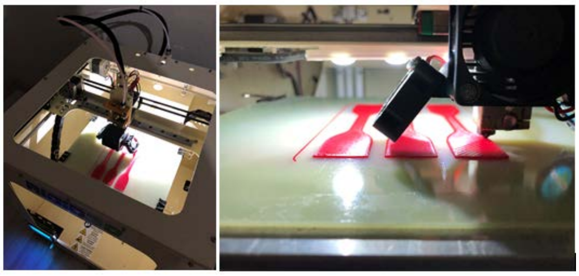

Fig. 1. Printing of test products using a 3D printer.

The standard sample dimensions of tensile test (ISO 527 - Type 2) and izod impact test (ISO 180 - Type 1) were presented in Figure 2.

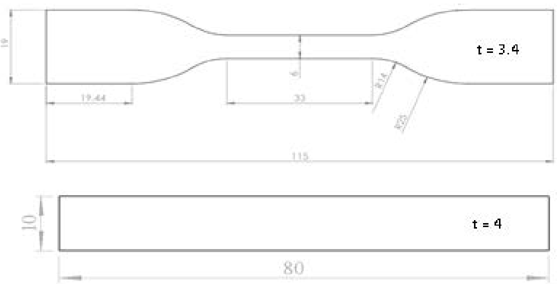

Fig. 2. Dimensions of the tensile and impact strength test samples (mm).

Tensile and izod impact tests

Tests were carried out in 10-ton tensile testing device and test speed of 5 mm / min in Duzce University laboratory. Izod impact tests were performed in XJJ-50w computer controlled charpy impact testing device machine (impact speed: 2.9 m/s, pendulum energy: 7.5 J, humidity: 60%, temperature: 23 °C).

Taguchi method and experimental design

Taguchi method is applied to reduce the number of tests, find the optimum process parameters for mechanical behaviors, low printing time and weight. Analytical methods such as Signal / Noise (S/N) ratio, regression analysis, and analysis of variance (ANOVA) were used for analysis the effects of parameters on mechanical behaviors and printing time (Çevik and Kam 2020; Kam et al. 2021). In this study, Taguchi L_9 was used as analysis method. In this approach, a statistical performance measure known as the S/N ratio is used to evaluate the results. "S" in this ratio refers to the signal ratio and "N" refers to the noise ratio. Since this study is desired to have mechanical behaviors, which is considered as quality properties, the "larger is better", approach is taken into account in calculating S / N ratios. The equation (eq.) given in eq. (1) was used to calculate the S / N ratios. The "smaller is the better", approach is taken into account in calculating S / N ratios. The eq. (2) was used to calculate the S / N ratios Control factors and levels were given in Table 3. Taguchi L_9 experiment design was given in Table 4.

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

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

Table 3. Control factors

Symbol	Factors	Unit	Levels	Output
A	Filament material	-	ABS PLA PET-G	Tensile strength, Elongation, Izod impact, Product weight, Printing time
B	Layer thickness	mm	0.15 0.2 0.25	
C	Raster angle	0	30 45 60	

Table 4. Experimental design.

Experiment No	Control factors		
	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

RESULTS AND DISCUSSION

Experimental design was carried out according to Taguchi L_9. The three products for each test were produced. After, tensile and izod impact tests were conducted. Test values were averaged. The ANOVA was analyzed the effect of process parameters on mechanical behaviors and printing time. ANOVA results revealing the effect on mechanical behaviors of 3D printing process parameters (filament materials, layer thickness, and raster angle) at a confidence level of 95 % and a significance level of 5 %. Experimental results (tensile strength, elongation, izod impact, product weight, printing time values) were given in Table 5 and their S/N ratios were shown in Table 6. The calculation was performed using the Taguchi method. The very good compromise between strength and elongation at break experimentally observed justifies the growing interest of academic and industrial communities for different filament materials.

Results of tensile strength

The main effects plot for strength and levels of the 3D printing process parameters was presented in Figure 3. ANOVA results and their contribution (%) were given in Table 7. All of printing process parameters was statistically significant according to the ANOVA results. In the printing process, it is preferred that the products have high mechanical behaviors. Table 8 shows to response table for S/N ratios. The layer thickness increased the strength, accordingly. The 45 degree of raster angle gave the optimum results according to the 30 and 60 degrees.

