Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 12, Special Issue 5, 2024
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

Investigating the Combined Effect of FDM 3D Printing Parameters on Tensile Behavior of ABS Plastic Using Taguchi Method

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Abstract

Fused Deposition Modelling (FDM) is a commonly utilized method in additive manufacturing. FDM is greatly affected by its printing parameters, which is why selecting the proper parameters is crucial for obtaining the desired properties of 3D printed parts. In this paper we have experimentally and statistically studied the influence of FDM 3D printing parameters (infill pattern, infill density and layer thickness) on tensile strength using Acrylonitrile Butadiene Styrene (ABS) filament. Nine experiment runs were set using Taguchi's method and the specimen were printed on an FDM 3D printer. Tensile strength tests were carried out using a Universal Testing Machine (UTM). Based on the results of tensile test, signal to noise ratio (S/N ratio) was found for maximizing the strength. The optimal values were determined using the signal-to-noise ratio (S/N ratio) and an analysis of variance (ANOVA). The results show that the optimal printing parameters are Honeycomb infill pattern with 90% infill density and 0.09 mm layer thickness. According to ANOVA, infill density had maximum influence (40.35%) on tensile strength followed by layer thickness (35.04%) and infill pattern (12.89%) respectively.

Keywords: FDM, ABS, Infill Density, Infill Pattern, Layer Thickness

INTRODUCTION

Additive manufacturing (AM) technology, commonly referred to as three-dimensional (3D) printing, selectively joins materials layer by layer using a 3D computer-aided design (CAD) model of the intended product [1]. Additive manufacturing (AM) is a very adaptable fabrication method that enables users to quickly produce complicated parts intended for specific applications [2]. Applications for 3D printing have been growing quickly since they are easy to change materials, require little oversight or upkeep, and have low production costs [3]. The design and manufacturing processes may now be carried out with greater speed and flexibility thanks to this technology. Furthermore, 3D printing machines are utilized in many industries to create sophisticated parts for the design stage since complicated shapes require a lot of time and money to construct using traditional manufacturing technologies, also 3D printing can reduce waste of materials, number of processes in the process, cost, and duration of manufacturing [4, 5]. Using Computer Aided Design (CAD) file to determine the final product's shape, makes design modification a simple process [6]. Material extrusion is a subset of additive manufacturing

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Received Date: March 11, 2024
Accepted Date: June 06, 2024
Published Date: August 02, 2024

Citation: Wajid Ali Hashmi, Abdul Rehman, G.S. Lathkar, P.R. Attar, M. Zubairuddin. Investigating the Combined Effect of FDM 3D Printing Parameters on Tensile Behavior of ABS Plastic Using Taguchi Method. Journal of Polymer & Composites. 2024; 12(Special Issue 5): S161–S169.

(AM) that includes fused deposition modelling (FDM) and fused filament fabrication (FFF). Using a predefined route to selectively deposit melted material, FDM creates components layer by layer [7]. The qualities of the component to be 3D printed can be directly controlled by adjusting several types of process parameters using FDM systems.

Several printing parameters used to produce parts from FDM printer have been studied and documented in literature. Among build orientation, raster orientation, nozzle diameter, extruder temperature, number of shells, extruding speed and infill density; build orientation, nozzle diameter and infill density are significant parameters which affect the tensile strength of the 3D printed PLA part [8]. Spatial orientation has less influence over the Young's modulus but higher influence on the tensile strength [9]. Reducing the void in 3D printed objects by increasing the raster size can improve the tensile strength of FDM parts [10]. Increasing the infill density increases the tensile strength and the young's modulus of the 3D printed part [11]. In this research, ABS plastic is used to 3D print the specimen for tensile testing. We looked at how layer thickness, infill density, and infill pattern, affected tensile strength of a 3D printed component. Taguchi's L9 array was used in the experiment's design for three levels and three parameters. Taguchi strategies utilize the signal/noise (S/N) ratio to measure the reliability of the investigational results, because this proportion accounts for both the average and the variation of these outcomes [12]. The Taguchi technique is an effective way to determine the optimal set of design parameters [13].

