Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 14th International Scientific and Practical Conference. Volume 3, 36-40

Research into the Accuracy of Holes in 3D Printing Using Taguchi Method

Valeri Bakardzhiev
Technical University of Sofia, Branch Plovdiv
Plovdiv, Bulgaria
bakardzhiev@tu-plovdiv.bg

Sabi Sabev
Technical University of Sofia, Branch Plovdiv
Plovdiv, Bulgaria
sabi_sabev@tu-plovdiv.bg

Konstantin Chukalov
Technical University of Sofia, Faculty of Industrial Technology
Sofia, Bulgaria
konstantin_chukalov@abv.bg

Plamen Kasabov
Technical University of Sofia, Branch Plovdiv
Plovdiv, Bulgaria
plamen.kasabov@abv.bg

Abstract. **The article discusses the impact of two factors on the accuracy of the hole sizes - print speed and layer thickness in 3D printing. Nine samples of the ABS polymer were printed by using a 3D printer, then the impact of both of the factors on the accuracy of 3D printing of the holes was evaluated. Taguchi's method was applied with the help of DOE in Minitab to evaluate the impact of the two factors.**

Keywords: 3D print, Taguchi's method, DOE, FDM

I. INTRODUCTION

3D printing is used to create various models in fields such as architecture, engineering, medicine and many other areas of modern life. The main goal of 3d printing is quickly and accurately manufacturing of of products that are prototypes or technologically difficult to manufacture.

We know many technologies for 3d printing, the most common types being FDM - Fused Deposition Modeling, SLA - Stereolithography and SLS - Selective Laser Sintering. Material deposition technology has gained ground with usage of polymers and t creation of patterns from Acrylonitrile Butadiene Styrene (ABS), Polystyrene (HIPS) and Polylactic Acid (PLA).

ABS polymer is most often used for 3D printing, by deposition of material. Although material deposition technology was created more than 20 years ago, in the last few years it has been very actively used because it is more technological to apply. The main advantage of it is that the material, in this case the ABS polymer, is previously created in the form of a thread, so-called filament, which is subsequently melted by an extruder with a certain polymer melting temperature of 230-250ºC and an extrusion speed, thus get different layers of 3d printing.

Of scientific interest is t accuracy of 3D printed details and possibility for industrial use in various fields of technology. [1] – [9]

Parida used the experimental design proposed by Taguchi based on the L27 orthogonal array. It was found the optimal combination of different parameters in this research. [13]

Zagorski drew comparisons between the samples in terms of surface, print time, volume of material used, sample weight and the deviation from the nominal geometry. [22]

II. METHODOLOGY

A. Material

The object of our research is creation of a 3d model fig.1.The 3D model is octagonal prism, length of sides-80mm with a central hole diameter of which is 22 mm and 4 holes in circular pattern with diameter of 16 mm. The holes will be measured for dimensional deviations to make comparisons in different modes of operation of 3d printer using material deposition technology. ABS material has been chosen with constant extruder temperature of 235ºC.

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2023vol3.7254

B. Equipment

a. 3D printer FlashForge Creator 3[10]

b. Software FlashPrint[11]

c. Software AutoDesk Inventor Pro 2023[12]

d. Software Minitab 2019[13]

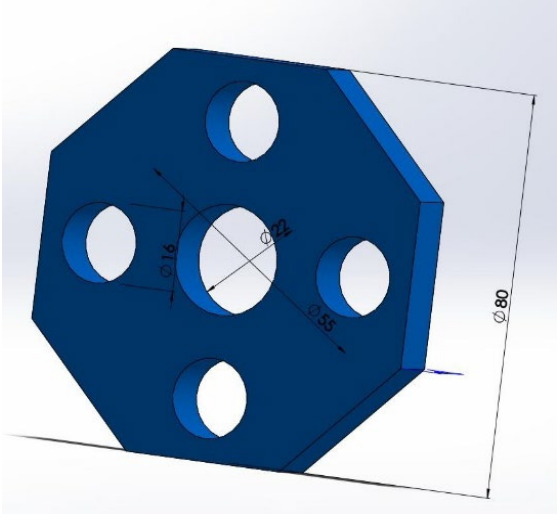

Fig.1. Model for 3D printing.