Regression Eq. was shown in eq. (3).

$$\text{Tensile strength (MPa)} = 27.028 - 5.434\,A1 + 2.176\,A2 + 3.259\,A3 - 2.151\,B1 + 0.536\,B2 + 1.616\,B3 - 0.084\,C1 - 1.656\,C2 + 1.571\,C3. \quad \textbf{(3)}$$

Table 5. Average test results.

No	A	B	C	Tensile strength values (MPa)	Elongation at break values (%)	Izod impact values (kj/m²)	Product Weight values (gr)	Printing Time values (min)
1	ABS	0.15	30	19.73	0.07	13.25	11.90	83
2	ABS	0.2	45	22.80	0.06	14.65	12.17	67
3	ABS	0.25	60	22.25	0.05	15.86	12.79	60
4	PLA	0.15	45	29.32	0.06	6.22	13.99	82
5	PLA	0.2	60	28.54	0.05	6.43	13.85	69
6	PLA	0.25	30	29.75	0.04	7.50	15.64	58
7	PET-G	0.15	60	25.58	0.05	16.93	13.96	84
8	PET-G	0.2	30	31.35	0.03	18.72	14.24	68
9	PET-G	0.25	45	33.93	0.02	21.51	15.47	62

Table 6. Signal / Noise rates.

No	A	B	C	Tensile strength S/N (dB)	Elongation at break S/N (dB)	Izod impact S/N (dB)	Product weight S/N (dB)	Printing time S/N (dB)
1	ABS	0.15	30	25.9025	-23.0980	22.4443	-21.5109	-38.3816
2	ABS	0.2	45	27.1587	-24.4370	23.3168	-21.7058	-36.5215
3	ABS	0.25	60	26.9466	-26.0206	24.0061	-22.1374	-35.5630
4	PLA	0.15	45	29.3433	-24.4370	15.8758	-22.9164	-38.2763
5	PLA	0.2	60	29.1091	-26.0206	16.1642	-22.8290	-36.7770
6	PLA	0.25	30	29.4697	-27.9588	17.5012	-23.8847	-35.2686
7	PET-G	0.15	60	28.1580	-26.0206	24.5731	-22.8977	-38.4856
8	PET-G	0.2	30	29.9248	-30.4576	25.4461	-23.0702	-36.6502
9	PET-G	0.25	45	30.6117	-33.9794	26.6528	-23.7898	-35.8478

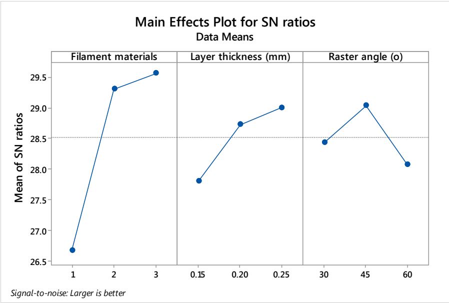

Fig. 3. S / N rates (strength).

Table 7. ANOVA (tensile strength).

Source	DF	Seq SS	Adj MS	F value	P value	(%)
A	2	134.660	134.660	30.33	0.032	75.94
B	2	22.572	22.572	5.08	0.165	12.73
C	2	15.649	15.649	3.52	0.221	8.82
Error	2	4.447	4.447			2.51
Total	8	177.329				100.0

Table 8. Response table

Levels	A	B	C
1	26.67	27.80	28.43
2	29.31	28.73	29.04
3	29.56	29.01	28.07
Delta	2.90	1.21	0.97
Rank	1	2	3

The test results were confirmed with the analysis of variance. ANOVA results showed the most effective parameter on tensile strength values to be filament materials (75.94 %), layer thickness were the most effective parameter after filament materials at 12.73 %, and the raster angle was lower at 8.82 %. The optimum values for the 3D printing process parameters of products were obtained at third level (A3) of filament materials, at third level of layer thickness (B3), and at second level (C2) of raster angles, respectively. The optimum strength for the 3D printing process parameters (Filament material, layer thickness, and raster angle) were PET-G, 0.25 mm, and 45 degree, respectively. Raster angles have an important effect on strength; 45 degree gives higher strength accordingly to the other raster angles (Fatimatuzahraa et al. 2011; Çevik and Kam 2020).

