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Influence of the Process Parameters on the Mechanical Properties of the FDM 3D Printed Samples

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Abstract: This research analyses the impact of infill density and layer thickness on the tensile strength of test samples fabricated using FDM 3D printing, with a particular focus on comparing samples produced with and without an adhesion layer. A two-factor factorial experimental design was employed, consisting of two levels and three replications. The infill density (20% and 50%) and layer thickness (0.1 mm and 0.2 mm) were defined as input variables, while tensile strength served as the output variable. Statistical methods, such as ANOVA, were used to analyse the experimental data and evaluate the significance of the individual factors and their interactions. The results revealed that for samples with an adhesion layer, the infill density, layer thickness, and their interaction had a statistically significant effect on tensile strength. In contrast, for samples without an adhesion layer, a significant effect was observed only for individual factors, with no significant interaction. The regression models exhibited high coefficients of determination (R^2) for both sample sets, confirming their strong reliability in predicting tensile strength. Furthermore, the t-test results indicated no statistically significant difference in tensile strength between samples manufactured with and without an adhesion layer.

Keywords: analysis of variance; FDM; regression model; tensile strength

1 INTRODUCTION

3D printing technologies enable the production of complex, geometrically demanding and individually tailored components that are difficult, and often impossible, to produce using conventional manufacturing methods. Thanks to the ability to create objects layer by layer, from digital 3D models, this technology has opened up completely new possibilities in various areas of human activity. Today, 3D printing is successfully applied in a wide range of sectors - from the manufacturing industry, medicine, architecture and construction, to the automotive, aerospace and space industries, but also in the fields of fashion, science and education.

A range of 3D printing technologies has been developed within the research and industrial community, including SLS (Selective Laser Sintering), SLA (Stereolithography) and FDM (Fused Deposition Modelling). FDM technology has become particularly popular and one of the most researched methods due to its simplicity, availability, lower cost and adaptability to a wide range of materials and applications [1-21].

The material selection for 3D printing depends on the purpose, functional, and mechanical and thermal properties requirements of the produced component. In FDM technology, PLA (polylactic acid), a biodegradable thermoplastic polymer that offers a good balance between ease of printing, precision, and environmental friendliness, is most often used. However, in order to improve the mechanical properties of the manufactured parts, scientific research is increasingly focusing on modifying existing materials through the application of various additives in composite materials, including carbon fibres [2, 8-11], as well as on the use of other materials such as ABS, PETG, etc. [16, 19].

At the same time, new printing technologies are being tested, with a detailed analysis of key mechanical properties - primarily tensile strength and bending test results and elastic modulus - which represent fundamental indicators of the quality and reliability of printed components [1-21].

Although significant progress has been made in the development of materials and the optimization of printing technologies in the last decade, the mechanical properties of 3D printed parts are still limited. The reason for this may relate to the number of parameters that simultaneously affect the printing process and are intertwined with each other, which makes it difficult to control and predict the results. The most commonly studied parameters include printing speed, infill density and pattern, layer thickness, layer width and height, filament and build plate temperature, print orientation, raster angle, nozzle temperature, and even model curvature [1-21].

In order to systematically examine the effects of the above parameters and find the optimal combination of printing parameters, the design of experiments method is often used in research. Among the most commonly used methods, the Taguchi method [1, 4-6, 15, 18] known for its efficiency in reducing the number of necessary experiments while maintaining high accuracy of results, and the response surface methodology (RSM) stand out [15, 19]. RSM allows a detailed analysis of interactions between parameters and modeling the relationship between input and output variables. Such approaches significantly contribute to the understanding of the FDM 3D printing process and enable the development of components with improved mechanical properties and optimised part characteristics.

The aim of this paper is to experimentally investigate the influence of selected FDM 3D printing process parameters, specifically the infill density and layer thickness, on the tensile strength of test samples made with and without an adhesion layer. The work applied a two-factor factorial design at two levels and three replications, where the infill density (20% and 50%) and the layer thickness (0.1 mm and 0.2 mm) were defined as input variables, while the tensile strength was observed as the output variable. The obtained experimental data were statistically analysed using the analysis of variance (ANOVA) method to determine the significance of the individual factors and their interactions. Based on the results, regression models were created to predict the tensile strength values of samples with and without an adhesion layer. The influence of the adhesion layer itself on the tensile strength was also examined using the *t*-test.

