



The Effect of Process Parameters on the Compression Property of Acrylonitrile Butadiene Styrene Produced by 3D Printer

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HIGHLIGHTS

- Investigating the influence of printing parameters such as infill pattern (Tri-Hexagon, Zig - Zag, Gyroid), infill density (25%, 50%, 75%), and layer thickness (0.1, 0.2, 0.3 mm) on the compressive strength of 3D printed parts of acrylonitrile butadiene styrene ABS materials using fused deposition modeling (FDM) technology.
- Nine specimens were fabricated with different processing parameters using a commercial FDM 3D printer and then were tested according to the ASTM D695 standard.
- The dominant factor affecting on compressive strength is infill density whereas layer thickness has the least effect.

ABSTRACT

Additive manufacturing (AM) by Fused Deposition Modelling (FDM) provides an innovative manufacturing method for complex geometry components. 3D printers have become easily accessible to the public. The technology used by these 3D printers is Fused Deposition Modelling. The majority of these 3D printers mainly use acrylonitrile butadiene styrene (ABS) to fabricate 3D objects. This study aims to investigate the influence of some printing parameters like infill pattern (Tri-Hexagon, Zig - Zag, and Gyroid), infill density (25%, 50%, and 75%), and layer thickness (0.1, 0.2, and 0.3 mm) on the compressive strength of ABS materials. The design of the experiment was achieved by Taguchi method. A total of nine specimens were fabricated with different processing parameters using a commercial FDM 3D printer and then were tested according to the ASTM D695 standard. Findings presented in this research showed that the compressive strength of printed parts depends on the printing parameters employed. Analysis of variance revealed that the infill density is the most sensitive parameter among the three parameters examined. The optimal printing parameters were (0.3 mm 75 %, Gyroid) for improving compression strength according to signal-to-noise (S/N) ratio analysis. Experiment number (9) showed the highest compression strength with a value of 44.64 MPa.

ARTICLE INFO

Handling editor: Muhsin J. Jweeg

Keywords:

3D printing
FDM
Taguchi method
Compressive strength
ABS

1. Introduction

Additive manufacturing (AM) or rapid manufacturing is an advanced manufacturing technology due to its special characteristics of flexibility, simplicity, and portability [1]. Among the different techniques used for producing polymeric 3D printing parts, Fused Deposition Modeling is one of the most popular additive manufacturing techniques. It's a 3D printing technology widely known for its speed, accuracy, and competitive cost. Moreover, a wide range of structures and complex geometries can be produced using this technique.

In FDM, based on a computer-aided design (CAD) model of the component, a computer program is used to slice the model into single layers with a defined thickness that builds up the full geometry of the object [2]. The process involves creating a model using 3D CAD, converting the three-dimensional model to a Standard Tessellation Language (STL) file, slicing the (STL) file into a G-code file, and prototyping the part using FDM three-dimensional printer until the printed part is complete [3]. FDM is one of the most promising rapid prototyping techniques because of its ability to create a variety of complex geometrical shapes and structures in the shortest amount of time [4]. FDM has multiple print settings, such as infill percentage layer thickness build orientation, etc., which have a direct effect on the mechanical properties, dimensional accuracy, quality, and building time of the final 3D part [5].

The interaction of various process parameters and raw material properties determines the mechanical behavior of 3D printed pieces [6]. Layer thickness, another printing parameter selected during the printing process, controls the height of each printed layer. The layer thickness is a more controversial parameter, for which a study concluded that the optimal level of parameters for maximum performance of their object always involves the smallest layer thickness (0.178 mm) [7]. Another study found that as the layer thickness increased, the tensile strength of their specimen decreased at first, then it increased [8]. The effect of infill pattern on the behavior of ABS polymer when subjected to compression load with filling patterns has been selected (i.e. rectangular and hexagonal), and it was found that the best option was the rectangular pattern at 0° and 90° when the high compression force is required [9].

The effect of infill setting on compression strength was investigated using various infill geometries, including rectangular, triangle, diamond, and hexagon. The compression test results indicated that infill geometries have some effects on compression strength and the elastic modulus of 3D printed parts [10]. For another important parameter, namely the infill density, a paper reported that higher density resulted in fewer voids in the infill and, as a result, higher strength [11].

The aim of this research is to determine the optimum printing parameters for FDM 3D printer machine (i.e. infill pattern, infill density, and layer thickness) to fabricate ABS products with high compressive strength using the Taguchi approach. Furthermore, the most significant printing parameters that affect the 3D printing product's compression strength, as well as their interaction were investigated.

2. Experimental Procedure

2.1 Materials Used

The material used for printing is an Acrylonitrile butadiene styrene (ABS) as a filament with a diameter of 1.75mm provided from SUNLU industrial CO., LTD. ABS is a thermoplastic copolymer that has an amorphous structure containing acrylonitrile (A), styrene (S), and polybutadiene (PB) monomers. Its properties can be adjusted by varying the ratio of its components or fabricated by varying process techniques. Generally, ABS has good chemical resistance, aging resistance, mechanical properties, and high impact strength.