The results of elongation at break

Filament materials were statistically significant. The S/N rates for elongation and levels of the process parameters were shown in Figure 4. The optimum process parameters obtained from analysis results were given in Table 9. Regression Eq. was shown in Eq. (4) elongation at break. The ANOVA results for elongation at break values were given in Table 10.

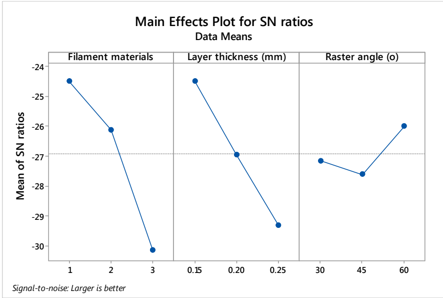

Fig. 4. S / N rates for elongation at break.

Table 9. Response table for S/N ratios.

Levels	A	B	C
1	-24.52	-24.52	-27.17
2	-26.14	-26.97	-27.62
3	-30.15	-29.32	-26.02
Delta	5.63	4.80	1.60
Rank	1	2	3

Table 10. ANOVA for elongation at break.

Source	DF	Seq SS	Adj MS	F value	P value	(%)
A	2	0.001089	0.000544	49.00	0.020	55.68
B	2	0.000822	0.000411	37.00	0.026	42.05
C	2	0.000022	0.000011	1.00	0.500	1.14
Error	2	0.000022	0.000011			1.14
Total	8	0.001956				100.00

Tests results were confirmed with the ANOVA. The results showed the most effective parameter on elongation values to be filament materials (55.68 %), layer thickness were the most effective parameter after filament materials at 42.05 %, and the raster angle was lower at 1.14 %. The optimum values for the printing process parameters of products were obtained at first level (A1) of filament materials, at first level of layer thickness (B1), and at third level (C3) of raster angles. The optimum elongation values for the process parameters (filament material, layer thickness, and raster angle) were ABS, 0.15 mm, and 60o, respectively. The 30 and 45 degrees of raster angle made the samples more brittle and elongation (%) of the products is much reduced. It has shown similar results in the literature (Kam et al. 2017; Çevik and Kam 2020; Kam et al. 2021).

The results of izod impact strength

$$\text{Elongation (\%)} = 0.04778 + 0.01222\,A1 + 0.00222\,A2 - 0.01444\,A3 + 0.01222\,B1 - 0.00111\,B2 - 0.01111\,B3 - 0.00111\,C1 - 0.00111\,C2 + 0.00222\,C3. \quad \textbf{(4)}$$

The main effect plot for 3D printing process parameters was given in Figure 5. It was wanted to be have high strength in printing process. Table 11 shows to the ANOVA results. Filament material is an important parameter for strength properties, accordingly. The optimum process parameters obtained from analysis results were given in Table 12. Linear Regression Eq. was given in Eq. (5) for izod impact value.

Izod impact (kJ/m²) $=13.452+1.134\,A1-6.736\,A2+5.601\,A3-1.319\,B1-0.186\,B2+1.504\,B3-0.296\,C1+0.674\,C2-0.379\,C3.$ **(5)**

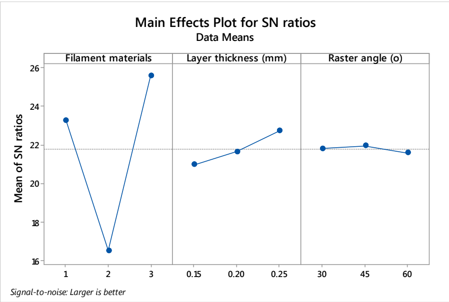

Fig. 5. S / N rates for izod impact.

Table 11. Analysis of variance for izod impact values.

Source	DF	Seq SS	Adj MS	F Value	P Value	%
A	2	234.081	117.041	278.57	0.004	93.97
B	2	12.112	6.056	14.41	0.065	4.86
C	2	2.057	1.029	2.45	0.290	0.83
Error	2	0.840	0.420			0.34
Total	8	249.091				100.00

Table 12. Response table for S/N ratios.