2 EXPERIMENTAL PART

According to ISO 527 standard [22], twelve (12) test samples with an adhesion layer and twelve (12) test samples without an adhesion layer were made of GENERIC PLA material, using the FDM 3D printing process on the Wanhao Duplicator D12 300 Dual 3D printer, which is shown in Fig. 1.

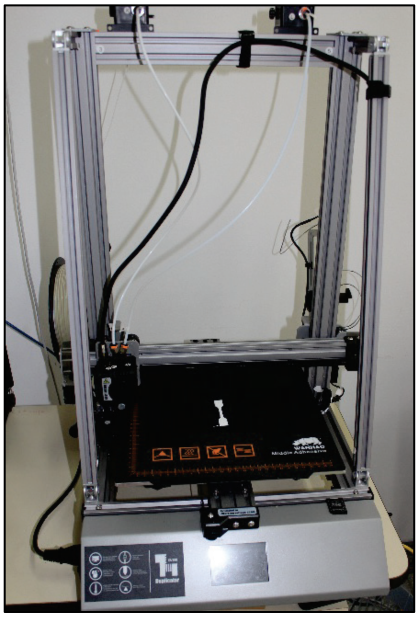

Figure 1 3D printer Wanhao Duplicator D12 300 Dual

A two-level factorial design with three replications was applied. When planning the experiment, the basic principles of experimental design were respected - replication and randomisation, and the principle of blocking was not applied. The input variables, or factors, are the infill density (20% and 50%) and the layer thickness (0,1 mm and 0,2 mm). The output variable, or response, is the tensile strength. In addition to the variables that changed (infill density and layer thickness), other factors were kept constant: nozzle temperature 210 °C, print speed 50 mm/s, worktable temperature 60 °C. The type of filling was Grid. The tensile strength was measured on a Shimadzu AGS-X device, as shown in Fig. 2. Test samples without an adhesion layer, prior to tensile strength testing, are shown in Fig. 3, while Fig. 4 shows the test samples after the test.

To investigate the influence of the adhesion layer on tensile strength, samples with an adhesion layer were fabricated. The adhesion layer is typically used to improve the bonding of the sample to the build platform and to prevent deformations during the printing process. The adhesion layer was made of the same material as the samples (GENERIC PLA material), with a thickness of 0,1 mm and a build plate adhesion type set to raft. An example of a test sample with an adhesion layer is shown in Fig. 5.

Figure 2 Shimadzu AGS-X tensile testing machine

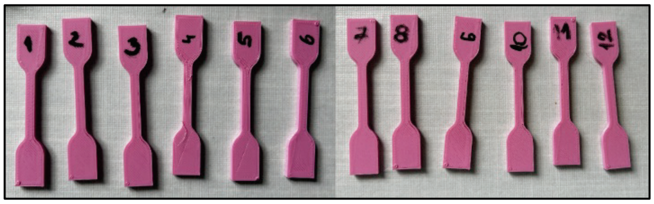

Figure 3 Test samples without an adhesion layer before tensile strength testing

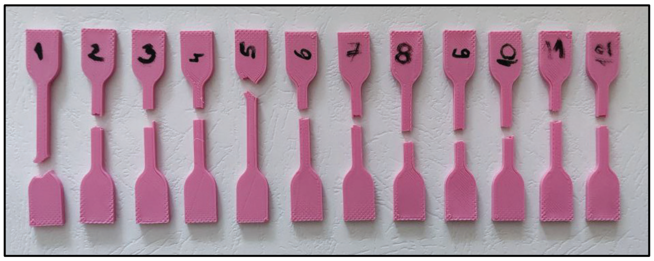

Figure 4 Test samples without an adhesion layer after the tensile strength test

Figure 5 Test sample with an adhesion layer

3 TENSILE STRENGTH ANALYSIS

Since the values of the infill density and the layer thickness were varied at two levels, a two-way ANOVA was performed to determine the significance of the influence of individual parameters and their interaction on the tensile strength of the samples. Additionally, a *t*-test was used to determine whether there was a statistically significant difference in the tensile strength values between samples made with and without an adhesion layer.

