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Araştırma Makalesi / Research Article

Optimization of Printing Parameters of PLA and ABS Produced by FFF

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ABSTRACT: In this study, the changes in tensile strength of PLA and ABS specimens, the most commonly used materials in additive manufacturing with FFF, were investigated as a function of fill rate and print speed. Tensile specimens were fabricated for different fill rates and speeds and tensile tests were performed. Increasing the fill rate increases the tensile strength. Increasing or decreasing the print speed too much has a negative effect on tensile strength. Filament usage and printing times were also calculated. With the data obtained, an optimization model was created using response surface methodology. The aim of this study is to optimize the strength/cost of ABS and PLA, the two preferred FFF materials. The novelty of the study is to investigate the strength/cost optimization for different material types in terms of UTS, filament consumption and printing speed. For each material type, high tensile strength, low printing time and low filament used conditions were determined for the optimization model. The optimum parameters for PLA are obtained at 66.77% fill level and 78.43% speed rate. For ABS, optimum values are obtained at 79.5% fill rate and 135% speed rate. Then, samples were produced for optimum conditions and experiments and calculations were repeated. The numerical results obtained with the model were compared with the experimental results. It is found that the model estimates the output parameters with high accuracy. This proves the accuracy of the proposed optimization model.

Keywords: 3D printing, Tensile strength, ABS, PLA, Optimization

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1. INTRODUCTION

Metal Fused filament fabrication (FFF), a type of additive manufacturing (AM), is a method based on converting the designs prepared with computer aided design (CAD) data programs into G codes, and then melting the raw material (filament) with an extruder in accordance with the G codes and depositing it in layers (Khan et al., 2018). This method has rapidly popularized due to its low equipment and raw material costs, short production time and easy applicability (Alabd and Temiz, 2024). With this rapid expansion, FFF has been used in various fields such as aerospace industry (Yao et al., 2019), robotics (Kaya et al., 2023), biomedical applications (Pehlivan et al., 2024). This method is also preferred because infill rate, infill pattern and printing speed are adjustable (Fontana et al., 2022). In addition, the process allows for functional grading and manufacturing at different fill rates, making it possible to create regions with different mechanical properties on the same product (Temiz, 2024b). This is especially desirable for biomedical structures such as individually specialized prosthesis-orthotics (X. Wang et al., 2016).

Although there are many positive aspects, there are also negative aspects of the FFF process. The mechanical properties and dimensional stability of the products obtained as a result of the process vary as a function of many parameters such as fill rate and fill pattern, layer height (Srinivasan et al., 2020), build orientation (Öz and Öztürk, 2023), extrusion temperature (Hikmat et al., 2021), operating conditions of the product (Grasso et al., 2018). The fact that the mechanical performance of FFF, which is quite new and developing day by day, depends on many parameters has caused researchers to focus on this field. The most preferred filament types as printing raw materials are polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) and polyethylene terephthalate glycol (PETG) (Güdür et al., 2023). In the study performed by Rajpurohit and Dave in which the variation of the ultimate tensile strength (UTS) value of PLA according to the printing parameters was investigated; raster angle, raster width, layer height indicating layer angle were selected as variables (Rajpurohit and Dave, 2019). Tensile tests demonstrated that all variables were effective on UTS. It was also found that the raster angle has an effect on fracture mechanics (Rajpurohit and Dave, 2019). In another study, the effect of fill pattern on UTS and flexural strength was investigated. Rectilinear, concentric, HoneyComb and HilbertCurve patterns were selected as fill patterns. The tests showed that the fill pattern was effective on the mechanical properties and the best strength was obtained with rectilinear fill pattern (Khan et al., 2018). In the study by Dwiyati et al. in which the variation of tensile strength of ABS according to layer thickness was investigated, it was found that the decrease in layer thickness increased the tensile strength (Dwiyati et al., 2019). Rifuggiato et al. examined the effect of fill rate and fill pattern on UTS and reported that the gaps formed in the microstructure and the distribution of these gaps are effective in the differentiation of UTSs (Rifuggiato et al., 2022).

The changes in mechanical properties depending on quite different parameters require optimization studies to be carried out on production parameters. In the study by Samykano et al. layer height, raster angle and filler density for ABS material were optimized according to UTS and production costs. According to the results, the best UTS/cost ratio was obtained with 0.5 mm layer height, 65º raster angle and 80% fill density (Samykano et al., 2019). In another study, optimization of layer height, raster angle and layer width for UTS and surface roughness of PLA specimens was performed. Optimum results were obtained for 0 º raster angle, 0.1 mm layer height and 0.6 mm layer width (Temiz, 2024a). Although optimization studies focus on changing the printing parameters, there are also comparative optimization of specimens produced by different AM methods. Bayraklılar et al. compared the mechanical properties of ultraviolet radiation (UVR) polymer produced by stereolithography (SLA) with ABS and PLA produced by FFF. The comparisons were made on tensile and flexural strengths and hardnesses. The best results for all input parameters were obtained with UVR. Differences in mechanical properties were found to be based on differences in microstructure (Bayraklılar et al., 2023).

Although there are studies in the literature on both the mechanical properties of the specimens produced with FFF and the optimization of printing parameters, there is no study in which both the mechanical properties and strength/cost ratios of different materials are investigated in detailed. In addition, previous studies have investigated the effect of fill rate, layer height and printing orientation on mechanical properties for a single material type. However, the comparison of mechanical properties and cost changes for different material types is a gap in the literature. The parameters investigated were selected according to this gap in the literature. In the current study, tensile tests were performed on specimens produced from two different materials, ABS and PLA, at different fill rates and at different printing speeds. The data obtained were evaluated in terms of UTS, printing times and the amount of filament spent. The results were optimized by response surface methodology (RSM). The aim of this study is to optimize the strength/cost of ABS and PLA, the two preferred FFF materials. The novelty of the study is to investigate the strength/cost optimization for different material types in terms of UTS, filament consumption and printing speed. By establishing the optimum parameters, it will be possible to increase the strength of the parts produced with 3D printing for the manufacturing sector and reduce labor and production costs.

2. MATERIALS AND METHODS

2.1 Materilas

The specimens investigated in the study were produced from two different filaments compatible with FFF, namely PLA and ABS. The filaments were purchased from the same company and have a diameter of 1.75 mm. The mechanical properties of the filaments are detailed in Table 1. The fill pattern for all specimens is grid.