C. Parameters,

The created 3D model was transferred to processing program slicer FlashPrint 5. For our research, we have considered optimization of printing parameters proposed by other authors[14]-[21]. We have previously created a planning of the experiment according to Taguchi's model and we have determined the values of the two parameters-printing speed and layer height shown in tab. 1.

TABLE 1 3D PRINTING PARAMETERS

Print №	Parameter 1	Parameter 2
1	0,1	10
2	0,1	45
3	0,1	80
4	0,25	10
5	0,25	45
6	0,25	80
7	0,4	10
8	0,4	45
9	0,4	80

Constant parameters as follow:

- Platform temperature: 110 ºC.
- Extrusion temperature: 235 ºC.
- Print speed: 10-80 [mm/s].
- Travel speed: 120 [mm/s].
- Number of shells: 3.
- Layer thickness: 0,1-0,4 [mm].
- Nozzle diameter: 0,4 [mm].

Based on the parameters in Table 1, 13 samples were printed, the printing process is shown in Fig.2. In order for more précised results, the samples were printed from same roll with ABS polymer filament.

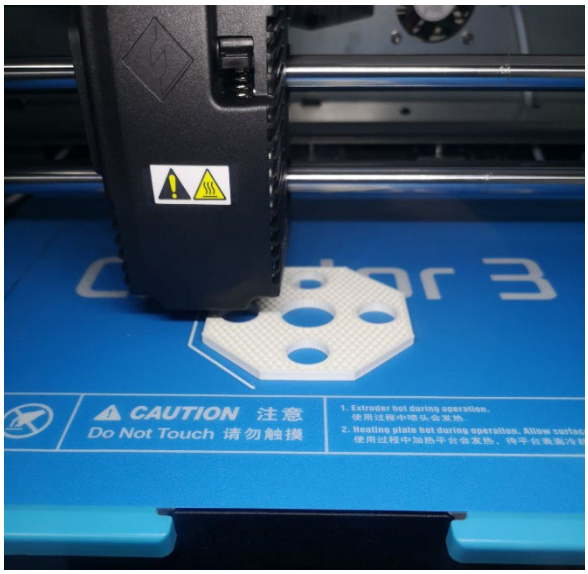

Fig.2. 3D Printing process.

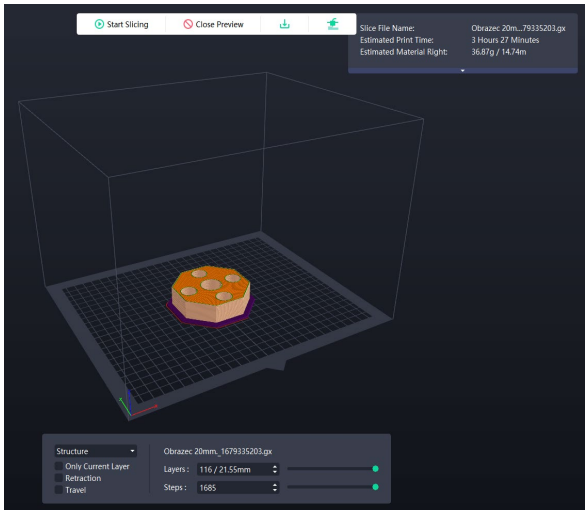

Fig.3. FlashPlot slice process.

III. RESULTS AND DISCUSSION

The statistical information required for the analysis is obtained by using automatic measuring system ReniShaw OMP40 mounted on the CNC Mill HAAS VS2ss. The measurement is shown in Fig.4 - 5.

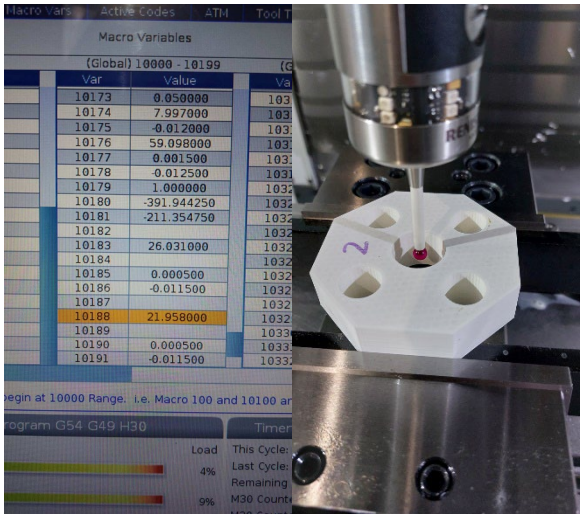

Fig.4. Measurement process.