3.1 Tensile Strength Analysis of Samples with an Adhesion Layer

The design of the experiment and the measured tensile strength values of samples made with an adhesion layer are shown in Tab. 1. MS Excel was used for statistical analysis of data.

Table 1 Design of experiment and measured values of tensile strength for samples with an adhesion layer

Conventional layout	Trial no.	Infill density, %	Layer thickness, mm	Tensile strength 1, MPa
10	1	50	0,2	35,97
3	2	20	0,1	34,74
2	3	20	0,1	35,98
12	4	50	0,2	36,47
8	5	50	0,1	38,12
11	6	50	0,2	36,3
7	7	50	0,1	38,08
5	8	20	0,2	31,99
6	9	20	0,2	31,28
9	10	50	0,1	37,76
4	11	20	0,2	32,65
1	12	20	0,1	35,51

Tab. 2 shows the report from the Descriptive Statistics tool, which includes basic statistical parameters for samples with an adhesion layer.

The Data Analysis tool - ANOVA: Two-Factor with Replication was used for the analysis of variance. Tab. 3 shows the report of the ANOVA: Two-Factor with Replication tool for samples with an adhesion layer.

Table 2 Descriptive statistics tool reports for samples with an adhesion layer

Tensile strength 1, MPa	
Mean	35,40
Standard Error	0,67
Median	35,98
Mode	#N/D
Standard Deviation	2,32
Sample Variance	5,40
Kurtosis	–0,67
Skewness	–0,67
Range	6,84
Minimum	31,28
Maximum	38,12
Sum	424,85
Count	12

The average tensile strength value is 35,40 MPa (Mean), the median is 35,98 MPa (Median), the estimated standard deviation of the base set based on the sample data is 2.32 MPa (Standard Deviation), and the sample variance is 5,40 MPa (Sample Variance). The minimum tensile strength value is 31,28 MPa (Minimum), and the maximum value is 38,12 MPa (Maximum). From Tab. 1, it is evident that the minimum tensile strength value was achieved for a filling percentage of 20% and a layer thickness of 0,2 mm, while the maximum tensile strength value was achieved for a filling percentage of 50% and a layer thickness of 0,1 mm.