Table 1. Mechanical Properties of PLA and ABS (Esun, 2024b, 2024a)

Material	Density (g/cm^3)	Flexural Modulus (MPa)	Tensile Strength (MPa)	Bending Strength (MPa)	Elongation (%)
PLA	1.23	1973	60	74	20
ABS	1.04	1177	43	66	22

2.2 Optimization Methodology

Optimizations were performed using RSM. The reason for choosing this optimization method is that RSM allows the estimation of non-experiment conditions with great accuracy with a small number of experiments. (Karamanlı et al., 2024). The inputs for this study are material type, fill rate and speed rate. The outputs are UTS, spent filament and printing time. The aim of the optimization is to find the optimum printing parameters for high tensile strength, low spent filament and printing time conditions. The design matrix for RSM was created with MiniTab Software. The matrix used was L18 full factor design. The design matrix and printing parameters are given in Table 2. The inputs for the RSM model can be given as in equation 1(K. Wang and Lam, 1999):

$$y = F(x_1, x_2, x_3, \dots, x_m) \tag{1}$$

where $x_1, x_2, x_3, \ldots, x_m$ and y indicates input and output parameters respectively. The main principle of RSM is to relate inputs to outputs. This is obtained by modelling a quadratic equation (equation 2) (K. Wang and Lam, 1999);

$$y = b_0 + \sum_{i=1}^{m} b_i x_i + \sum_{i=1}^{m-1} \sum_{j \geq i}^{m} b_{ij} x_i \, x_j + \sum_{i=1}^{m} b_{ii} x_i^2 + \varepsilon \quad (2)$$

In the equation, i indicates the linear coefficient, j indicates the second-order coefficient, b indicates the regression coefficient, m indicates the number of parameters, and ε indicates the error defined in the response (K. Wang and Lam, 1999). Furthermore, the effect levels of the parameters were evaluated utilizing Analysis of Variance (ANOVA). The calculations regarding statistics occurred with a confidence level of 95%.

Table 2. L18 full factor design matrix for response surface methodology

Test No	Material Type	Fill Rate (%)	Speed Rate (%)
1	ABS	70	125
2	ABS	100	75
3	ABS	100	100
4	ABS	85	135
5	PLA	100	100
6	ABS	70	75
7	PLA	70	75
8	PLA	65	100
9	PLA	70	125
10	PLA	85	135
11	PLA	100	125
12	PLA	85	100
13	PLA	85	65
14	ABS	65	100
15	ABS	85	65
16	ABS	100	125
17	PLA	100	75
18	ABS	85	100

2.3 Specimen Production

For tensile tests, a tensile specimen in the shape of a dog-bone according to ASTM D638-14 Type-1 was preferred (ASTM, 2022). The dimensions of the specimen are illustrated in Figure 1. The computer aided design (CAD) model of the specimen was created with the student version of SOLIDWORKS and saved in STL format. Slicing and G-code generation was performed with Creality's slicing software.

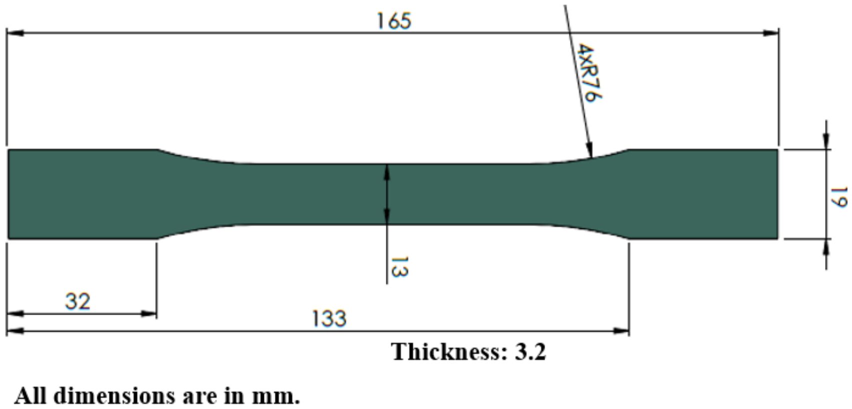


Figure 1. ASTM D638-14 Type-1 tensile test specimen (ASTM, 2022)

The specimens were produced with a Creality K1 model 3D printer. Printing parameters were selected according to the parameters recommended by Esun company for Creality K1 model 3D printer (Esun, 2024c). The recommended printing speeds were accepted as 100% speed rate. Printing parameters for 100% speed rate are given in Table 3. All of the printing speed parameters were changed in the same percentages according to the optimum value of each material type. For example, for a PLA sample produced under 75% speed rate conditions, the infill production speed is 225 mm/s, while for ABS it is 37.5 mm/s. During printing operations, the in-cab conditions were controlled by a temperature and humidity meter. The whole production was carried out at 26-38 °C in-cabinet temperature and 32-44% humidity conditions. At least 3 specimens were produced for each condition. The heating table temperature for PLA specimens was 60 °C and for ABS was 105 °C. No adhesion enhancing adhesive was used in the production of both specimens.

Table 3. Printing parameters for 100% speed rate (Esun, 2024c)

Material Type	Printing Temperature (°C)	Layer Height (mm)	Printing Speed (mm/s)	
PLA	220	0.2	Infill	:300
			Outer Wall	:200
			Inner Wall	:300
			Top/Bottom	:200
			Travel	:500
			Layer	:50
			Skirt	:50
ABS	240	0.2	Infill	:50
			Outer Wall	:30
			Inner Wall	:25
			Top/Bottom	:25
			Travel	:100
			Layer	:20
			Skirt	:20

2.3 Tensile Tests

Tensile tests were performed using a 60 kN tensile machine at room temperature at a speed of 5 mm/min in accordance with ASTM D638 (ASTM, 2022). The specimens were subjected to tensile tests until fracture. The tests were repeated at least three times for each condition and the final values were determined by averaging the results. The process steps of the study are presented in Figure 2.