METHODOLOGY

Materials

The filament used to build the specimen was ABS of 1.75mm diameter. It was purchased from Zortrax who sells it under the name Z-ABS. Table 1 shows the properties of Z-ABS. ABS has great stiffness, weldability, and insulating qualities. It retains impact resistance even at low temperatures and has excellent abrasion and strain resistance. Furthermore, it has dimensional stability, assuring mechanical strength and stability throughout time. However, it has low resistance to aromatic hydrocarbons, halogenated hydrocarbons, and alcohols.

Table 1. Properties of ABS filament.

Mechanical Properties	**Value**	**Unit**
Tensile Strength	30.46	MPa
Elongation at max Tensile Stress	4.52	%
Elongation at Break	11.08	%
Density	1.195	g/cm^3
Glass Transition Temperature	107.89	°C

Methods

A tensile test specimen was created as 3D CAD model using SOLIDWORKS. The dimensions of the specimen were as specified in ASTM D638 tensile test method. The volume of specimen was approximately 16900 mm^3 and thickness of the walls were 1.2 mm.

Figure 1 shows the 3D model of the tensile test specimen. The CAD model was exported as Stereolithography (STL) file format for slicing in Z-Suite software. Z-Suite allows us to control the infill density, decide a predefined infill pattern and set the layer thickness based on the nozzle size of the printer. Using the Taguchi method, combinations for infill density, infill pattern, and layer thickness were identified for the tensile tests. The model was then sliced with the decided permutation and was exported to the 3D printer. The FDM 3D printer used was Zortrax M200 with the build size of 200 × 200 × 180 mm. Figure 2 shows the dimension of the specimen according to ASTM D638.

Figure 3 conveys the combination of infill patterns and infill densities.

Journal of Polymer & Composites
Volume 12, Special Issue 5
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Figure 4 shows the orientation in which the specimens were laid for printing.

Figure 5 shows the printing of specimen with infill of truncated square pattern at 60% infill density on 0.09 mm layer thickness.

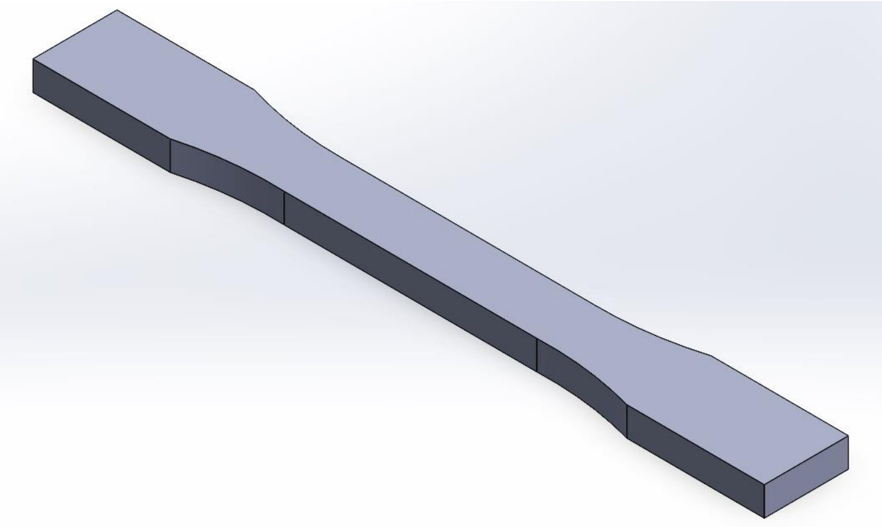


Figure 1. CAD model of the Tensile Test Specimen.

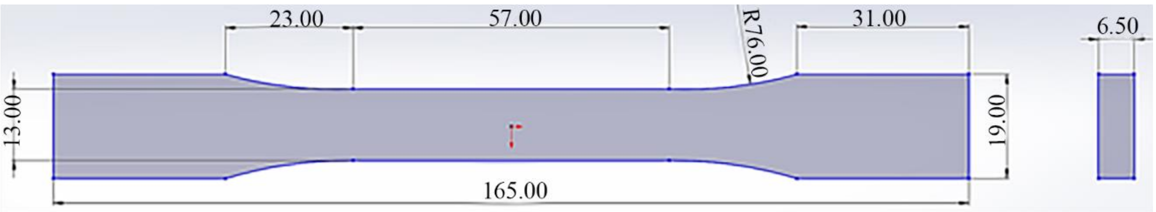


Figure 2. Dimensions of the Tensile Test Specimen in mm.