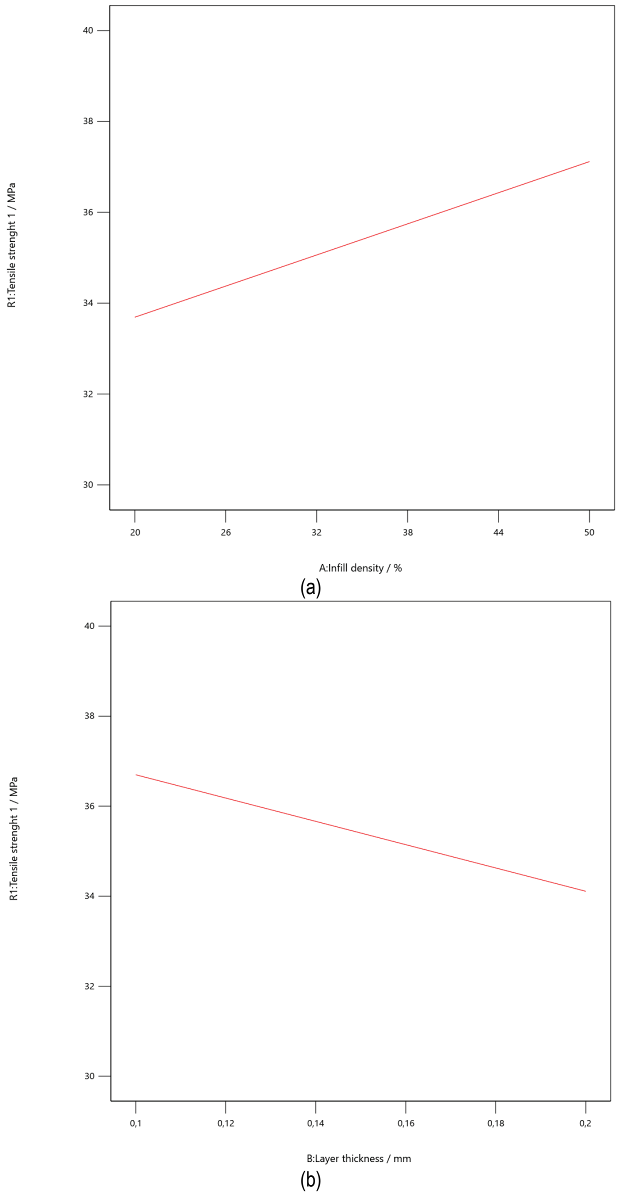

Figure 6 Corelation between tensile strenght 1 (samples with an adhesion layer) and (a) denisity infill; (b) layer thickness

Fig. 6 illustrates the correlation between tensile strength 1 (samples with an adhesion layer) and the parameters of infill density and layer thickness. A positive correlation is evident between tensile strength 1 and infill density, demonstrating that an increase in infill density enhances tensile strength (Fig. 6a). Conversely, a negative correlation is observed between tensile strength 1 and layer thickness, indicating that greater layer thickness diminishes tensile strength (Fig. 6b).

In order to investigate the influence of infill density and layer thickness factors on the response - tensile strength, it is necessary to compare the values of the calculated *F* ratios with the tabular values of the *F* variable. The value of the *F* ratio for the infill density factor is 145,89, and the corresponding tabular value of the *F* variable (F_{crit} value) is 5,32. The *F*-ratio is greater than the tabular value of the *F* variable, so it can be concluded that the change in the level of the infill density factor affects the change in tensile strength; the infill density is a significant factor. The same conclusion can be made based on the probability *P*-value for the calculated F-ratio. The probability for the calculated *F* ratio (*P*-value) is $2{,}04\times10^{-6}$, which is less than 0,05 (probability of a type I error α), so it can be concluded that the factor is significant, as the change in the level of the infill density factor affects the tensile strength.

Table 3 ANOVA tool report: Two-Factor with Replication for samples with an adhesion layer

Source of Variation	SS	df	MS	*F*	*P*-value	F_{crit}
Infill density	35,19	1	35,19	145,89	2E^{-06}	5,32
Layer thickness	20,10	1	20,10	83,32	$1{,}7\text{E}^{-05}$	5,32
Interaction	2,16	1	2,16	8,95	0,0173	5,32
Within	1,93	8	0,24			
Total	59,38	11				

The *F*-ratio value for the layer thickness factor is 83,32, and the corresponding table value of the *F* variable (F_{crit} value) is 5,32. The *F*-ratio is greater than the table value of the *F* variable, so it can be concluded that changing the level of the layer thickness factor also affects the change in tensile strength, i.e. the layer thickness is significant. The probability for the calculated *F*-ratio (*P*-value) is $1{,}67\times10^{-5}$, which is less than 0,05 (probability of a type I error α), so it can be concluded that the factor is significant; changing the level of the layer thickness factor affects tensile strength.

The *F*-ratio value for the interaction of the factors - infill density and layer thickness (Interaction) is 8,95 and the corresponding table value of the *F* variable (F_{crit} value) is 5,32. The *F* ratio is greater than the table value of the *F* variable, so it can be concluded that the interaction of factors *A* (infill density) and *B* (layer thickness) also affects the change in tensile strength; thus, the interaction of infill density and layer thickness is significant. The probability for the calculated *F*-ratio (*P*-value column) is 0,0173, which is less than 0,05 (probability of a type I error α), so it can be concluded that the interaction of the factors is significant, and the interaction of infill density and layer thickness affects tensile strength.

In order to obtain a model that will predict the dependence of tensile strength on the factors - infill density and layer thickness, it is necessary to conduct regression modelling. To obtain the regression model, the Regression tool in MS Excel was used.