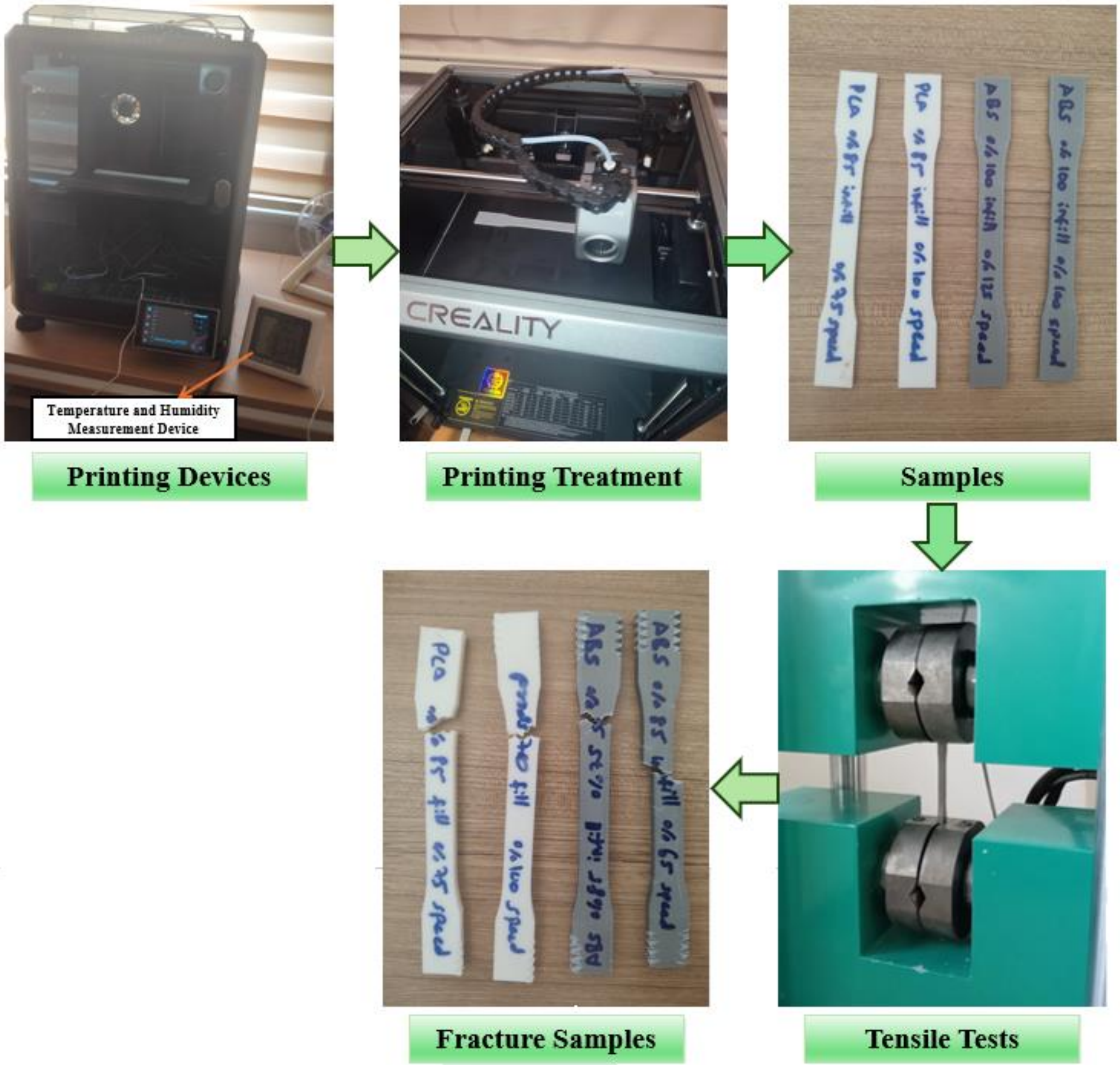


Figure 2. Specimen production and tensile tests processes

3. RESULTS AND DISCUSSION

3.1 Tensile Tests Results

In this section, tensile test results were analyzed and evaluated. The results obtained are given in Table 4. The stress-elongation curves obtained as a result of the tests are shown in Figure 3. When the results for 85% fill rate (Figure 3(a)) were analyzed; it was found that all PLA specimens reached better tensile strength values than ABS specimens. The best UTS were obtained in PLA specimens for 100% speed rate with 39.02 MPa. The UTS of the specimens produced at 65% speed rate with 35.45 MPa were close to the maximum. When the speed rate increased to 135%, a decrease in UTS was observed. This indicates that increasing the speed rate too much negatively affects the tensile strength. When the UTSs of ABS were analyzed, it was found that the specimens produced with 135% speed rate exhibited the best performance with 29.56 MPa. The specimens produced with 100% speed rate exhibited similar UTS performance. However, the UTS of the specimens produced with 65% speed rate decreased by approximately 29% with 20.96 MPa. ABS materials require higher printing and table temperature. When the printing speeds are reduced, the material melted with the extruder cools faster than desired. The decrease in UTSs for 65% speed rate could be explained by layer adhesion and delamination defects (Darsin et al., 2022; Singaravel et al., 2024). Analyzing the elongation ratios, it was observed that ABS performed better in contrast to the UTS results. For ABS, the transformation from the elastic to the plastic region occurs at higher elongation ratios. This difference could be explained by the better ductility of ABS (Esun, 2024b, 2024a). The results demonstrated that the yield strength of PLA specimens was better than that of ABS. The best yield strength of 34.03 MPa was obtained for PLA specimens for 100% speed rate. The best yield strength for ABS was 24.95 MPa for 135% speed rate. The yield strength results were in parallel with the tensile strength results.

