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Research into 3D Printing Layer Adhesion in ABS Materials

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***Abstract*. The purpose of this article is to determine the impact of the two factors – layer thickness and printing speed in the adhesion of the layers in the ABS polymer. ABS control test tubes were printed and the tensile strength of each tube was measured. By means of statistical analysis, it was determined the impact of the layer thickness and the print speed on the adhesion between the layers. The research was focused on one of the most used materials in 3D printing. It can be concluded from the obtained results that the layer thickness has the greatest impact on the adhesion.**

Keywords: Adhesion between, DOE, FDM 3D print.

I. INTRODUCTION

3D printing is a technology that has been known for over 30 years, but its rapid use and development of the technology took place in years after 2000. New materials and new technologies were created in order to increase speed of creating 3D models and reduce printing time.

The most common technologies for 3D printing are FDM - Fused Deposition Modeling, SLA - Stereolithography and SLS - Selective Laser Sintering. Material deposition technology has gained ground with the use of polymers and the creation of patterns from Acrylonitrile Butadiene Styrene (ABS), Polystyrene (HIPS) and Polylactic Acid (PLA).

Material deposition technology is relatively easy to implement as it uses an extruder. A polymer is used in the form of a thread that melts and builds a 3D model layer by layer. Depending on the different printing parameters, the layers have different adhesion properties and hence that increases the strength of the model being printed. In order to be able to use the printed 3D models in industry, we need to know their mechanical properties well. Achieving optimal printing parameters so adhesion between layers is maximized and results in increased strength of the 3d model. Many authors have studied the influence of temperature on the characteristics of the printed model [9]-[11].

One of the main problems of 3D printing is the adhesion between the individual layers. Better adhesion leads to better mechanical properties of the printed model and it can be used for industrial applications. In order to study the adhesion of the layers, we need to set some parameters that need to be changed. In our case, these are the main printing parameters, of which one parameter is the height of its own, and the second parameter is the printing speed.

We will work with a constant extruder temperature of 235º C to avoid some additional defects that could occur in the printing process, one of which is uneven melt flow. In addition, it is possible to clog the extruder as a result of an extremely low temperature below 220ºC or an extremely high temperature above 250ºC. [1] – [3].

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II. METHODOLOGY

A. Material

The object of our research is the creation of a 3d model fig.1. The three-dimensional model is a sample with a length of 100 mm and a width of 70 mm. 13 samples have been printed, which we are testing in tension. In order examination to be as accurate as possible, the samples are printed upright as shown in fig. 2. All samples are printed from one roll of ABS polymer filament. Printing takes place at a constant temperature of 235ºC ±1ºC for each sample.

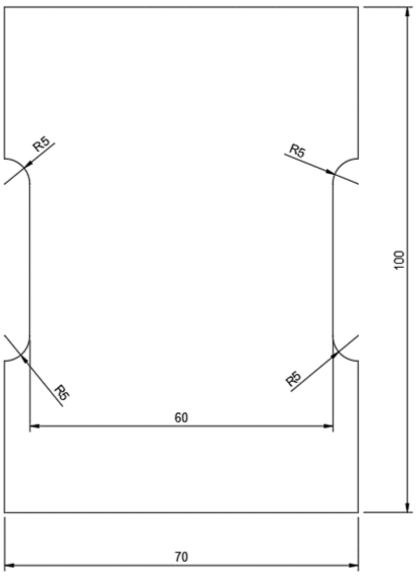

Fig. 1. Model for 3D print.

There are authors who propose different constructions of the test tube [9-10], some of which are standardized. Considering the used test equipment and the brittleness of the material, the selected model in fig. 1 is the most optimal. We will test the ultimate tensile force.