For samples with an adhesion layer, the following values of regression coefficients were obtained: $\beta_0 = 38{,}26$; $\beta_1 = 0{,}029$, $\beta_2 = -45{,}678$, $\beta_{12} = 0{,}565$ based on which a regression model can be written, Eq. (1):

$$y = 38{,}26 + 0{,}029 \cdot x_1 - 45{,}678 \cdot x_2 + 0{,}565 \cdot x_1 \cdot x_2 \tag{1}$$

where y is the response - tensile strength, x_1 is the factor - infill density, and x_2 is the factor - layer thickness, $x_1\,x_2$ is the interaction between two factors - infill density and layer thickness. The regression model with real variables is, Eq. (2):

$$\begin{aligned} \mathit{tensile\,strength} &= 38{,}26 + 0{,}029 \cdot \mathit{infill\,density} - 45{,}678 \cdot \\ &\cdot \mathit{layer\,thickness} + 0{,}565 \cdot \mathit{infill\,density} \cdot \mathit{layer\,thickness} \end{aligned} \tag{2}$$

The tensile strength will increase by 0,029 MPa for each unit increase in the percentage of filling, while it will decrease by 45,678 MPa for each unit increase in the layer thickness. For the obtained regression model, the coefficient of determination R^2 is 0,9675.

Tab. 4 presents the measured tensile strength 1 values, the corresponding predicted values (calculated according to Eq. (2)), and the residuals. The results demonstrate that the model exhibits minimal discrepancy between the actual and predicted tensile strength 1 values. The high coefficient of determination (R^2) further confirms that the model demonstrates strong predictive accuracy for tensile strength 1.

Table 4 Actual and predicted values, and residuals for tensile strength 1 (samples with an adhesion layer)

Trial no.	Infill density, %	Layer thickness, mm	Actual tensile strength 1, MPa	Predicted tensile strength 1, MPa	Residual, MPa
1	50	0,2	35,97	36,25	–0,28
2	20	0,1	34,74	35,41	–0,67
3	20	0,1	35,98	35,41	0,57
4	50	0,2	36,47	36,25	0,22
5	50	0,1	38,12	37,99	0,13
6	50	0,2	36,30	36,25	0,05
7	50	0,1	38,08	37,99	0,09
8	20	0,2	31,99	31,97	0,02
9	20	0,2	31,28	31,97	–0,69
10	50	0,1	37,76	37,99	–0,23
11	20	0,2	32,65	31,97	0,68
12	20	0,1	35,51	35,41	0,10

3.2 Tensile Strength Analysis of Samples without an Adhesion Layer

The experimental design and measured tensile strength values of samples made without an adhesion layer are shown in Tab. 5.

Tab. 6 shows the Descriptive Statistics tool report with basic statistical parameters for samples without an adhesion layer. The average tensile strength value is 36,28 MPa (Mean), the median is 36,25 MPa (Median), the estimated standard deviation of the base set based on the sample data is 2,63 MPa (Standard Deviation), and the sample variance is 6,90 MPa (Sample Variance). The minimum tensile strength value is 32,65 MPa (Minimum), and the maximum value is 40,27 MPa (Maximum). From Tab. 5, it is evident that the minimum tensile strength value is achieved for a filling percentage of 20% and a layer thickness of 0,2 mm, while the maximum tensile strength value is achieved for a filling percentage of 50% and a layer thickness of 0,1 mm.

Table 5 Design of experiment and measured values of tensile strength for samples without an adhesion layer

Conventional layout	Trial no.	Infill density, %	Layer thickness, mm	Tensile strength 2, MPa
10	1	50	0,2	36,77
3	2	20	0,1	34,45
2	3	20	0,1	35,73
12	4	50	0,2	37,54
8	5	50	0,1	39,59
11	6	50	0,2	37,7
7	7	50	0,1	40,27
5	8	20	0,2	32,65
6	9	20	0,2	33,18
9	10	50	0,1	39,22
4	11	20	0,2	33,51
1	12	20	0,1	34,74

Table 6 Descriptive statistics tool reports for samples without an adhesion layer

Tensile strength 2, MPa	
Mean	36,28
Standard Error	0,76
Median	36,25
Mode	#N/D
Standard Deviation	2,63
Sample Variance	6,90
Kurtosis	–1,39
Skewness	0,13
Range	7,62
Minimum	32,65
Maximum	40,27
Sum	435,35
Count	12

Fig. 7 illustrates the correlation between tensile strength 2 (samples without an adhesion layer) and the parameters of infill density and layer thickness. As observed for tensile strength 1, a positive correlation is also present in this case between tensile strength 2 and infill density, with higher infill density resulting in increased tensile strength (Fig. 7a). Conversely, a negative correlation is evident between tensile strength 2 and layer thickness, with an increase from 0,1 mm to 0,2 mm leading to a reduction in tensile strength (Fig. 7b).