Table 4. Tensile test results

Material Type	Fill Rate (%)	Speed Rate (%)	UTS (MPa)	Spent Filament (m)	Printing Time (min)
ABS	70	125	23.123	6.15	47.5
ABS	100	75	29.987	7.54	86.5
ABS	100	100	32.915	7.54	65.5
ABS	85	135	29.559	6.99	51
PLA	100	100	45.191	7.53	23.5
ABS	70	75	23.253	6.15	72.5
PLA	70	75	34.29	6.18	21
PLA	65	100	28.094	5.9	20
PLA	70	125	33.502	6.18	20
PLA	85	135	33.807	6.94	21.5
PLA	100	125	42.365	7.53	23
PLA	85	100	39.204	6.94	22
PLA	85	65	38.448	6.94	23.5
ABS	65	100	20.958	5.94	55
ABS	85	65	26.316	6.99	81.5
ABS	100	125	32.79	7.54	55
PLA	100	75	39.204	6.94	22
ABS	85	100	27.605	6.99	61

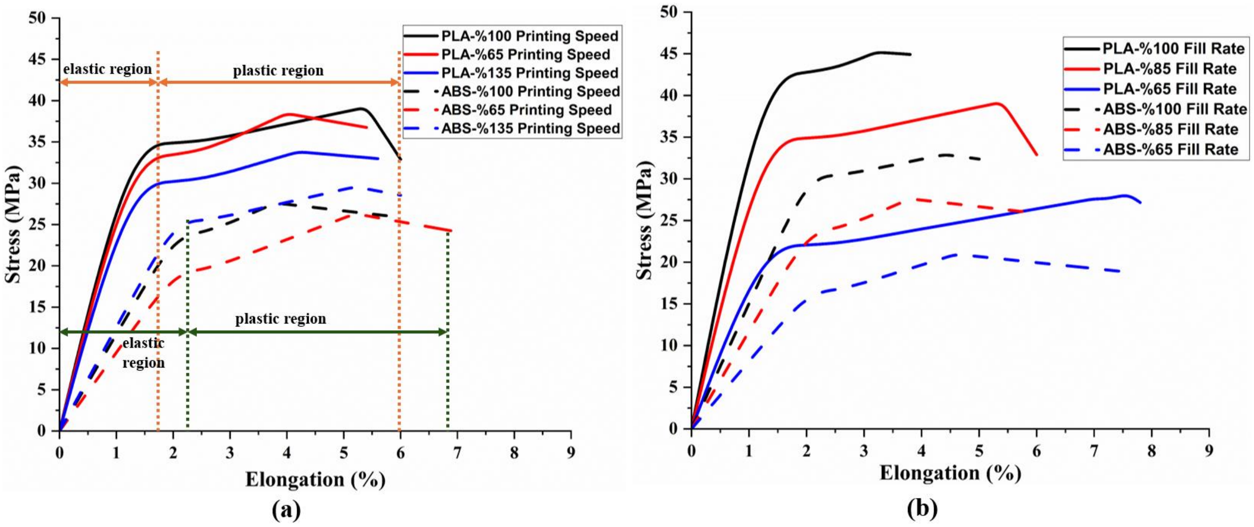


Figure 3. Stress-elongation curves for 85% fill rate (a) and stress-elongation curves for 100% speed rate (b)

Figure 3(b) shows the stress-elongation curves for different fill rates at 100% speed rate. The results clearly indicate that the UTS increases with the increase in the fill rate. The highest UTS of 45.19 MPa was obtained for PLA specimens produced at 100% filling rate. For 85% fill rate, this value decreased to 39.20 MPa and for 65% fill rate it decreased to 28.09 MPa. The reason for this is that the air gap decreases with the increase in the fill rate and the product exhibits a more homogeneous property. Air gaps affect the heat distribution during production, causing residual stresses and reducing the UTS (Atakok et al., 2022). For ABS, the results are parallel to PLA results and UTS increases as the fill rate increases. Another significant result is that the ductility increases with the decrease in the fill rate for the specimens with the same properties. The reason for this is that the specimens have a more homogeneous structure and show more rigid behavior with the increase in the fill rate as in UTS (Atakok et al., 2022; Rifuggiato et al., 2022). As stiffness increases, ductility decreases and therefore elongation decreases.

Similarly, in a study examining the tensile strength of ABS for three different filling ratios, it was found that increasing the filling rate increased the UTS. In addition, SEM analyses showed that the changes in tensile strength were caused by internal gaps (Rifuggiato et al., 2022). In another study in which the change of the tensile strength of PLA according to the printing parameters was examined, it was found that the increase in the fill rate increases the UTS in parallel with the results obtained (Rismalia et al., 2019). Although the increase in the fill rate also increases the UTS, it also increases the printing times and the amount of filament spent. This has a negative impact on production costs. This situation requires an optimization study examining the printing parameters.

3.2 Statistical Evaluation and Optimization

In this section, ANOVA and optimization results are evaluated. The summary of the optimization model is presented in Table 5. Here, it is observed that the R^2 value, which expresses the realism of the model, is greater than 94% for all output parameters. This indicates that the model is highly compatible with experimental data and has a high representation ability. Pred. R^2 value, which expresses the predictive ability of the model, varies between 84-97%. It means that the prediction accuracy is between 84-97% for specimens that have not been examined experimentally and this indicates that the model has a very high prediction accuracy.

Table 5. Model summary

	S	R^2	Adj. R^2	Pred. R^2
UTS (MPa)	1.996	94.47%	91.45%	84.11%
Flament Spent (%)	0.156	95.58%	93.17%	85.71%
Printing Time (%)	2.647	99.19%	98.74%	97.70%

ANOVA results are given in Table 6. The results obtained show that material type and fill rate are effective in the change of UTS ($p<0.05$). Speed rate had no significant effect on UTS ($p>0.05$). The most effective parameter in the change of UTS was material type with 53.83%, while the effect of fill rate was found to be 38.68%. The related regression equations are given in equation 3(a) and equation 3(b).

When the filament spent results were analyzed, the only output that was effective on this parameter was the fill rate with 93.09%. Other parameters had no significant effect on filament spent ($p>0.05$). The related regression equations are shown in equation 4(a) and equation 4(b). All parameters have an effect on printing time change. The most effective parameter on printing time is material type with 84.06%, followed by speed rate with 6.92% and fill rate with 1.45%. Although the fill rate is significant ($p<0.05$), the reason for the low effect rate is that the preparation time for printing is quite high and most of the printing time is spent here. The regression equations for filament spent are given in equation 5(a) and equation 5(b).