B. Equipment

a. 3D printer FlashForge Creator 3 [5]

b. Software FlashPrint [6]

c. Software AutoDesk Inventor Pro [7]

d. Software Minitab [8]

C. Parameters,

The created 3D model is transferred to the processing program slicer FlashPrint 5. We have set the following constant parameters:

- Platform temperature: 110 ºC.
- Extrusion temperature: 235 ºC.
- Print speed: 20-120 [mm/s].
- Travel speed: 120 [mm/s].
- Number of shells: 3.
- Layer thickness: 0,1-0,4 [mm].
- Nozzle diameter: 0,4 [mm].

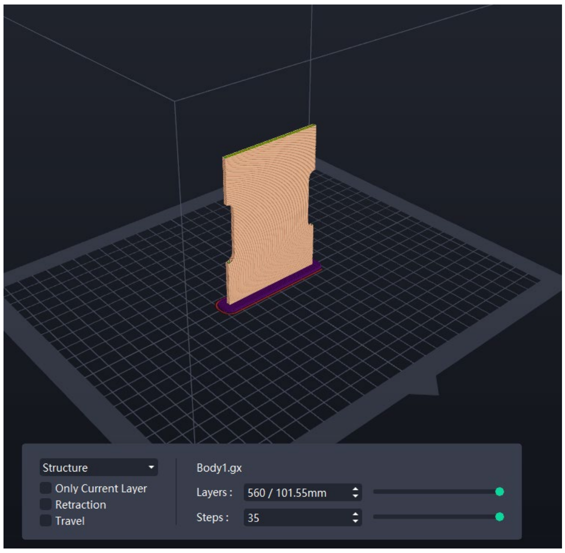

Fig. 2. Model in the FlashPrint5.

We have previously created a planning of the experiment according to Central Composite Design and have determined the values of the two parameters print speed and layer height shown in tab. 1-2.

TABLE 1 DESIGN SUMMARY

Factors:	2	Replicates:	1
Base runs:	13	Total runs:	13
Base blocks:	1	Total blocks:	1

TABLE 2 3D PRINTING PARAMETERS

Print №	Parameter 1	Parameter 2
1	0,1	80
2	0,35	52
3	0,14	52
4	0,25	80
5	0,14	108
6	0,25	80
7	0,25	80
8	0,25	80
9	0,25	40
10	0,25	80
11	0,35	108
12	0,25	120
13	0,4	80

We have used the parameters in the table. 2 and we have printed 13 samples, the printing process is shown in fig.3.

Fig. 3. 3D Printing process.

III. Results and discussion

The specimens were tested on a calibrated electromechanical tensile machine (fig. 4)

Fig. 4. Testing machine.

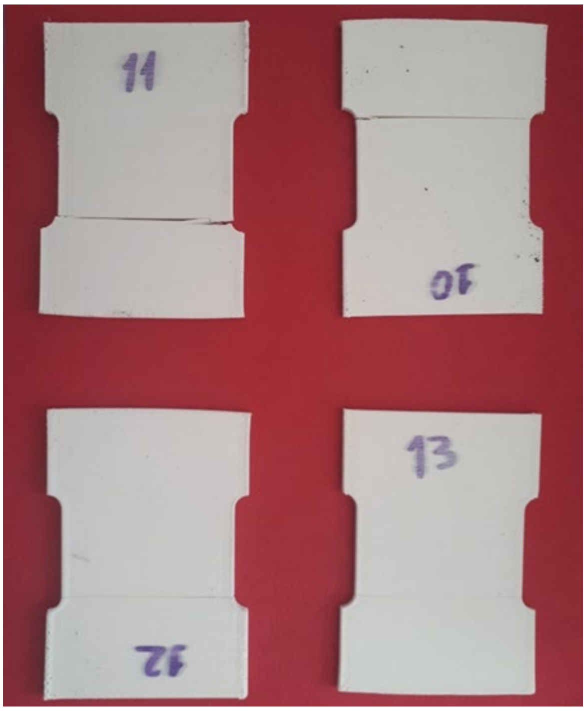

Fig. 5. Measurement process.

Thirteen specimens were tensile tested and the experimental results are presented in tabular form, Table 3.