2.2 Selecting of process parameters

In this work, the ABS material was selected to fabricate samples. Fused Deposition Modelling (FDM) 3D printers were used to print all of the samples used in the experiments. With selected FDM parameters (infill density, infill pattern, and layer thickness) each with three levels of infill density levels which are (25%, 50%, and 75%), layer thickness levels which are (0.1, 0.2, and 0.3) mm, and infill pattern levels which are (Tri-Hexagon, Zig - Zag, and Gyroid), as shown in Figure 1. software Cura 4.8 was used for slicing.

- Infill density: is the amount of plastic used on the print's inside. More plastic is used on the inside of your print with a higher infill density.
- Layer thickness: is the thickness of each layer constituting the object.
- Infill pattern: is the internal structure and shape of a part's material. Infill patterns can affect a part's strength, weight, print time, and even flexibility. They can range from basic lines to more complex geometric shapes.

2.3 The Experiment Design

The Taguchi Technique, which incorporates the orthogonal array, allows the analysis of interactions among different parameters. For each experiment, different parameter combinations and their levels are given. Taguchi method employs special orthogonal arrays to investigate the quality characteristics of processes with a limited number of tests [12]. Taguchi approach is based on performing experiments to verify the affectability of response variables to a combination of control parameters by using an orthogonal array to obtain the best set of control parameters [13]. The L9 array was chosen for this experiment, and the levels of the parameter can be found in Table 1.

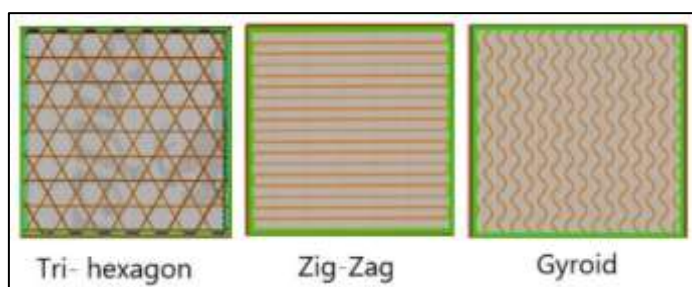


Figure 1: Selected types of infill pattern



Figure 2: FDM 3D printer machine



Figure 3: Compression test device



Figure 4: Deformation in samples of each run after being subjected to compression test

The signal-to-noise ratio (S/N ratio) is used to identify the control factor settings that minimize the variability caused by the noise factors [14]. The experimental factors that have the larger S/N ratio are represented as the optimal factors because a greater S/N ratio will result in a smaller product variance around the target value [15]. Since the goal of the experiment is to maximize the response. Therefore, the S/N ratio of static designs used for quality characteristics in this work was "Larger is better" calculated by the signal-to-noise ratio formula as shown in Eq. (1).

$$S/N = -10 * \log(\Sigma(1/Y^2)/n) \tag{1}$$

where y is the value of the response variable (compressive strength).

2.4 3D Printer Machine

Samples were printed through FDM machine (Creality Ender 3) as shown in Figure 2 with a nozzle diameter of 0.6 mm, extrusion temperature of 220 °C, bed temperature of 80°C, shell thickness of 1.4 mm, built orientation on flat raster angle [0°/90°], and printing speed of 100 mm/s. The material used for printing is Acro-Nitrile Butadiene Styrene (ABS) filament with a diameter of 1.75mm.

2.5 Compression Test

The samples for compression testing were prepared according to ASTM D695 standard of plastics as a block shape with dimensions of (12.7 x 12.7 x 25.4mm) [16]. The compression tests were conducted using a universal computerized testing machine as shown in Figure 3 with a 50 KN capacity and a crosshead speed of (5mm/min). Here, the compressive load was applied quasi-statically on the samples until failure. Figure 4 shows the nine ABS printed samples that were subjected to compression test, where each sample was represented by each experiment of the Taguchi orthogonal array.

3. Results and Discussion

The compression test results and S/N ratio for ABS 3D printed samples of all nine experiments are shown in Table 2. Each experiment of the orthogonal array was used to reflect each sample. Specimen that was printed with (75%, 0.2 mm, and Gyroid) of experiment number (9) showed the highest compression strength.

Table 3 indicates the relative effect of each parameter on compression strength according to the rank. The infill density parameter has the largest effect on compressive strength and the infill pattern and the layer thickness parameters have less effect, respectively.

Figure 5 shows the main effects plot for the S/N ratio. Based on the S / N ratio analyses, the optimum value for each parameter can be found regardless of the S/N ratio option (larger is better), and the highest SN ratio represents the optimized value. It is found that with the infill pattern, Gyroid has a higher effect on improving compressive strength while infill patterns zig-zag and tri-hexagon have a smaller effect, respectively.