Table 6. ANOVA results

	Source	DF	Contribution	F-Value	P-Value
UTS (MPa)	Fill Rate	1	38.68%	76.92	0.000
	Speed Rate	1	0.08%	0.01	0.922
	Material Type	1	53.83%	103.30	0.000
	2-Way Interaction	3	1.88%	1.25	0.340
	Error	11	5.53%		
	Total	17	100%		
Flament Spent (m)	Fill Rate	1	93.09%	231.73	0.000
	Speed Rate	1	0.36%	0.39	0.548
	Material Type	1	0.52%	0.91	0.361
	2-Way Interaction	3	1.61%	1.33	0.313
	Error	11	4.42%		
	Total	17	100%		
Printing Time (%)	Fill Rate	1	1.45%	19.58	0.001
	Speed Rate	1	6.92%	86.26	0.000
	Material Type	1	84.06%	1086.63	0.000
	2-Way Interaction	3	6.77%	30.56	0.000
	Error	11	0.81%		
	Total	17	100%		

$$UTS\ for\ PLA = 30.50 + 0.104\ Fill\ Rate - 0.216\ Speed\ Rate + 0.00229\ Fill\ Rate\ x\ Speed\ Rate \tag{3a}$$

$$UTS\ for\ ABS = 17.90 + 0.071\ Fill\ Rate - 0.159\ Speed\ Rate + 0.00229\ Fill\ Rate\ x\ Speed\ Rate \tag{3b}$$

$$Flament\ Spent\ for\ PLA = 4.80 + 0.0201\ Fill\ Rate - 0.0137\ Speed\ Rate + 0.000197\ Fill\ Rate\ x\ Speed\ Rate \tag{4a}$$

$$Flament\ Spent\ for\ ABS = 4.64 + 0.0265\ Fill\ Rate - 0.0167\ Speed\ Rate + 0.000197\ Fill\ Rate\ x\ Speed\ Rate \tag{4b}$$

$$Printing\ Time\ for\ PLA = 3.70 + 0.230\ Fill\ Rate + 0.113\ Speed\ Rate - 0.0015\ Fill\ Rate\ x\ Speed\ Rate \tag{5a}$$

$$Printing\ Time\ for\ ABS = 72.20 + 0.495\ Fill\ Rate - 0.374\ Speed\ Rate - 0.0015\ Fill\ Rate\ x\ Speed\ Rate \tag{5b}$$

3D surface plots and contour plots were generated for each parameter to analyze the interactions of the optimization parameters UTS, speed rate and fill rate with respect to each other. 3D surface plots and counter plots generated for UTS are illustrated in Figure 4. When the results for PLA (Figure 4(a) and (b)) were analyzed; the best UTS values were found to be at 100% fill rate and 80-110% speed rate conditions. Reducing the fill rates and increasing the speed rate could negatively affect the UTS. When produced at lower speeds, PLA has more time to absorb heat, which increases the degree of crystallization of PLA. Increased crystallinity could improve tensile strength as the material transforms from a more amorphous form to a semi-crystalline form (Hsueh et al., 2021; Tichý et al., 2021). If the printing speed is reduced too much, it may cause separation between layers (delamination) with excessive solidification. When the printing speed is increased too much, internal stress may occur and this may cause delamination (Balasubramanian et al., 2024).

When the plots for ABS (Figure 4(c) and (d)) were analyzed, it was found that the best UTS values were obtained at high speeds in opposite to PLA. At very low printing speeds, the time between two sequential layers increases. This may cause interlayer non-bonding and thermal problems (Guimarães et al., 2020). Another remarkable issue was that for ABS specimens produced at speed rates above 130% and low fill rates, the UTS was minimum. The reason for this situation could be explained by the fact that the time required for cooling between the 2 overlapping layers cannot be fulfilled with both the decrease in the fill rate and the decrease in the printing speed and there is not enough cooling time for the molten material (Daly et al., 2023). The increase in the fill rate increased the tensile strength as in PLA specimens. The reason for this increase is related to the decrease in the micro gaps in the specimen and the more homogeneous structure as mentioned before (Atakok et al., 2022).