TABLE 3 EXPERIMENTAL RESULTS

№	Speed	Layer	kN
1	80	0.10	0.59
2	52	0.35	1.30
3	52	0.14	0.70
4	80	0.25	0.91
5	108	0.14	0.77
6	80	0.25	0.91
7	80	0.25	0.91
8	80	0.25	0.91
9	40	0.25	1.08
10	80	0.25	0.91
11	108	0.35	1.00
12	120	0.25	1.12
13	80	0.40	1.10

Statistical processing of the obtained experimental results was made in Minitab software. The obtained results of the regression analysis are shown in table 4.

Regression Equation

$$kN = 0.387 + 6.063\ Layer - 0.01074\ Speed - 3.20\ Layer*Layer + 0.000115\ Speed*Speed - 0.03345\ Layer*Speed$$

TABLE 4 COEFFICIENT

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	0,39	0,20	(-0.079; 0.853)	1,97	0,09	
Layer	6,06	0,85	(4.065; 8.062)	7,17	0,00	42,42
Speed	-0,01	0,00	(-0.01880; -0.00267)	-3,15	0,02	49,06
Layer*Layer	-3,20	1,31	(-6.30; -0.10)	-2,44	0,05	25,97
Speed*Speed	0,00	0,00	(0.000071; 0.000159)	6,22	0,00	37,87
Layer*Speed	-0,03	0,01	(-0.04903; -0.01788)	-5,08	0,00	28,7

TABLE 5 MODEL SUMMARY

S	R-sq	R-sq(adj)	PRESS
0,0387538	97,47%	95,66%	0,07
R-sq(pred)	**AICc**	**BIC**	
81,96%	-19,27	-37,71	

TABLE 6 ANALYSIS OF VARIANCE

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0,40	97,47%	0,40	0,081	53,86	0
Layer	1	0,29	69,47%	0,08	0,077	51,45	0
Speed	1	0,00	0,61%	0,01	0,015	9,91	0,016
Layer*Layer	1	0,02	4,05%	0,01	0,009	5,95	0,045
Speed*Speed	1	0,06	14,01%	0,06	0,058	38,7	0
Layer*Speed	1	0,04	9,33%	0,04	0,039	25,79	0,001
Error	7	0,01	2,53%	0,01	0,002		
Lack-of-Fit	3	0,01	2,53%	0,01	0,004	*	*
Pure Error	4	0,00	0,00%	0,00	0,000		

The regression analysis is statistically significant because the Pearson coefficient is above 95%. Figures 7-9 show the standardized residuals. Experimental results number 5 and number 12 have a deviation of more than ± 2 and appear to be inflectionally accurate to the regression equation. Figure 10 shows a normal distribution of the residuals. The factor that has the most significant influence on the ultimate tensile force of the sample is the height of the layer fig.11. The second factor indicates a negligible effect on the ultimate tensile force.

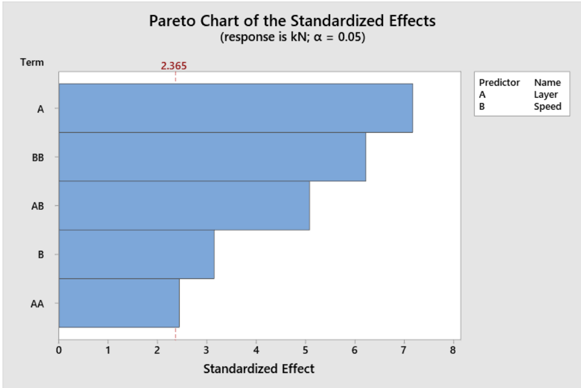

Fig. 6. Pareto chart.

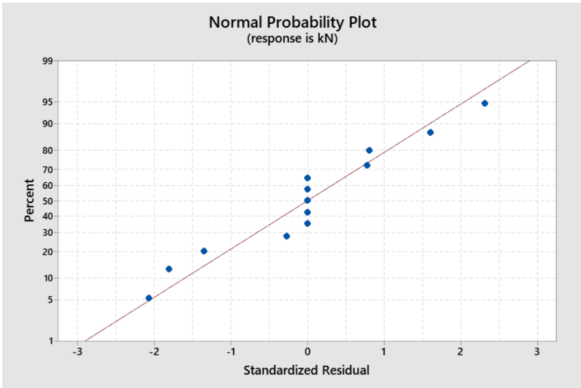

Fig. 7. Probability plot.