Table 1: The L9 orthogonal array

Experiment No.	Parameter levels		
	Infill density (%)	Infill pattern	Layer thickness (mm)
1	25	Tri-hexagon	0.1
2	25	Zig-Zag	0.2
3	25	Gyroid	0.3
4	50	Tri-hexagon	0.2
5	50	Zig-Zag	0.3
6	50	Gyroid	0.1
7	75	Tri-hexagon	0.3
8	75	Zig-Zag	0.1
9	75	Gyroid	0.2

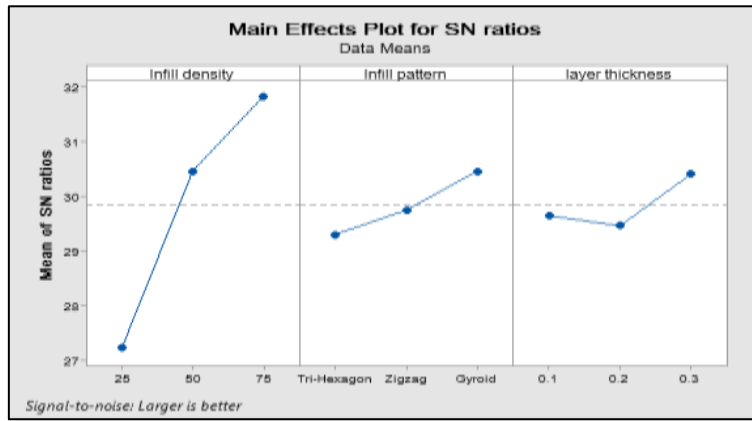


Figure 5: Plot of S/N ratio for compression strength of experiments

Table 2: Signal-to-noise ratio of Taguchi design of (L9) for compression strength

Experiment no.	Infill density	Infill pattern	layer thickness	Compressive strength (MPa)	S/N Ratio
1	25	Tri-Hexagon	0.1	23.42	27.3917
2	25	Zigzag	0.2	20.86	26.3863
3	25	Gyroid	0.3	24.76	27.875
4	50	Tri-Hexagon	0.2	28.22	29.0111
5	50	Zigzag	0.3	39.15	31.8546
6	50	Gyroid	0.1	33.61	30.5294
7	75	Tri-Hexagon	0.3	37.6	31.5038
8	75	Zigzag	0.1	35.52	31.0095
9	75	Gyroid	0.2	44.64	32.9945

Table 3: Response of signal to noise ratios for larger is better

Level	Infill density	Infill pattern	Layer thickness
1	27.22	29.30	29.64
2	30.47	29.75	29.46
3	31.84	30.47	30.41
Delta	4.62	1.16	0.95
Rank	1	2	3

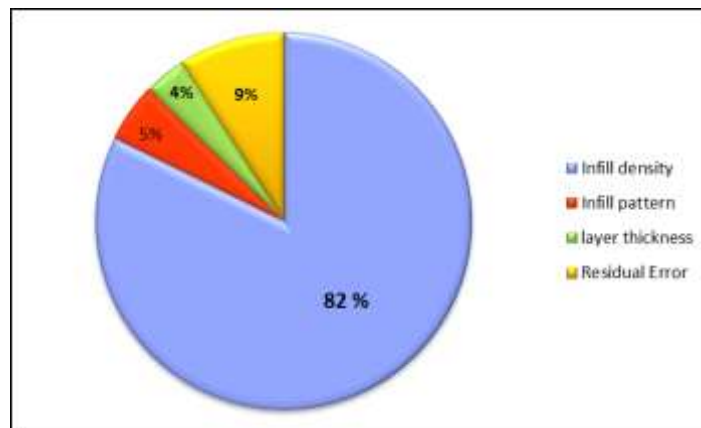


Figure 6: Percentage contributions of process parameters on compressive strength

Table 4: Analysis of Variance (ANOVA) for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution
Infill density	2	33.753	33.753	16.8763	9	0.1	82 %
Infill pattern	2	2.069	2.069	1.0343	0.55	0.645	5 %
layer thickness	2	1.519	1.519	0.7593	0.4	0.712	4 %
Residual Error	2	3.751	3.751	1.8755			9 %
Total	8	41.091					100

As the infill density percentage increases, the compressive strength will increase, and this is compatible with a study that reports that the mechanical properties improve when infill density increases, while less infill leads to a decrease in the mechanical properties of the printed part [17]. Also, the compressive strength will increase as layer thickness increased.

The optimal parameters of the process to achieve higher compressive strength were the layer thickness of 0.3mm, infill density of 75 %, and infill pattern of Gyroid.

From the results obtained from the analysis of variance for S/N ratios, we can find how much each factor contributed to the response (compressive strength) as tabulated in Table 4. The infill density has contributed to 82% while the infill pattern has contributed to 5%, and the layer thickness has contributed to 4 %, as shown below in Figure 6.

4. Conclusions

The optimum printing parameters of ABS materials in terms of compressive strength improvement were investigated in this study. The Taguchi method was used for the design of the experiment to reduce the number of experiments. A commercial FDM 3D printer machine was used to print ABS samples with different printing parameters such as layer thickness, infill density, and infill pattern. The results showed that the mechanical properties of the 3D printed product are largely affected by the process parameters showing an anisotropic behavior. It has been shown that the dominant factor affecting compressive strength is infill density whereas layer thickness has the least effect. The Taguchi method analysis showed that the optimal level for each parameter was the infill density of 75 %, the infill pattern of Gyroid, and the layer thickness of 0.3 mm for improving compressive strength.

Author contribution

All authors contributed equally to this work.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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