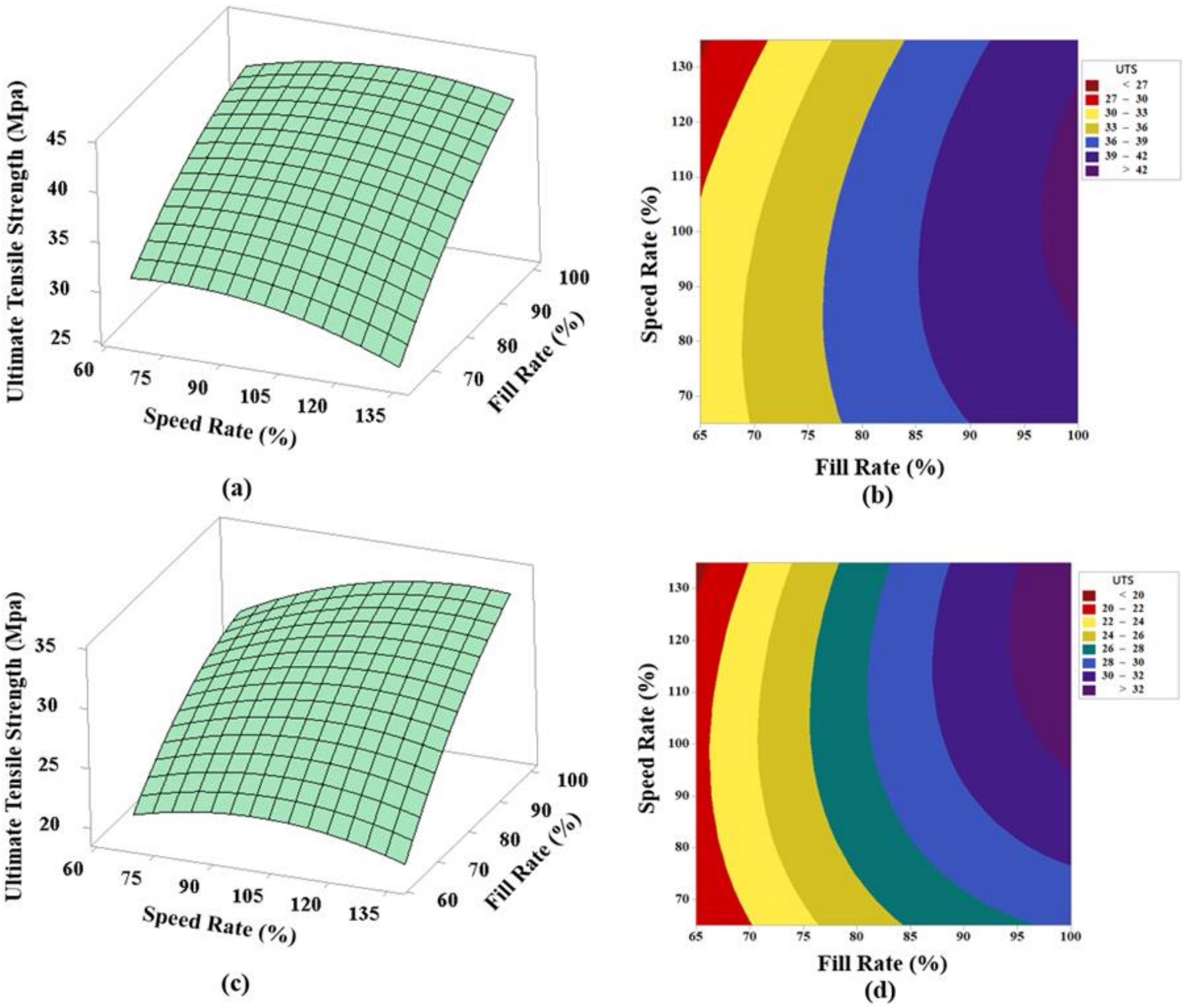


Figure 4. 3D surface plots of PLA (a) and ABS (c), contour (2D) plots of PLA (b) and ABS (d) for UTS

In Figure 5, changes of printing time for PLA and ABS according to the input parameters are given. According to the plots; as the fill rates decrease and the speed rate increases, the printing time decreases. This result was more evident in the plots of ABS samples due to the longer production times (Figure 5(c) and (d)). According to the optimization plots for PLA (Figure 4(a) and (b)), after 115% speed rate, the printing time increases slightly as the speed rate increases. The experimental data (Table 4) clearly indicates that the increase in speed rate decreases the printing time for all speeds. This difference is within the range of errors for the model formed and is since the production times for PLA samples are considerably shorter than ABS samples. In addition, the fact that the material type and fill rate are highly effective on the printing time causes deviations for the speed rate results. This caused a mismatch within the optimizations model for rates above 115%. A further study examining only high speed rate values could be performed to eliminate these variations and errors.

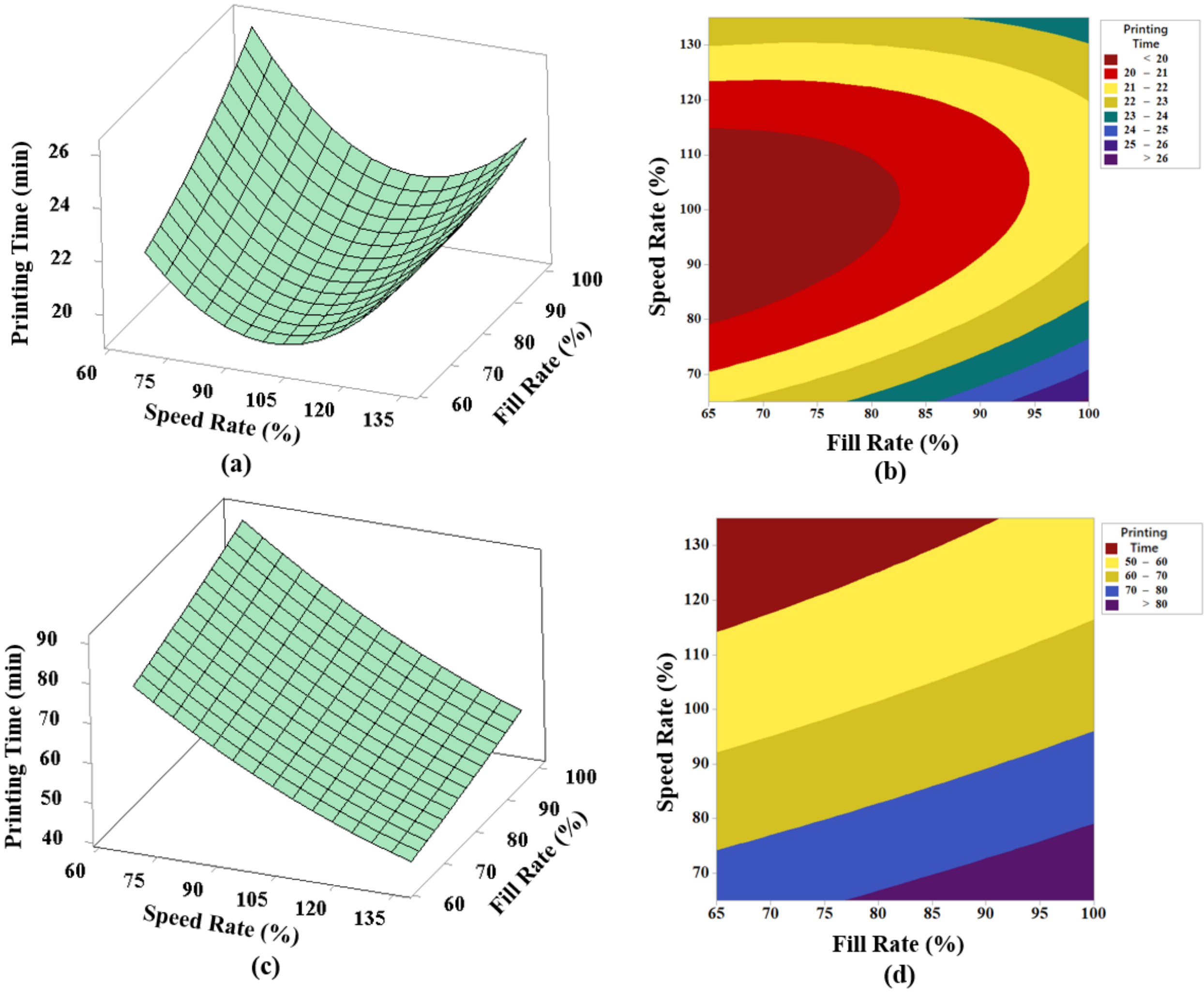


Figure 5. 3D surface plots of PLA (a) and ABS (c), contour (2D) plots of PLA (b) and ABS (d) for printing time

The change plots of filament spent according to the input parameters are given in Figure 6. The effective parameter in the change of filament spent is the fill rate. Speed rate and material type have no effect on filament spent. For a sample produced at 65% fill rate, 6 meters of filament was spent. When the fill rate was increased to 100%, the amount of filament spent increased to over 7.5 meters.