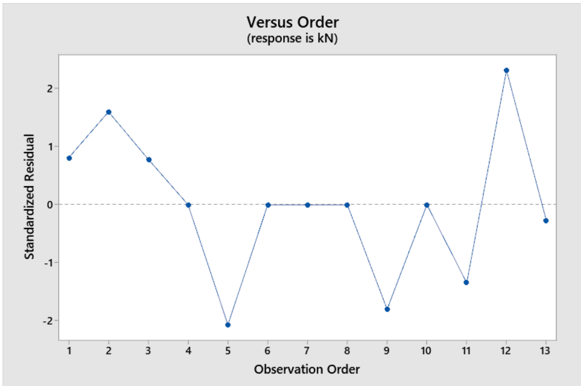

Fig. 8. Versus order.

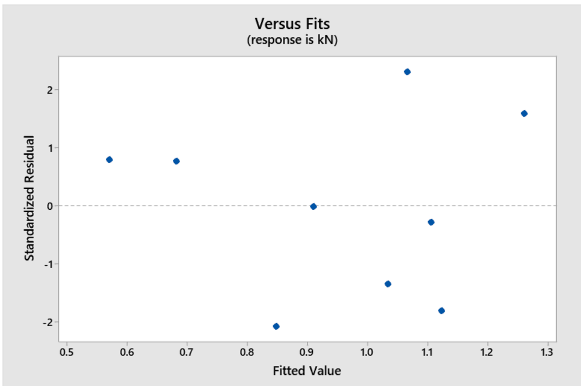

Fig. 9. Versus fits.

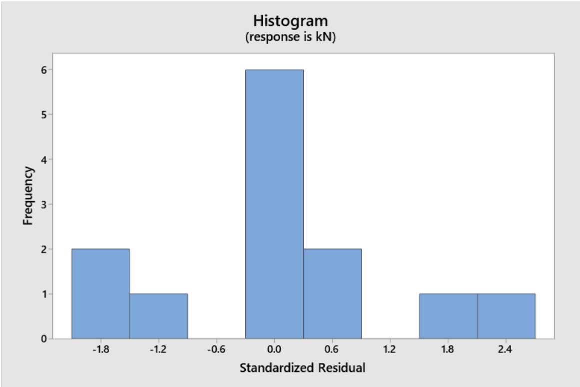

Fig. 10. Histogram.

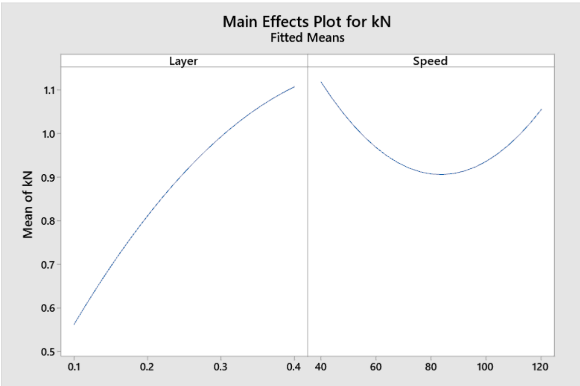

Fig. 11. Main Effects.

IV. Conclusions

In conclusion, we can draw the following conclusions:

- The central compositional planning made is correct.
- With the used measuring equipment we get adequate measurements.
- After the regression model analysis, the P-value values are below 0.05, therefore the factors are statistically significant. Therefore the layer thickness has the greatest importance to the tensile strength of the tested specimens. The larger the layer thickness, the larger the tensile strength of the specimen.
- The obtained results can serve in the development of 3D models requiring increased tensile strength.

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