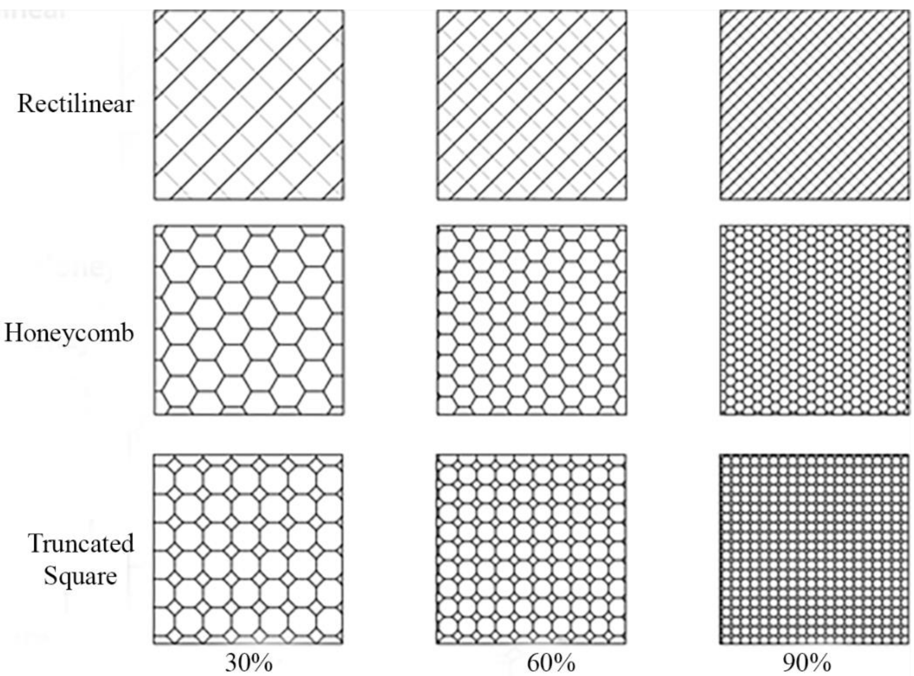


Figure 3. Infill Density and Infill patterns.

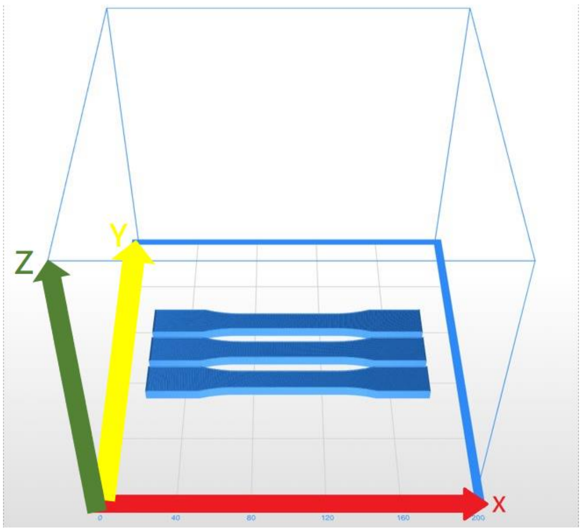


Figure 4. Printing orientation of specimens.

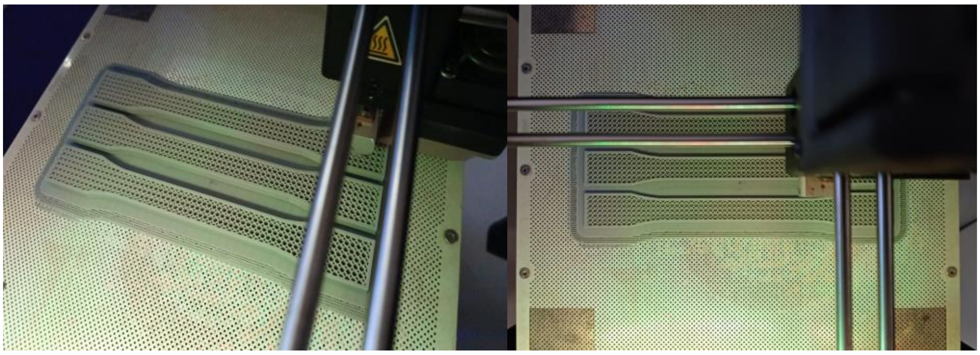


Figure 5. Printing of Specimen.

