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Dimensional Optimization of Additive Manufacturing Process

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ABSTRACT

Today, the use of layered production (3D printer) technology is becoming widespread. Prototype products can be manufactured by this method and also end-user parts as well. In this study, it is aimed to minimize the dimensional deviation of the parts obtained via 3D printing with PLA material. Within the scope of the study, 16 different experiments were conducted and five different parameters such as filling rate, printing speed, fill pattern, extruder temperature, and layer height were considered. For these parameters, four levels for each were determined and experiments were conducted. Then, Signal/Noise analysis was performed to determine the parameter levels that minimize dimensional deviations. Layer height and printing speed were identified to be important parameters in the final analysis

INTRODUCTION

Today, many technological innovations are being launched out at an increasing speed of progress and most of them are implemented in industrial areas with the expedition. Especially with the development of the computer systems, innovation enhancements gained a tremendous acceleration. The layered production (3D printer) technology might be called as one of these technological innovations.

The layered production method is used in many fields from health to the automotive, defense industry and entertainment sector (Thompson et al., 2016; Zolfagharian et al., 2016; Gökçearslan, 2017; Sanjayan and Xia, 2018; Wei et al., 2018). For example, Yıldıran made a study on the usability of 3D printers in the fashion and clothing sectors (Yıldıran, 2016). In his study, he showed that customized products could be obtained by 3D printers.

Atalay et al. have shown that combining layered production and medical imaging systems can be a powerful diagnostic tool and may also aid in complex surgery (Atalay et al., 2016). Yıldırım et al. investigated the usability of 3D printers in education (Yıldırım, Yıldırım and Çelik, 2018). They showed that 3D printers are well used in health and engineering areas but not enough in education. Gür has been able to produce a large piece that does not fit in the printer by separating it into layers in a 3D printer (Gür, 2017). Wankhede et al, analyzed the influence of the input experimental parameters on layered production. They used the Taguchi method for the optimization process (Wankhede et al., 2019). Also, some researchers used the Taguchi method for optimization of layered production (Aslani et al., 2020; Pant et al., 2020).

Although prototype parts can be produced quickly in layered production, the dimensions of the parts may differ from the actual size. The dimensional deviation may vary in X, Y and Z directions (Santana, Lino Alves and da Costa Sabino Netto, 2017; Güler and Çetinkaya, 2018; Mahmood, Qureshi and Talamona, 2018).

In this study, optimization tryouts were performed in order to minimize dimensional deviations in the parts which were obtained by 3D printing technology. Firstly, experimental design was fulfilled according to L16 orthogonal sequence by the Taguchi method. Then, the parts were produced by layered production technology and their dimensions in X and Y directions were measured. Deviations from the required value were determined. Then, Signal/Noise (S/N) analysis and optimization studies were executed.

METHODS AND MATERIALS

Printing process of the parts were performed on the Makerbot Replicator II printer with 1.75 mm diameter PLA filament. The experimental design was done with the Taguchi method. L16 orthogonal sequence was used. Factors and levels used in the experiments were given in Table 1.

First of all, a cube with 20 mm edges was drawn in the SolidWorks software. . After printing, the letters X, Y, and Z are engraved on the surfaces to avoid confusing the print direction of the part (Fig. 1). The file

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was saved as *.stl and opened in Makerbot Desktop (version 3.10.1.1389). The part was located in the center of the printer table. The letter X on the part was positioned to be parallel to the X-axis. Y was also set to be parallel to the Y-axis. Print files (*.x3g files) were created by defining individual parameter levels for each test set given in Table 2. These files were transferred to the 3D printer and cube parts were then printed.

Table 1. Factors and levels.