Levels	A	B	C
1	23.26	20.96	21.80
2	16.51	21.64	21.95
3	25.56	22.72	21.58
Delta	9.04	1.76	0.37
Rank	1	2	3

The results showed the most effective parameter on izod impact values to be filament materials (93.97 %), layer thickness were the most effective parameter after filament materials at 4.86 %, and the raster angle was lower at 0.83 %. The optimum values for the printing process parameters of products were obtained at third level (A3) of filament materials, at third level of layer thickness (B3), and at second level (C2) of raster angles. Optimum izod impact strength for printing parameters (filament material, layer thickness, and raster angle) were PET-G, 0.25 mm, and 45o, respectively. The 45 degree of raster angle gave the most optimum results according to the 30 and 60 degrees. The 30 and 60 degrees of raster angle made the samples more brittle and elongation (%) of the products is much reduced. It has shown similar results in the literature (Lanzotti et al. 2015; Kam et al. 2017; Çevik and Kam 2020; Kam et al. 2021).

The results of the product weight and printing time values

The lowest printing time was also obtained as 53 minute (min) in product the number of 6 and the lowest weight was also obtained as 9.22 gr in product the number of 1 (Table 5). Determining the effect of process parameters on the product costs is very important. The products can be manufactured with various possible raster angles. Provided that quality levels are fixed at a certain level, products need to be printed quickly and at low costs. A convenient raster angle ensures optimal use of resources and reduces cost. Cost is one of the areas of improvement in printing process as economically (Turner et al. 2014; Lanzotti et al. 2015; Kam et al. 2017; Çevik and Kam 2020; Kam et al. 2021).

S/N rates for product weight values were shown in Figure 6. ANOVA results were presented in Table 13. It was desired to have low printing time in 3D printing process. The optimum 3D printing process parameters obtained from analysis results were given in Table 14. Regression Eq. was shown in Eq. (6) for estimation of product weight.

Product weight (gr) = $13.7789-1.492\,A1+0.714\,A2+0.778\,A3-0.496\,B1-0.359\,B2+0.854\,B3+0.148\,C1+0.098\,C2-0.246\,C3.$ **(6)**

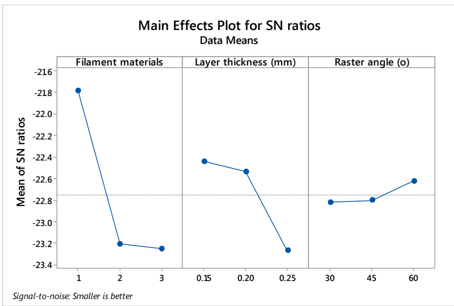

Fig. 6. S / N rates for product weight values.

Table 13. ANOVA table (product weight values).

Source	DF	Seq SS	Adj MS	F value	P value	%
A	2	10.0263	10.0263	99.71	0.010	73.10
B	2	3.3134	3.3134	32.95	0.029	24.16
C	2	0.2751	0.2751	2.74	0.268	2.01
Error	2	0.1006	0.1006			0.73
Total	8	13.7153				100.00

Table 14. Response table (product weight values).

Levels	A	B	C
1	-21.78	-22.44	-22.82
2	-23.21	-22.54	-22.80
3	-23.25	-23.27	-22.62
Delta	1.47	0.83	0.20
Rank	1	2	3

The results showed the most effective parameter on product weight to be filament materials (73.10 %), layer thickness were the second effective parameter at 24.16 %, and the raster angle was lower at 2.01 %. The optimum values for the printing process parameters of products were obtained at third level (A3) of filament materials, at third level of layer thickness (B3), and at first level (C1) of raster angles, respectively. The optimum values for the parameters (filament material, layer thickness, and raster angle) were PET-G, 0.25 mm, and 30^{o}, respectively. The 30 degree of raster angle gave the optimum results according to the 45 and 60 degrees.