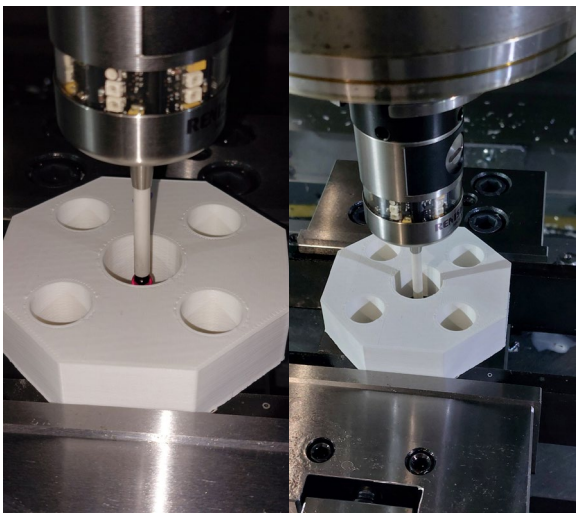

Fig.5. Measurement process.

The samples were measured in three vertical directions and in two perpendicular horizontal directions. The obtained results are averaged and shown in table 2.

TABLE 2 EXPERIMENTAL RESULTS

SAMPLE	DOWN	MIDLE	UP	S	Δ
1	21.8	21.85	21.97	21.87	0.13
2	21.71	21.85	21.95	21.84	0.16
3	21.7	21.85	21.95	21.83	0.17
4	21.7	21.72	21.84	21.75	0.25
5	21.65	21.7	21.8	21.72	0.28
6	21.62	21.62	21.65	21.63	0.37
7	21.55	21.8	21.85	21.73	0.27
8	21.56	21.81	21.89	21.75	0.25
9	21.62	21.65	21.8	21.69	0.31

Mathematical - statistical processing was performed with program product MINITAB. The data from Table 2 were processed and the following regression model was obtained:

Regression Equation

$$\ln(\delta) = -2.873 + 9.46\ \text{Layer} + 0.00294\ \text{Speed} - 13.68\ \text{Layer*Layer} - 0.0635\ \text{Layer*Layer*Speed} + 0.000268\ \text{Layer*Speed*Speed}$$

B In tables tab. 3 - 5 the results of the regression analysis are given..

TABLE 3 COEFFICIENTS FOR TRANSFORMED RESPONSE

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	-2.873	0.148	(-3.345; -2.401)	-19.37	0.000	
Layer	9.46	1.23	(5.54; 13.38)	7.68	0.005	38.55
Speed	0.00294	0.00187	(-0.00301; 0.00890)	1.57	0.214	4.83
Layer*Layer	-13.68	2.63	(-22.05; -5.32)	-5.21	0.014	45.13
Layer*Layer*Speed	-0.0635	0.0286	(-0.1543; 0.0274)	-2.22	0.113	21.91
Layer*Speed*Speed	0.000268	0.000143	(-0.000189; 0.000724)	1.87	0.159	22.96

TABLE 4 MODEL SUMMARY FOR TRANSFORMED RESPONSE

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.0729351	98.33%	95.54%	0.176326	81.53%	94.53	-16.09

TABLE 5 ANALYSIS OF VARIANCE FOR TRANSFORMED RESPONSE

Source	DF	Seq SS	Contribution	Adj SS	Seq MS	F-Value	P-Value
Regression	5	0.938602	98.33%	0.93860	0.187720	35.29	0.007
Layer	1	0.514777	53.93%	0.31346	0.514777	96.77	0.002
Speed	1	0.120495	12.62%	0.01317	0.120495	22.65	0.018
Layer*Layer	1	0.276909	29.01%	0.14421	0.276909	52.06	0.005
Layer*Layer*Speed	1	0.007888	0.83%	0.02626	0.007888	1.48	0.310
Layer*Speed*Speed	1	0.018532	1.94%	0.01853	0.018532	3.48	0.159
Error	3	0.015959	1.67%	0.01596	0.005320		
Total	8	0.954561	100.00%				