Factor	Levels				Unit
	1	2	3	4	
Infill Ratio	10	30	50	90	%
Printing Speed	60	80	100	120	mm/min
Fill Pattern	Linear (D)	Honeycomb (B)	Diamond (E)	Moroccan Star (F)	
Extruder Temperature	220	225	230	235	°C
Layer Height	0.06	0.1	0.15	0.2	mm

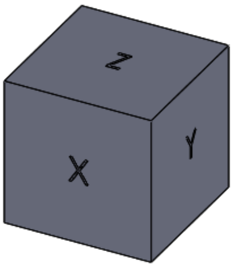

Fig. 1. Part view on SolidWorks.

The parts produced within the scope of the study were given in Fig. 2. All parts were measured for three times in both X and Y directions by INSIZE 1108 digital caliper with 0.01 mm accuracy. Then, the averages of these measurements were taken as the exact edge dimensions for each. The deviation was calculated by subtracting the projected edge dimension, which is 20 mm differedfrom the exact dimensions. The experimental set and dimensional measurement results were given in Table 2.

A B

Fig. 2. Parts produced within the scope of the study. A: All 16 tracks. B: Close-up view.

In this study, signal noise (S/N) analysis and parameter optimization were performed. S/N analysis was performed in the Minitab program. S/N ratios were calculated using the smaller better formula since dimensional deviations were desired to be minor (Özek and Taşdemir, 2009; Kuş, Motorcu and Ekici, 2016; Ay, 2017; Mert and Ekinci, 2017; Siyambaş, Bayraktar and Turgut, 2017).

RESULTS

S/N ratios obtained as a result of S/N analysis were given in Table 3. S/N ratios for the deviation in the X and Y directions were given in the upper and lower part of the table, respectively. In this table, the maximum S/N ratio of each parameter indicates the optimum level of that parameter. In the Delta line, the difference between the maximum S/N ratio and the smallest S/N ratio of each parameter was given. These differences are encoded in the last line which is named as Rank, from larger to smaller. The parameter with a larger delta indicates the most effective parameter for the process (Balaji, Murthy and Rao, 2016; Gulati et al., 2016; Seçgin and Özsert, 2019; Şen, Taşdemir and Seçgin, 2020).

Table 2. Results of the measurement.

Experimental Setup						X Direction Dimension Measurement		Y Direction Dimension Measurement	
Experiment No	Extruder Temperature	Printing Speed	Infill Ratio	Fill Pattern	Layer Height	Average Dimension	Deviation	Average Dimension	Deviation
1	220	60	10	D	0.06	20.07	0.07	19.91	-0.09
2	225	80	10	B	0.1	20.10	0.10	19.99	-0.01
3	230	100	10	E	0.15	20.14	0.14	20.00	0.00
4	235	120	10	F	0.2	20.17	0.17	20.02	0.02
5	230	60	30	B	0.2	20.20	0.20	20.08	0.08
6	235	80	30	D	0.15	20.11	0.11	19.98	-0.02
7	220	100	30	F	0.1	20.11	0.11	19.98	-0.02
8	225	120	30	E	0.06	20.10	0.10	19.96	-0.04
9	235	60	50	E	0.1	20.19	0.19	20.08	0.08
10	230	80	50	F	0.06	20.08	0.08	19.93	-0.07
11	225	100	50	D	0.2	20.13	0.13	19.97	-0.03
12	220	120	50	B	0.15	20.20	0.20	20.06	0.06
13	225	60	90	F	0.15	20.23	0.23	20.14	0.14
14	220	80	90	E	0.2	20.28	0.28	20.17	0.17
15	235	100	90	B	0.06	20.10	0.10	19.95	-0.05
16	230	120	90	D	0.1	20.08	0.08	19.96	-0.04

According to Table 3, the most effective parameter causing deviation in the X direction is “layer height”, while the most effective parameter causing deviation in the Y direction is “printing speed”. This difference is thought to result from the fill pattern effect. S/N analysis graph for the X-direction deviation is given in Fig. 3. S/N analysis graph for Y-direction deviation is given in Fig. 4.

Table 3. Signal to noise ratios.