S / N rates for printing time values were presented in Figure 7. Table 15 presents the ANOVA results. It was desired to have low printing time and printing cost. The results of optimum process parameters were given in Table 16. Regression eq. was shown in Eq. (7) for printing time and printing cost values.

Printing time (min) = 70.333 - 0.333 A1 - 0.667 A2+ 1.000 A3 + 12.667 B1- 2.333 B2- 10.333 B3 - 0.667 C1 + 0.000 C2+ 0.667 C3. **(7)**

The results showed the most effective parameter on printing time to be layer thickness (98.55 %), filament materials were the second effective parameter at 0.56 %, and the raster angle was lower at 0.32 %. The optimum values for the printing process parameters of products were obtained at third level (A3) of filament materials, at first level of layer thickness (B1), and at third level (C3) of raster angles, respectively. The optimum printing process parameters (filament material, layer thickness, and raster angle) were PET-G, 0.15 mm, and 60 degree, respectively. The 60 degree of raster angle gave the most optimum results according to the 30 and 45 degrees. The layer thickness increased the printing time values increased proportionally. The filament material and raster angle values are not statistically important according to the analysis results.

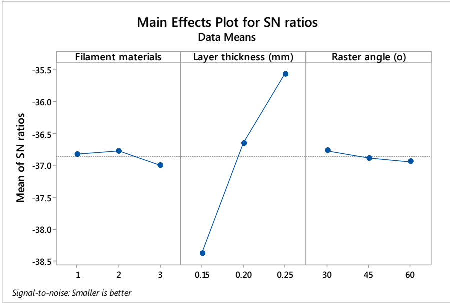

Fig. 7. S / N rates for printing time values.

Table 15. ANOVA table (printing time).

Source	DF	Seq SS	Adj MS	F value	P value	%
A	2	4.667	2.333	1.00	0.500	0.56
B	2	818.00	409.00	175.29	0.006	98.55
C	2	2.667	1.333	0.57	0.636	0.32
Error	2	4.667	2.333			0.56
Total	8	830.00				100.00

Table 16. Response table for S/N ratios (printing time).

Levels	A	B	C
1	-36.82	-38.38	-36.77
2	-36.77	-36.65	-36.88
3	-36.99	-35.56	-36.94
Delta	0.22	2.82	0.18
Rank	2	1	3

CONCLUSIONS

In this study, it was aimed to optimization of 3D printing process parameters on mechanical behaviors and printing time of the printed products with different filament materials (ABS, PLA, and PET-G) using Taguchi Method. The obtained test values were statistically analyzed. Experimental and statistical results showed that the filament materials are the major parameter affecting the mechanical behaviors. The filament materials can be the most effective parameter on mechanical behaviors. The most effective parameter on tensile strength values to be filament materials (75.94 %), layer thickness (12.73 %), and the raster angle (8.82 %). 3D printing parameters (filament material, layer thickness, and raster angle) for the optimum strength were PET-G, 0.25 mm, and 45 degree, respectively. The tensile strength decreased along with increasing of the layer thickness. The 45 degree of raster angle gave the most optimum results. The raster angle of 45° is the highest tensile strength at each individual layer when compared to raster angles of 30° and 60°. The most effective parameters on elongation to be filament materials (55.68 %), layer thickness (42.05 %), and the raster angle (1.14 %). The optimum elongation of determined for the process parameters were ABS, 0.15 mm, and 60 degree, respectively. The most effective parameters on izod impact values to be filament materials (93.97%), layer thickness (4.86%), and the raster angle (0.83%). The optimum izod impact of determined for the printing process parameters were PET-G, 0.25 mm, and 45 degree, respectively. The optimum results for the mechanical behaviors (tensile strength, elongation, and izod impact) were A_3 B_3 C_2, A_1 B_1 C_3, and A_3 B_3 C_2, respectively. The most effective parameters on product weight to be filament materials (73.10%), layer thickness (24.16%), and the raster angle (2.01%). The optimum values of determined for the printing process parameters were PET-G, 0.25 mm, and 30 degree, respectively. The most effective parameters on printing time to be layer thickness (98.55 %), filament materials (0.56%), and the raster angle (0.32%). The optimum printing process parameters were PET-G, 0.15 mm, and 60 degree, respectively. The 60 degree of raster angle gave the most optimum results according to the 30 and 45 degrees. The layer thickness increased the printing time values increased proportionally. The filament material and raster angle values are not statistically important. The optimum results for the product weight and printing time were A_3 B_3 C_1, and A_3 B_1 C_3, respectively. Finally, statistical study was performed for prediction of mechanical behaviors and printing time of products. In addition, by improving the material properties, it will be possible to provide support for manufacturer and designers to reduce printing time and printing costs. Mechanical behaviours and printing time can be improved by using appropriate 3D printing process parameters. PET-G products showed that optimum and best results thanks to filaments' thermal and mechanical behaviors. In the printing process of products with appropriate process parameters, it was observed the improvement technological and economical.