P - the coefficient of multiple correlation. The multiple correlation coefficient is insignificant if the value is less than 0.05;

The analysis of the residuals does not indicate a violation of the assumptions of the regression analysis. From fig. 6. is seen that all the standardized residuals are within the interval ±2. Therefore, it can be concluded that there are no gross errors. The histogram shows that the distribution of the residuals is normal.

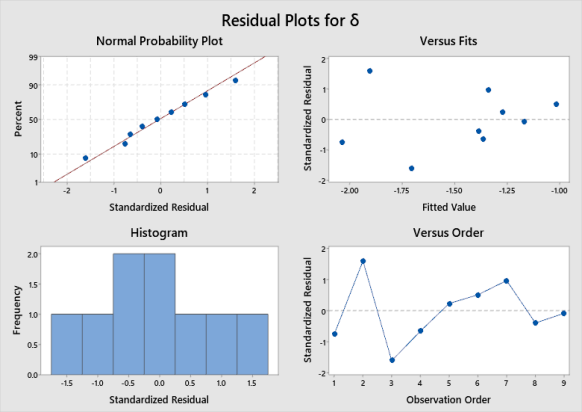

Fig.6. Standardized residual.

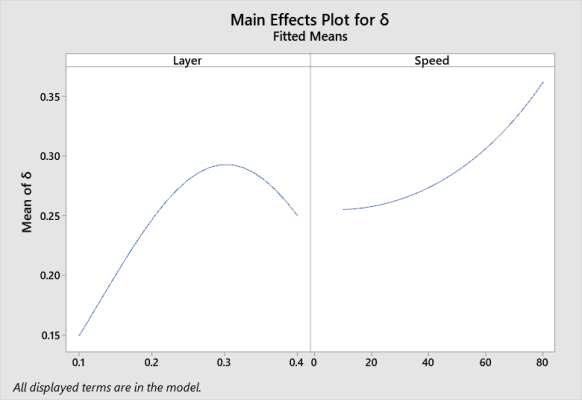

Fig 7. Main effects plot.

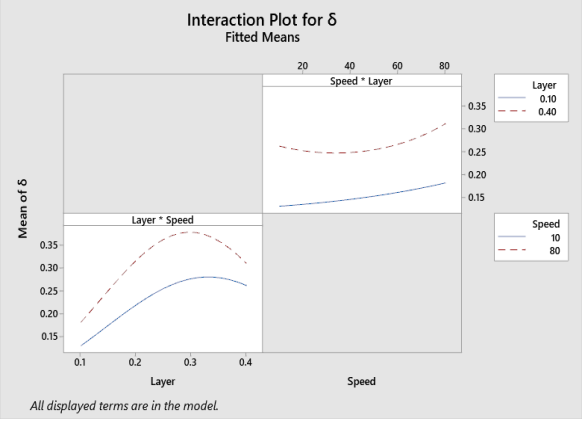

Fig 8. Interaction plot.

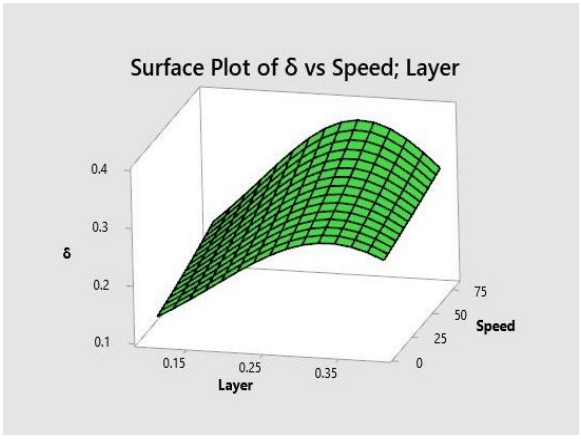

Fig 9. 3D Surface plot.