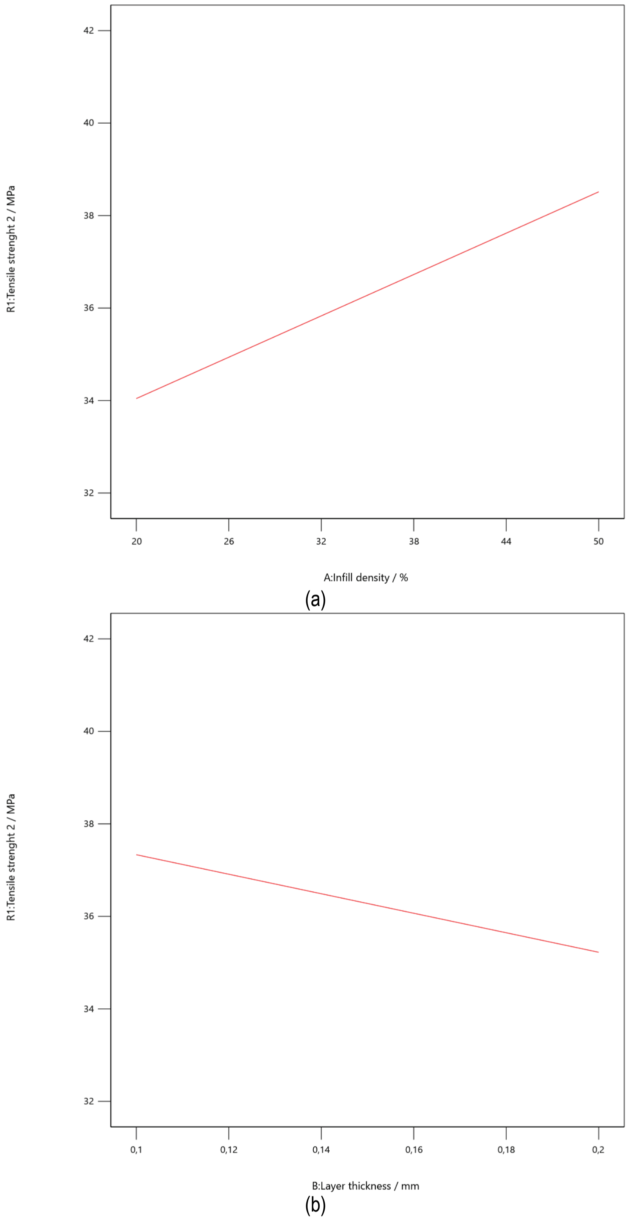

Figure 7 Corelation between tensile strenght 2 (samples without an adhesion layer) and (a) denisity infill; (b) layer thickness

Tab. 7 shows the ANOVA: Two-Factor with Replication tool report for samples without an adhesive layer.

Table 7 ANOVA tool report: Two-Factor with Replication for samples without an adhesion layer

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Infill density	59,99	1	59,99	205,17	$5{,}51\text{E}^{-07}$	5,32
Layer thickness	13,33	1	13,33	45,61	0,000145	5,32
Interaction	0,19	1	0,19	0,63	0,4493	5,32
Within	2,34	8	0,29			
Total	75,85	11				

The F-ratio value for the infill density factor is 205,17 and the corresponding table value of the F variable (F_{crit} value) is 5,32. The F-ratio is greater than the table value of the F variable, indicating that changing the level of the infill density factor affects the change in tensile strength; therefore, the percentage of filling is a significant factor. The same conclusion can be drawn based on the probability P-value for the calculated F-ratio. The probability for the calculated F-ratio (P-value) is $5{,}51 \times 10^{-7}$, which is less than 0,05 (probability of a type I error α), so it can be concluded that the factor is significant, and changing the level of the infill density factor affects the tensile strength.