Dimension Deviation	Level	Infill Ratio	Printing Speed	Fill Pattern	Extruder Temperature	Layer Height
Deviation in X direction	1	18.94	16.20	20.58	17.00	21.21
	2	17.98	17.84	16.99	17.57	18.77
	3	16.98	18.60	15.61	18.73	15.80
	4	16.50	17.75	17.22	17.10	14.61
	Delta	2.44	2.40	4.97	1.74	6.59
	Rank	3	4	2	5	1
Deviation in Y direction	1	35.23	20.51	27.85	23.72	24.63
	2	29.23	27.12	27.25	28.26	30.34
	3	24.75	34.63	28.85	30.55	30.98
	4	21.48	28.44	26.75	28.17	24.75
	Delta	13.75	14.12	2.10	6.83	6.35
	Rank	2	1	5	3	4

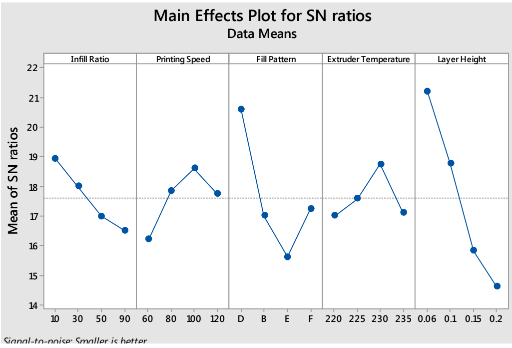

Fig. 3. S/N analysis graph for deviation in the X direction.

The optimum levels can be easily read from the S/N analysis graphs in Fig. 3 and Fig. 4. In these graphs, the level of each factor giving the largest S/N ratio is the optimum level. The optimum levels determined were given in Table 4.

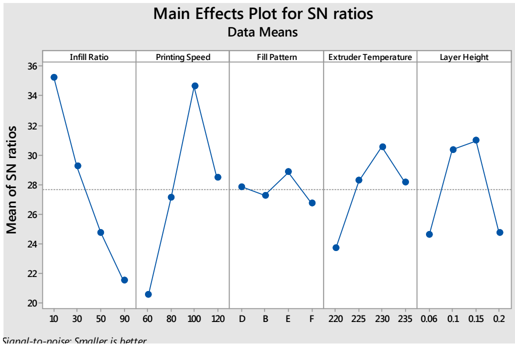

Fig. 4. S/N analysis graph for deviation in the Y direction.

After the optimum levels were determined, validation experiments were performed using these levels. Dimensional deviations were also found to be very low in the validation experiments.

Table 4. Optimum levels of factors.

Dimensional Deviation	Infill Ratio	Printing Speed	Fill Pattern	Extruder Temperature	Layer Height
For deviation in X direction	10	100	D	230	0.06
For deviation in Y direction	10	100	E	230	0.15

CONCLUSIONS

In this study, 20x20x20 cube pieces were produced by layered production technology and optimum parameter levels were determined in order to minimize dimensional deviations. For this purpose, five different parameters such as fill rate, printing speed, fill pattern, extruder temperature and layer height were determined and four levels were determined for each of these parameters. The experimental design was made using the Taguchi method and L16 orthogonal array. Signal/Noise ratios were determined by measuring the edges of the manufactured parts in the directions parallel to the X and Y axes. The optimum parameter levels were determined. As a result of the study, the following results were obtained:

- The most effective parameter for the deviation in the X direction is the layer height.
- The most effective parameter for the deviation in the Y direction is the printing speed.
- Optimal parameter levels for deviation in the X direction:
  - Infill Rate: 10%
  - Printing Speed: 100 mm/min
  - Filling Pattern: Linear
  - Extruder Temperature: 230 ° C
  - Layer height: 0.06 mm
- Optimal parameter levels for deviation in the Y direction:
  - Infill Rate: 10%
  - Printing Speed: 100 mm/min
  - Filling Pattern: Diamond
  - Extruder Temperature: 230 ° C
  - Layer height: 0.15 mm

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