Table 2. Process Parameters and their levels

Parameter	Levels			Units
	1	***2***	***3***	
Infill Pattern (A)	Rectilinear	Honeycomb	Truncated Square	-
Infill Density (B)	30	60	90	%
Layer Thickness (C)	0.09	0.19	0.39	Mm

Table 2 contains the three process parameters and three levels. The core of Taguchi's methods lies in the application of parameter design, an engineering approach to process or product design which focuses on determining the parameter configurations that produce the highest quality characteristic levels with the least amount of variation. The Taguchi approach uses an orthogonal array (OR) to arrange components and their levels in order to modify the average and decrease variation. Additionally, the Taguchi approach lowers production costs since fewer experiments are needed [14] Table 3.

Tensile Test

The width, thickness and overall length of the specimen were measured. The maximum deviations in dimensions were within 1% which is acceptable in ASTM D638 norms. The thickness of specimen was measured at 3 locations, at the middle of the long axis and 5 mm from both the ends of long axis. This was done to verify flat crossection along the length of specimen. The testing was done on a Shimadzu Universal Testing Machine at CIPET (Central Institute of Petrochemicals Engineering and Technology, Aurangabad, India) testing labs. The chuck speed was set at a 5 mm/min speed for testing and all specimens were tested at room temperature. Figure 6 shows the specimen after the testing is conducted.

Journal of Polymer & Composites
Volume 12, Special Issue 5
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Table 3. Taguchi Orthogonal array L9 (3, 3).

Run	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

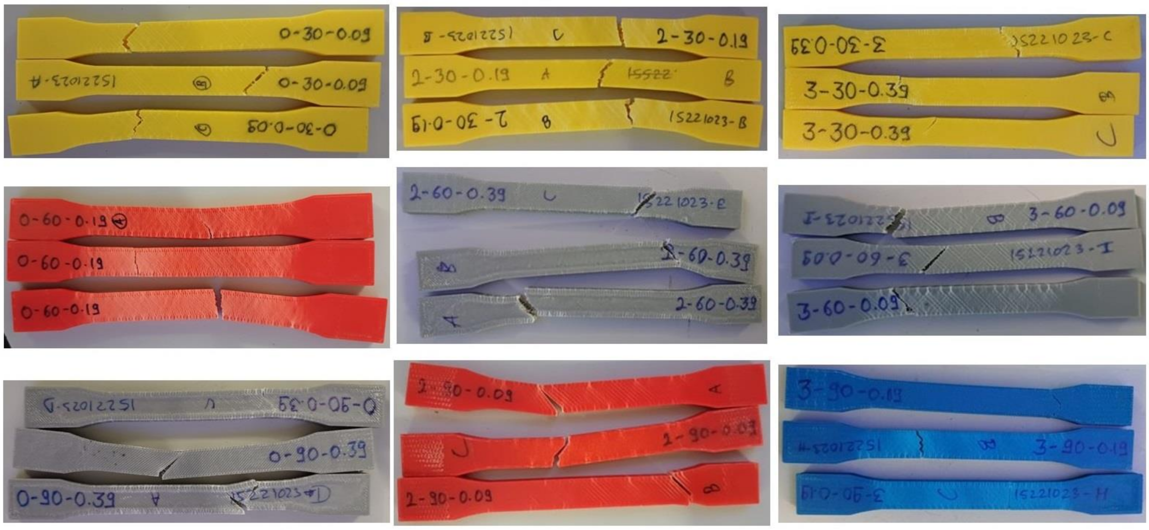


Figure 6. Specimen after tensile testing.

Finite Element Simulation of Tensile Test

Finite element simulations were performed using ANSYS software. 3D tensile specimen geometry-based part was modeled in SOLIDWORKS software and imported in ANSYS. ABS material properties were assigned to the model.