The F-ratio value for the layer thickness factor is 45,61, and the corresponding table value of the F variable (F_{crit}

value) is 5,32. The *F*-ratio is greater than the table value of the *F* variable, so it can be concluded that the change in the level of the layer thickness factor also affects the change in tensile strength, i.e. the layer thickness is significant. The probability for the calculated *F*-ratio (*P*-value) is 0,000145, which is less than 0,05 (probability of a type I error α), so it can be concluded that the factor is significant, i.e. the change in the level of the layer thickness factor affects tensile strength.

The *F*-ratio value for the interaction of the factors - infill density and layer thickness is 0,63, and the corresponding tabular value of the *F* variable (F_{crit} value) is 5,32. The *F*-ratio is smaller than the tabular value of the *F* variable, so it can be concluded that the interaction of the factor does not affect the change in tensile strength, - the interaction of infill density and layer thickness is not significant. The probability for the calculated *F*-ratio (*P*-value) is 0,4493, which is greater than 0,05 (probability of a type I error *α*), so it can be confirmed that the interaction of the factor is not significant.

For samples with an adhesion layer, regression modeling was also performed with the aim of obtaining a model that would predict the dependence of tensile strength on the infill density and layer thickness factors. For samples without an adhesion layer, the following values of regression coefficients were obtained: $\beta_0 = 34{,}225$; $\beta_1 = 0{,}149$ and $\beta_2 = -21{,}083$, based on which a regression model can be written, Eq. (3):

$$y = 34{,}225 + 0{,}149 \cdot x_1 - 21{,}083 \cdot x_2 \tag{3}$$

where y is the response - tensile strength, x_1 is the factor - infill density, and x_2 is the factor - layer thickness. The regression model with real variables is, Eq. (4):

$$\begin{aligned} &tensile\,strength = 34{,}225 + 0{,}149 \times infill\,density \\ &-21{,}083 \times layer\,thickness \end{aligned} \tag{4}$$

The tensile strength will increase by 0,149 MPa for each unit increase in the infill density, while it will decrease by 21,083 MPa for each unit increase in the layer thickness. For the obtained regression model, the coefficient of determination R^2 is 0,967.

Table 8 Actual and predicted values, and residuals for tensile strength 2 (samples without an adhesion layer)

Trial no.	Infill density, %	Layer thickness, mm	Actual tensile strength 2, MPa	Predicted tensile strength 2, MPa	Residual, MPa
1	50	0,2	36,77	37,46	–0,69
2	20	0,1	34,45	35,10	–0,65
3	20	0,1	35,73	35,10	0,63
4	50	0,2	37,54	37,46	0,08
5	50	0,1	39,59	39,57	0,02
6	50	0,2	37,70	37,46	0,24
7	50	0,1	40,27	39,57	0,70
8	20	0,2	32,65	32,99	–0,34
9	20	0,2	33,18	32,99	0,19
10	50	0,1	39,22	39,57	–0,35
11	20	0,2	33,51	32,99	0,52
12	20	0,1	34,74	35,10	–0,36

Tab. 8 presents the results of the measured tensile strength 2 values (samples without an adhesion layer), the predicted values (calculated according to Eq. (4)), and the residuals. The table shows that the error between the actual and predicted tensile strength 2 values is small, as the model obtained from Eq. (4) exhibits a high coefficient of determination ($R^2 = 0.967$), indicating that it can reliably predict tensile strength 2.

3.3 Tests of the Equality of Two Means - t-test

In order to examine whether there is a significant difference in the tensile strength values of samples with and without an adhesion layer, a hypothesis test on the equality of arithmetic means of the basic sets based on the samples (*t*-test) was performed. The testing was performed using the Data Analysis Tool of MS Excel.

Since the variances of the basis sets are unknown, it is necessary to test the hypothesis of their equality. To test the hypothesis of equality of variances of the basis sets, the null and alternative hypotheses are, Eq. (5), [24]:

$$\begin{aligned} &\mathrm{H}_0\colon \sigma_1^2 = \sigma_2^2 \\ &\mathrm{H}_1\colon \sigma_1^2 \neq \sigma_2^2 \end{aligned} \tag{5}$$

The alternative hypothesis is two-tailed, and therefore, it is impossible to use the *F*-Test Two-Sample for Variances tool test. To conclude on the equality of variances of the basic sets, the F_0 variable is used, which is calculated according to Eq. (6), [24]:

$$F_0 = \frac{S_1^{\,2}}{S_2^{\,2}} \tag{6}$$

where S_1^2 represents the variance of the first sample (test samples with an adhesion layer), and S_2^2 represents the variance of the second sample (test samples without an adhesion layer).