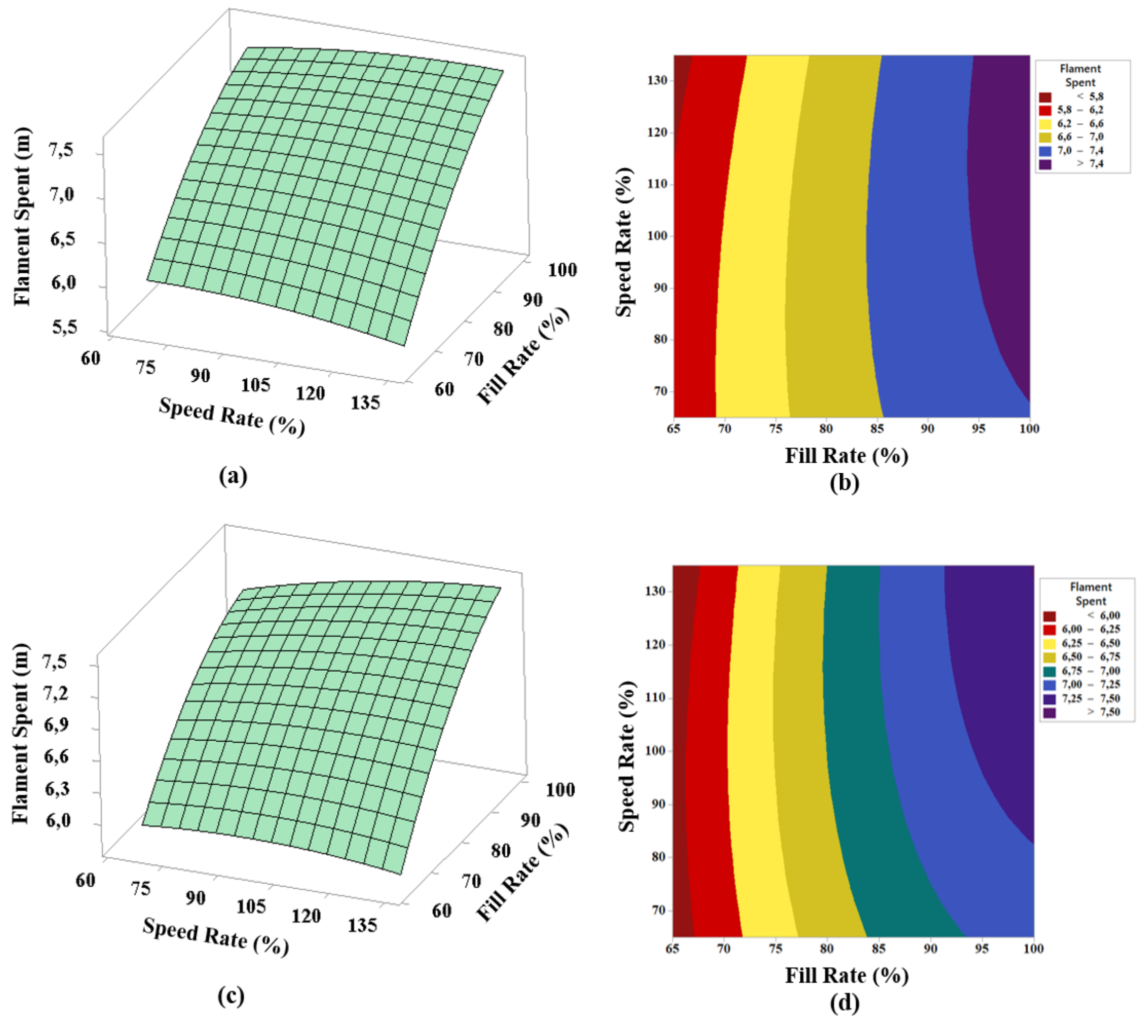
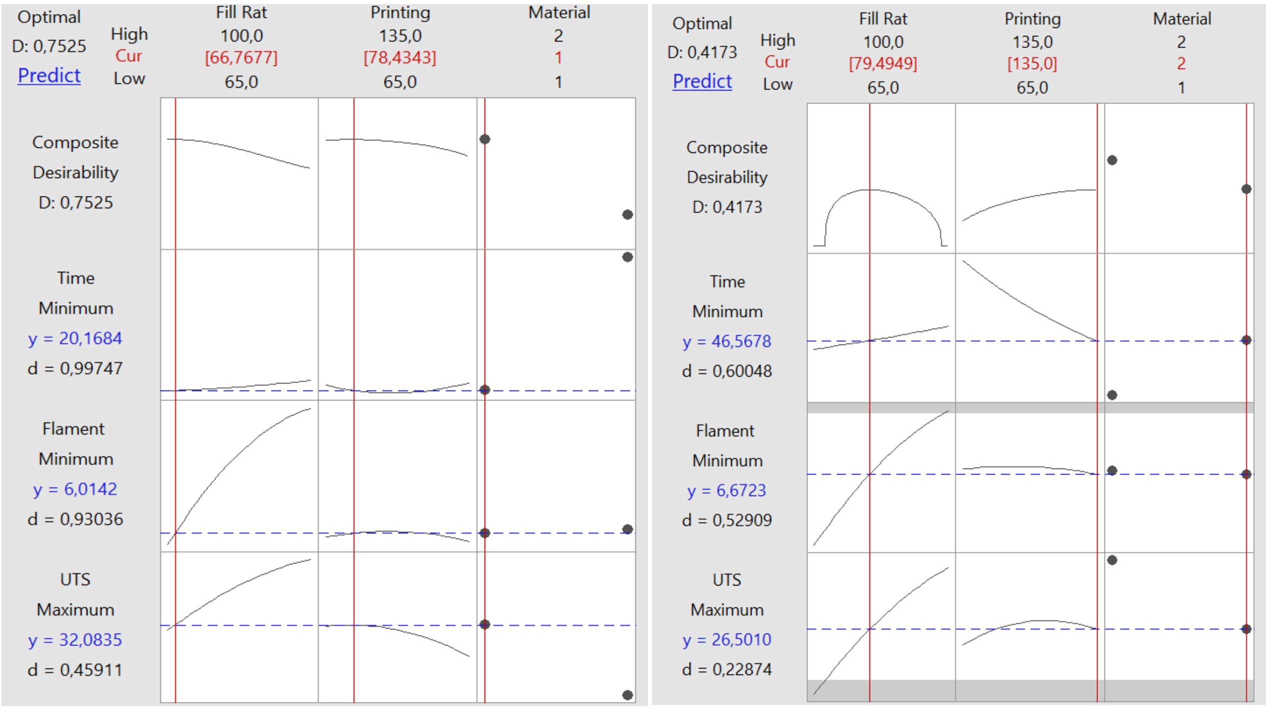