RESULTS AND DISCUSSION

In the Taguchi method, there are two kinds of factors: noise factors and control factors. Control factors can be manipulated and maintained while noise factors are unmanageable. Taguchi method utilizes signal to noise ratio (S/N ratio) to make the process insensitive to changes in noise factors. There are 3 standard characteristics of S/N ratio based on the result named Largest-is-best, Smallest-is-best, Nominal-is-best. In this situation, we desire maximum tensile strength, hence 'largest is best' equation is used to find the S/N ratio [15].

$$\frac{S}{N} = -10 \times log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

In this study, average of 3 samples was considered for all the runs, therefore n = 1. The tensile test results and S/N ratio are shown in Table 4. The highest tensile strength was show in run 6 by honeycomb infill pattern with 90% infill density and 0.09 mm layer thickness. Run 7 had the lowest tensile strength, with a truncated square infill pattern, 30% infill density, and 0.39 mm layer thickness. Table 4 shows that a higher tensile test is obtained when the layer thickness is decreased while the infill density is increased, and vice versa. Each parameter's influence and corresponding level are shown in Table 5. The optimum parameters were selected using Table 5. Table 5 shows the S/N ratio for each factor that is selected to maximize tensile strength. As Table 5 shows, the optimum set of parameters are A-2 B-3 C-1. The optimum parameters are honeycomb infill pattern, 90% infill density and 0.09 mm layer thickness. Figure 7 shows the stress strain curve of all 9 tensile test runs.

Table 4. Tensile Test Results

Run	A	B	C	Mean Tensile Strength (MPa)	S/N Ratio (dB)
1	1	1	1	12.6	22.0074
2	1	2	2	13.2	22.4115
3	1	3	3	12.4	21.8684
4	2	1	2	11.9	21.5109
5	2	2	3	11.9	21.5109
6	2	3	1	32	30.103
7	3	1	3	10.6	20.5061
8	3	2	1	14.7	23.3463
9	3	3	2	16.2	24.1903

Table 5. Response table for S/N ratio

Level	Infill Pattern	Infill Density	Layer Thickness
1	22.10	21.34	25.15
2	24.37	22.42	22.70
3	22.68	25.39	21.30
Delta	2.28	4.05	3.86
Rank	3	1	2

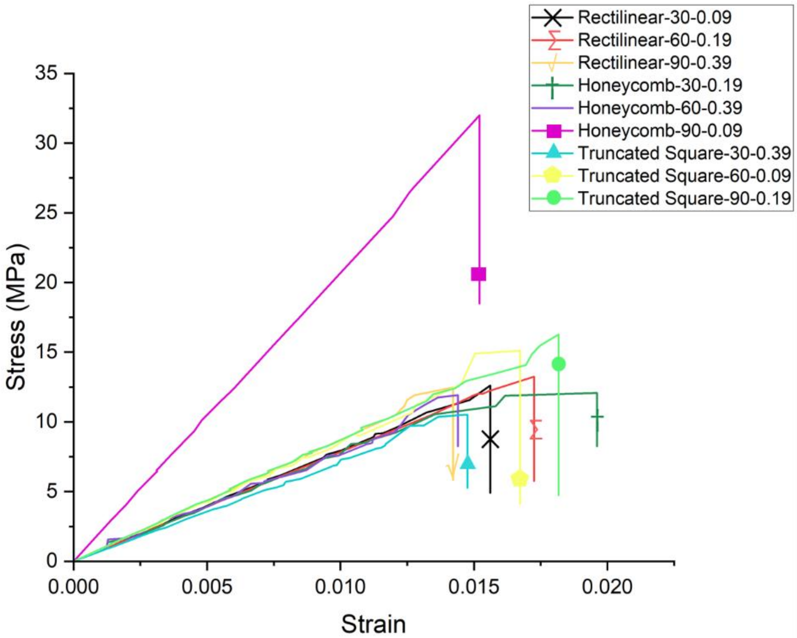
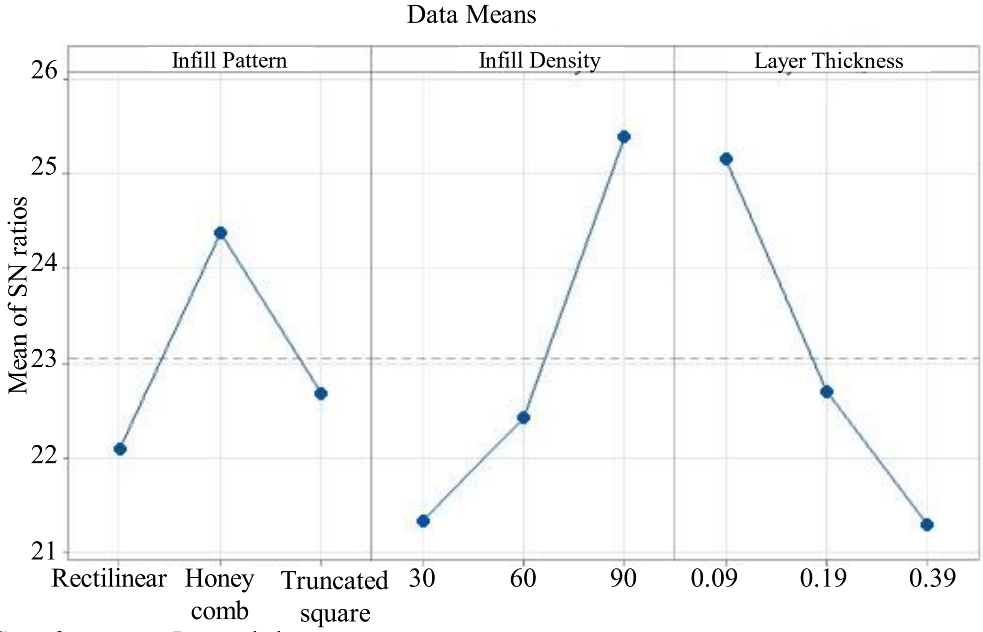