The variance of the first sample S_1^2 is 5,40, while the variance of the second sample S_2^2 is 6,90. The value of the F_0 variable is as follows, Eq. (7):

$$F_0 = \frac{S_1^{\,2}}{S_2^{\,2}} = \frac{5{,}40^2}{6{,}90^2} = 0{,}613 \tag{7}$$

It is necessary to check whether the calculated value of F_0 is within the limit values, Eq. (8), [24]:

$$F_{\alpha/2,n_1-1,n_2-1} < F_0 < F_{1-\alpha/2,n_1-1,n_2-1} \tag{8}$$

The limit values of the F_0 variable are 3,474 and 0,288. The calculated value of the F_0 variable is within the limit values, and it can be concluded that the variances of the basic sets from which the samples were taken are equal. Based on the conclusion reached, the hypothesis of equality of the arithmetic means of the basic sets can be tested using the *t-Test: Two-Sample Assuming Equal Variances tool*. The null and alternative hypotheses are, Eq. (9), [24]:

$$\begin{aligned} &H_0: \mu_1 = \mu_2 \\ &H_1: \mu_1 \neq \mu_2 \end{aligned} \tag{9}$$

Tab. 9 shows the report of the *t*-test: Two-Sample Assuming Equal Variances tool.

Table 9 Report of the t-Test: Two-Sample Assuming Equal Variances tool

t-Test: Two-Sample Assuming Equal Variances		
	Tensile Strength 1, MPa	Tensile Strength 2, MPa
Mean	35,40	36,28
Variance	5,40	6,90
Observations	12	12
Pooled Variance	6,15	
Hypothesized Mean Difference	0	
df	22	
t Stat	–0,86	
P(*T* <= *t*) one-tail	0,199	
t Critical one-tail	1,72	
P(*T* <= *t*) two-tail	0,39	
t Critical two-tail	2,07	

Since the alternative hypothesis is two-tailed, it is necessary to compare the value of the calculated variable *t Stat* with the threshold value *t Critical two-tail*. The variable *t Stat* is –0,86, and the threshold value *t Critical two-tail* is 2,07. Since the value *t Stat* is less than *t Critical two-tail*, the alternative hypothesis is rejected, i.e. the null hypothesis of the equality of the arithmetic means of the basic sets is accepted. The same conclusion can be drawn based on the probability value P ($T \leq t$) two-tail. Since the probability is 0,39, which is greater than 0,05 (the probability of a type I error α), the null hypothesis is accepted, and it is concluded that there is no significant difference in the values of the tensile strengths of samples with and without an adhesion layer.

4 CONCLUSION

In this paper, the influence of the infill density and layer thickness on the tensile strength of samples manufactured by FDM 3D printing was experimentally investigated, with the aim of developing regression models for predicting mechanical properties. The research was conducted using a factorial experimental design with two levels and three replications, and the test samples were manufactured with and without an adhesion layer. The obtained results were statistically analysed using the analysis of variance (ANOVA) method in MS Excel.

The analysis of samples with an adhesion layer revealed that the infill density, the thickness of the layer and their interaction have a significant impact on the tensile strength, while for samples without an adhesion layer a significant impact was confirmed for both individual factors, but not for their interaction. In both cases, regression models with high coefficients of determination were created ($R^2 = 0.9675$ for samples with an adhesion layer and $R^2 = 0.967$ for samples without an adhesion layer), which confirmed their high accuracy in predicting the tensile strength.

Using a *t*-test, it was determined that there is no statistically significant difference in tensile strength values between samples made with and without an adhesion layer ($p = 0.39 > 0.05$), indicating that the adhesion layer does not significantly affect the mechanical properties. Therefore, it can be concluded that making samples without an adhesion layer can save time and material consumption without negatively affecting the tensile strength of the printed samples, provided that the printing process and product geometry are not affected.

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