REFERENCES

Abeykoon, C., Sri-Amphorn, P. and Fernando, A. "Optimization of fused deposition modeling parameters for improved PLA and ABS 3D printed structures," *Int. J. Light. Mater. Manuf.*, Vol.3, No.3, pp. 284-297 (2020).

Adam, G.A.O. and Zimmer, D. "On design for additive manufacturing: evaluating geometrical limitations," *Rapid Prototyp. J.* Vol.21, No.6, pp. 662-670 (2015).

Çevik, Ü. and Kam, M. "A Review Study on The Mechanical Properties of Products Obtained by Metal / Polymer Composite Filament Production and FDM Method," *Journal of Nanomaterials*, (2020).

Dorigato, A., Moretti, V., Dul, S., Unterberger, S. H. and Pegoretti, A. "Electrically conductive nanocomposites for fused deposition modelling", *Synthetic metals*, Vol.226, pp. 7-14 (2017).

El Magri, A., El Mabrouk, K., Vaudreuil, S., Chibane, H. and Touhami, M. E. "Optimization of printing parameters for improvement of mechanical and thermal performances of 3D printed poly parts", *J. of App. Poly. Sci.*, No. 49087 (2020).

Fantini, M., Crescenzio, F. D., Persiani, F., Benazzi, S. and Gruppioni, G. "3D restitution, restoration and prototyping of a medieval damaged skull," *Rapid Prototyping Journal*, pp. 318-324 (2008).

Fatimatuzahraa, A. W., Farahaina, B., and Yusoff, W. A. Y. "The effect of employing different raster orientations on the mechanical properties and microstructure of Fused Deposition Modeling parts," *Symp. Eng. Ind. Appl.* pp. 22-27 (2011).

Kam, M., Saruhan, H. İpekçi, A. "Investigation the Effect of 3D Printer System Vibrations on Surface Roughness of the Printed Products," *Düzce Üniversitesi Bilim ve Teknoloji Dergisi*, Vol.7, No.2, pp. 147-157 (2019).

Kam, M., Saruhan, H., İpekçi A. "Experimental Analysis of Vibration Damping Capabilities of Sleeve Bearings Printed Using FDM Method," *Journal of Polytechnic*, (2021).

Kam, M., Saruhan, H., İpekçi A. "Investigation of 3D printing filling structures effect on mechanical properties and surface roughness of PET-G material products," *Gaziosmanpaşa Bilimsel Araştırma Dergisi,* Vol.6, No.ISMSIT2017, pp. 114-121 (2017).

Kam, M., Saruhan, H., İpekçi A. "Investigation the effects of 3D printer system vibrations on mechanical properties of the printed products," *Sigma J. Eng and Nat. Sci.* Vol.36, No.3, pp. 655- 666 (2018).

Kam, M., İpekçi A. and Şengül, Ö. "Taguchi optimization of fused deposition modeling process parameters on mechanical characteristics of PLA+ filament material," *International Journal of Science and Technology*, (2021). doi:10.24200/SCI.2021.57012.5020

Kam, M., İpekçi A. and Şengül, Ö. "Investigation of the effect of FDM process parameters on mechanical properties of 3D printed PA12 samples using Taguchi method," *Journal of Thermoplastic Composite Materials.* (2021). doi:10.1177/08927057211006459

Kannan, S., Vezhavendhan, R., Kishore, S., and Kanumuru, K. V. "Investigating the effect of orientation, infill density with Triple raster pattern on the tensile properties for 3D Printed samples," *IOP SciNotes*, Vol.1, No.2, 024405 (2020).