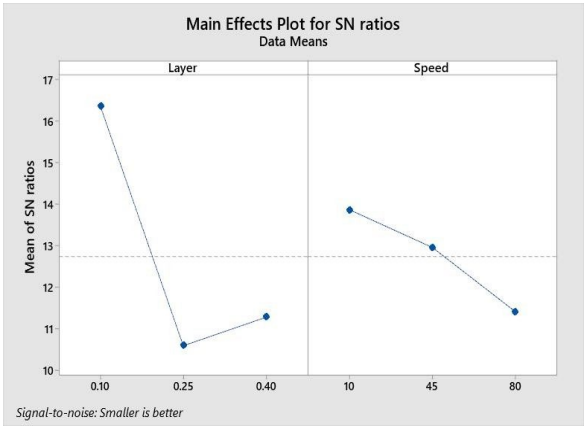

Fig. 10. S/N ratio printing parameters.

IV CONCLUSIONS

From the obtained results we may draw the following conclusions:

1. Regression analysis is statistically significant P-value <0.05.
2. The coefficient of determination is over 95%, therefore the resulting analysis has a very high correlation.
3. The layer height factor has the greatest influence and mainly affects size accuracy.
4. The speed factor has a minor impact on accuracy.
5. The resulting regression model well and adequately describes the influence of speed and layer height on printing accuracy.

ACKNOWLEDGMENTS:

The scientific research, the results of which are presented in the paper, was financed by project BG05M2OP001-1.002-0023 - Competence Center "Intelligent Mechatronic, Eco- and Energy-Saving Systems and Technologies" of Technical University of Sofia, branch Plovdiv.

REFERENCES

[1] N. Cuong, N. Duy, H. Nghi, N. Tho,, Application of Box-Behnken, ANN, and ANFIS Techniques for Identification of The Optimum Processing Parameters for FDM 3D Printing Parts" Journal of Industrial Engineering and Halal Industries. 3. p.64-86. 2022 E-ISSN 2722-8142

[2] X. Zhao, W. Ma, W. Aiyiti, A. Kasimu, R. Jia, "Investigation of influence of printing modes on the quality of 6-PSS FDM 3D printed thin-walled parts", Results in Engineering, Volume 17, 2023, ISSN 2590-1230,
https://doi.org/10.1016/j.rineng.2023.100926.

[3] T. Kalavathi Devi, E.B. Priyanka, P. Sakthivel,"Paper quality enhancement and model prediction using machine learning techniques", Results in Engineering, Volume 17, 2023, 100950, ISSN 2590-1230,
https://doi.org/10.1016/j.rineng.2023.100950.

[4] S. Chowdhry, "Improving Strength of 3D Print Using RSM", International Journal of Engineering and Applied Sciences (IJEAS). 9. 6-8. 2022

[5] S. Sunder, V. Sahithi. "Process Parameter Optimization of FDM 3D Printer Using PETG and Carbon Fiber PETG." Materials Science Forum. Trans Tech Publications, Ltd., March 24, 2023. https://doi.org/10.4028/p-y4081e.

[6] P. Pristiansyah, H. Hasdiansah, A. Ferdiansyah. "Pengaruh Parameter Proses Pada 3D Printing FDM Terhadap Kekuatan Tarik Filament ABS CCTREE". Manutech : Jurnal Teknologi Manufaktur, vol. 14, no. 01, June 2022, pp. 15 -22, doi:10.33504/manutech.v14i01.210.

[7] A. Bist, R. Dobriyal, M. Gwalwanshi, S. Avikal, „Influence of layer height and print speed on the mechanical properties of 3D-printed ABS" AIP Conference Proceedings 8 November 2022; 2481 (1): 020012. https://doi.org/10.1063/5.0107304

[8] O. Zemcik i J. Sedlak, "Application of Linear Optimization on Parameters of 3D FDM Print", Tehnički vjesnik, vol.26, br. 4, str. 1164-1170, 2019. [Online]. https://doi.org/10.17559/TV-20170506140109

[9] V.Cabreira, R.Santana,"Effect of infill pattern in Fused Filament Fabrication (FFF) 3D Printing on materials performance", Matéria (Rio J.) 25 (03) • 2020 • https://doi.org/10.1590/S1517-707620200003.1126