Figure 7. Stress-Strain curve of all nine tensile tests obtained through simulation.

Figure 8 shows the main effect plot for SN ratios for infill pattern, infill density and layer thickness. ANOVA (variances analysis) is a statistical analysis that examines the experimentally observed and predicted quadratic model value differences [16]. Analysis of Variance (ANOVA) Table 6 further confirms that infill density has the highest influence of 40.35% on tensile strength followed by layer thickness with an influence of 35.04% and lastly infill pattern with 12.89% influence of tensile strength.

Table 6. Analysis of Variance.

Source	DoF	Sequential SS	Adjusted MS	F-Test	P-Value	P %
Infill Pattern	2	8.407	4.203	1.1	0.476	12.89
Infill Density	2	26.325	13.162	3.44	0.225	40.35
Layer Thickness	2	22.855	11.428	2.99	0.251	35.04
Residual Error	2	7.645	3.823	-	-	11.72
Total	8	65.232	-	-	-	-



Signal-to-noise: Larger is better

Figure 8. Main effect plot for S/N ratio of infill pattern, infill density and layer thickness.

It was very clear that with increasing infill density and decreasing layer thickness the tensile strength of specimen was increasing. The infill density provides more material within the part thereby increasing the load capacity while reducing layer thickness improves the bonding between layers, strengthening the part. In term of infill pattern, Honeycomb structure provides the better stress distribution because the uniform shape of void within the entire part. Following Figure 9 shows the relation between parameters.

CONCLUSION

In this research paper, tensile strength of 3D printed ABS specimens with 3 different parameters, infill pattern, infill density and layer thickness were studied. The permutations of parameters to set the experiment were decided using Taguchi's method. Results of the experiment shows that optimal parameters for maximum tensile strength are Honeycomb infill pattern, 90% infill density and 0.09 mm layer thickness.

According to the Analysis of Variance (ANOVA) table, infill density has the maximum influence (40.35%) on tensile strength followed by layer thickness (35.04%) and infill pattern (12.89%) respectively.

The tensile strength of part increases with increase in infill density as there is more material to sustain the forces within the specimen. Results show that layer thickness also has significant influence on the strength because 3D printing is a layer-by-layer manufacturing method. Because of poor surface finish within each layer, the error becomes significant enough to cause a decline in mechanical properties.