Kreemer, Z. H. "Rapid Prototyping Using FDM Systems", *Handbook of Manufacturing Engineering and Technology Springer*, pp. 2471-2483 (2014).

Lanzotti, A., Grasso, M., Staiano, G. and Martorelli, M. "The impact of process parameters on mechanical properties of parts fabricated in PLA with an open-source 3-D printer," *Rapid Prototyping Journal*, Vol.21, No.5, pp. 604-617 (2015).

Lee, C. S., Kim, S.G., Kim, H. J. and S. H. Ahn, "Measurement of anisotropic compressive strength of rapid prototyping parts," *Journal of Materials Processing Technology*, pp. 627-630 (2007).

Mahmood, S., Qureshi, A. J., Goh, K. L., and Talamona, D. "Tensile strength of partially filled FFF printed parts: experimental results," *Rapid Prototyp. J.* Vol.23, No.122 (2017).

Murphy, C. A. and Maurice, N. "Collins microcrystalline cellulose reinforced polylactic acid biocomposite filaments for 3D printing", *Poly. Comp.*, Vol.39, No.4, pp. 1311-1320 (2018).

Onwubolu, G. C. and Rayegani, F. "Characterization and optimization of mechanical properties of ABS parts manufactured by the fused deposition modelling process," *Int. J. Manuf. Eng.* pp. 1-13 (2014).

Popescu, D., Zapciu, A., Amza, C., Baciu, F., Marinescu, R. "FDM process parameters influence over the mechanical properties of polymer specimens: A review," *Polymer Testing*, Vol.69, pp. 157-166 (2018).

Ramli, F., Jailani, M. H., Unjar, Alkahari,, H. M. R., and Abdullah, M. A. "Integrated Recycle System Concept For Low Cost 3D-Printer Sustainability," *Proceeding of Mechan*

Samykano, M. S., Selvamani, K., Kadirgama, K., Ngui, W. K., Kanagaraj, G. and Sudhakar, K. "Mechanical property of FDM printed ABS:influence of printing parameters," *Int. J. Adv. Manuf. Technol.* (2019).

Sood, A. K., Ohdar, R. K., Mahapatra, S. S. "Improving dimensional accuracy of fused deposition modelling processed part using grey Taguchi method," *Materials and Design*, Vol.30, No.10, pp. 4243-4252 (2009).

Thompson, M. K., Moroni, G., Vaneker, T., Fadel, G., Campbell, R. I., Gibson, I. and Martina, F. "Design for additive manufacturing: trends, opportunities, considerations, and constraints", *CIRP Ann. - Manuf. Technol.* Vol.65, No.2, pp. 737-760 (2016).

Turner, B., Strong, N. R. and Gold, S. A "A review of melt extrusion additive manufacturing processes: I. process design and modeling," *Rapid Prototyping Journal*, Vol.20, No.3, pp. 192-204 (2014).

Vaezi, M., Chianrabutra, S., Mellor, B. and Yang, S. "Multiple material additive manufacturing Part 1: A Review," *Virtual and Physical Prototyping*, pp. 19-50 (2013).

Wong, J.Y., Pfahnl, A. C. "3D printing of surgical instruments for long-duration space missions", *Aviat Space Environ Med.*, Vol.85 No.7, pp. 758-763 (2014).

Wu, W. Z., Geng, P., Zhao, J., Zhang, Y., Rosen, D. W., and Zhang, H. B. "Manufacture and thermal deformation analysis of semicrystalline polymer polyether ether ketone by 3D printing," *Materials Research Innovations*, Vol.12, pp. 5-16 (2014).

Zhang, S. U., Han, J., Kang, H. W., Shin, B. C. "Thermo-mechanical properties of ABS parts fabricated by fused deposition modeling and vapor smoothing," *18th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE)*, pp. 1-6 (2017).

Ziemian, S., Okwara, M. and Ziemian, C. W. "Tensile and fatigue behavior of layered acrylonitrile butadiene styrene" *Rapid Prototyp. J.* (2015).