[10] FlashFofge, FlashForge Creator 3, March 2023. [Online]. Available:
https://www.flashforge.com/product-detail/flashforge-creator-3-pro-3d-printer [Accessed: March 18, 2023].
FlashFofge , FlashPrint 5, March 2023. [Online]. Available:
https://www.flashforge.com/product-detail/FlashPrint-slicer-for-flashforge-fdm-3d-printers [Accessed: March 18, 2023].
AutoDesk , Inventor Pro 2023, March 2023. [Online]. Available: https://www.autodesk.com/products/inventor/overview?term=1-YEAR&tab=subscription [Accessed: March 18, 2023].

[11] Minitab , March 2023. [Online]. Available:
https://www.minitab.com/en-us/solutions/analytics/statistical-analysis-predictive-analytics/[Accessed: March 18, 2022

[12] A. Parida, B. Routara, R.Bhuyan, „Surface roughness model and parametric optimization in machining of GFRP composite: Taguchi and Response surface methodology approach", Materials Today: Proceedings, Volume 2, Issues 4–5, 2015, Pages 3065-3074, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2015.07.247.

[13] D. Shah, K. Kamdar, S.Vaity, "Optimization of EDM Process Parameters Using GRA & Taguchi Method", Proceedings of International Conference on Intelligent Manufacturing and Automation. Lecture Notes in Mechanical Engineering. Springer, Singapore, 2023 https://doi.org/10.1007/978-981-19-7971-2_20

[14] N. Borra, V. Neigapula, "Parametric optimization for dimensional correctness of 3D printed part using masked stereolithography: Taguchi method", Rapid Prototyping Journal, Vol. 29 No. 1, pp. 166-184, 2023 https://doi.org/10.1108/RPJ-03-2022-0080

[15] N. Lokesh, P. Pattanayak, B. Das, H.C., P. Mahanta, "Evaluation and Optimization of Process Parameter for Surface Roughness of 3D-Printed PETG Specimens Using Taguchi Method at Constant Printing Temperature", Recent Advances in Mechanical Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore, 2023 https://doi.org/10.1007/978-981-16-9057-0_22

[16] M. Ahmad, A. Mohamad, "Analysis on Dimensional Accuracy of 3D Printed Parts by Taguchi Approach." Advances in Mechatronics, Manufacturing, and Mechanical Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore, 2021 https://doi.org/10.1007/978-981-15-7309-5_22

[17] M.Wicaksono, F.Nugraha, "Optimization of 3D Printing Parameters Using the Taguchi Method to Improve Dimensional Precision", Jurnal Teknologi, 12(2), pp. 70–75. 2022 doi: 10.35134/jitekin.v12i2.72.

[18] I.Mitropoulou, M. Bernhard, B.Dillenburger, "Print Paths Key-framing Design for non-planar layered robotic FDM printing" SCF '20: Proceedings of the 5th Annual ACM Symposium on Computational Fabrication November 2020 Article No.: 6Pages 1–10 https://doi.org/10.1145/3424630.3425408L.Galantucci, I.Bodi, J.Kacani, F. Lavecchia, Fulvio," Analysis of dimensional performance for a 3D open-source printer based on fused deposition modeling technique. 3rd CIRP global web conference on Production Engineering Research:Advancement beyond the state of the art." Conference: 3rd CIRP Global Web Conference on Production Engineering Research: Advancement Beyond State of the Art, CIRPe 2014 Code 113630At: Naples; ItalyVolume: Procedia CIRP 28 (2015) 82 – 87 DOI: 10.13140/2.1.2140.1928

[19] G.Percoco, L.Galantucci, F.Lavecchia, "Validation Study of an Analytical Model of FDM Accuracy." In book: DAAAM International Scientific Book 2011Chapter: 48 Publisher: Publisher DAAAM International Vienna DOI: 10.2507/daaam.scibook.2011.48

[20] M.Zagorski,Y.Sofronov,D.Ivanova, K.Dimova, "Investigation of different FDM/FFF 3D printing methods for improving the surface quality of 3D printed parts." AIP Conference Proceedings, 2022 2449. 060001. https://doi.org/10.1063/5.0090805