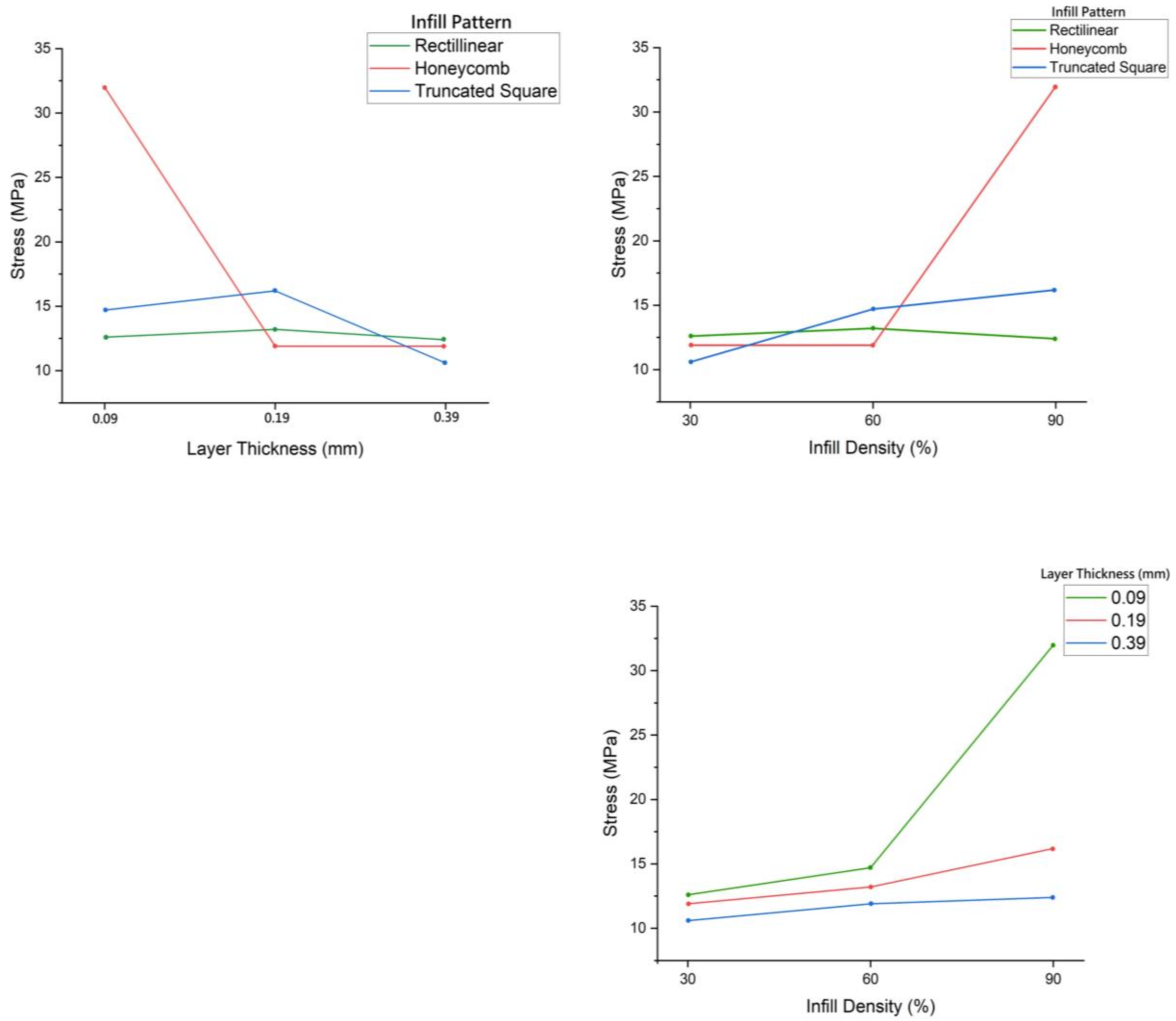


Figure 9. Interaction between parameters.

To accurately determine the optimal infill pattern, the specimens should be made at 10% infill density at 0.09 mm layer thickness. This is done to reduce the influence of layer thickness and infill density while concentrating on infill pattern. Surface roughness, compressive test, shear test and impact test can also be performed to feature the respective properties of 3D printed parts.

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