Figure 6. 3D surface plots of PLA (a) and ABS (c), contour (2D) plots of PLA (b) and ABS (d) for filament spent

Optimization was performed with the obtained data. Optimum values were found for both PLA and ABS. The values found for PLA also represented the optimum results for the model. Optimizations were performed in attempts to maximize UTS and minimize filament spent and printing time. Optimization curves are shown in Figure 7. According to the results, optimum values for PLA were obtained at 66.77% fill rate and 78.43% speed rate conditions. In addition, predictions were made to the optimization model for these conditions. The model predicted UTS as 32.08 MPa, filament spent as 6.01 m and printing time as 20 min. Optimum values for ABS were obtained at 79.5% fill rate and 135% speed rate. For these conditions, the model predicted UTS as 26.5 MPa, filament spent as 6.67 m and printing time as 46.5 min. For optimum parameters, 3 samples were produced and tensile tests were performed The optimum input-output values and experimental results for both material types are given in Table 7. According to this, the optimization model can predict the UTS with an error of 4.02% for PLA and 10.52% for ABS. Likewise, the model was able to predict the printing time with an error of 6.98% for PLA and 2.11% for ABS. For filament spent, these values decrease to 0.17% and 1.37% respectively. The prediction errors are very low, which proves the accuracy of the optimization model.



(a) **(b)**

Figure 7. Optimization curves for PLA (a) and for ABS (b)

Table 7. Results of optimization and experimental evaluation

	Input Parameters		**Output Parameters**		
	Fill Rate (%)	**Speed Rate (%)**	**UTS (MPa)**	**Flament Spent (m)**	**Printing Time (min)**
Optimization Results					
For PLA	66.77	78.43	32.084	6.01	20.0
For ABS	79.50	135	26.501	6.67	46.5
Experimental Results					
For PLA	66.77	78.43	30.842	6.00	21.5
For ABS	79.50	135	29.615	6.58	47.5

The results were consistent with previous optimization studies. In the study in which the optimum conditions of the printing parameters of ABS specimens were investigated with RSM, it was found that the increase in fill rate increased the UTS (Srinivasan et al., 2020). Similarly, the optimization study by Samykano et al. confirms the results (Samykano et al., 2019). In another study investigating the optimum production parameters of PLA specimens, it was stated that the speed rate increases the UTS at up to certain speed rates, but very high speed rates cause a decrease in UTS (Hikmat et al., 2021).

PLA is a biodegradable material, non-toxic (Yao et al., 2020) and particularly suitable for biomedical applications (Mishra et al., 2021). Tensile strength is also higher than ABS. However, working conditions begin to undergo structural deformation at temperatures above 60-65 °C. It is not suitable for applications operating under high temperature conditions. ABS begins to undergo structural deformation above 100 °C. This could make ABS the preferred choice of applications with high temperature operating conditions. However, contrary to PLA, ABS is toxic (Pellejero et al., 2020). By using the optimization model, predictions can be made for different applications according to material preference. In applications where durability is more important, fill rate, speed rate and calculations can be made according to the desired UTS values. Similarly, in applications where production speed and costs are important, production can be realized by decreasing fill rate and increasing speed rate. Due to the optimization model proposed in this study, all desired properties could be predicted with great accuracy without the need for experimental investigation.

4. CONCLUSION

In this study, tensile strength, filament spent and printing time changes of PLA and ABS produced by FFF according to printing parameters were investigated and optimized. According to the results obtained:

- Tensile strength of PLA specimens is higher than ABS specimens. The UTS of PLA produced at 100% fill rate and 100% speed rate is 45.19 MPa, while the UTS of ABS produced with the same printing parameters is approximately 32.92 MPa. However, the elongation rate of ABS specimens is higher.
- For both PLA and ABS, the tensile strength increases as the fill rate increases. However, the amount of filament spent and production times also increase. Thus, this increases production costs.
- Increasing the speed rate too much negatively affected the UTS of PLA samples. On the other hand, the best UTSs of ABS samples were obtained at 135% speed rate. It is obvious that increasing the speed rate too much for ABS will have negative effects. The fact that the speed increase rate used for the optimization model is the same for PLA and ABS is an obstacle for investigating the effect of higher speeds on ABS, in this study. In another study, the effect of higher speed rates on ABS could be investigated in more detail.
- The optimum parameters for PLA are obtained under 66.77% fill rate and 78.43% speed rate. For ABS, optimum values are obtained at 79.5% filling rate and 135% speed rate.
- The optimization model was able to predict the tensile strength with an error of 4.02% for PLA and 10.52% for ABS. Likewise, the model was able to predict the printing time with an error of 6.98% for PLA and 2.11% for ABS. For filament spent, these values decrease to 0.17% and 1.37% respectively.
- Through optimization, printing parameters could be selected according to the desired tensile strength and the time spent for trial and error could be reduced. In addition, by selecting the correct printing parameters according to the desired mechanical properties, the material and labor costs and the time spent for printing could also be reduced.

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6. CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

7. AUTHOR CONTRIBUTION

İsmail Aykut KARAMANLI contributed to determining and managing the concept and/or design process of the research, data collection, data analysis and interpretation of the results, preparation of the manuscript, critical analysis of the intellectual content, as well as providing final approval and full responsibility. Kadircan TAHNAL contributed to data collection, and data analysis and interpretation of the results.

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