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A Decision-Making Model for FDM Printing Parameters Selection

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Abstract**:** *This study examines how printing parameters affect the mechanical properties of 3D-printed parts. It also introduces a decision-making model for selecting the best combination of printing parameters while multiple performance measures are considered. A 2^3-experiment was conducted with printing parameters of material type (ABS and PLA), layer thickness (0.14 mm and 0.29 mm), and infill pattern (regular and honeycomb), resulting in eight combinations of parameters. After then, a VIKOR-based decision-making model is introduced to select the best combination of the selected printing parameters. A standard tensile test is performed to determine the mechanical properties, while printing mass and time are obtained from the printer. VIKOR method stated that the best combination of printing parameters, leading to the best overall performance, is PLA material with a layer thickness of 0.14 mm and a regular infill pattern. This study offers a thorough decision-making model to choose the best printing settings.*

Keywords: *3D printing, FDM, Parameter Selection, DOE, Vikor*

1. Introduction

Additive manufacturing (AM) is a growing technology with a wide range of applications such as aerospace, automotive, healthcare, and product development [1]. 3D printing is an AM approach, which has the ability to generate complex geometries and customized parts with minimal waste and tooling costs [2]. The properties of 3D-printed parts by FDM are highly dependent on various printing parameters such as infill density, layer thickness, and infill geometry. Selecting the optimal combination of parameters is crucial for achieving the desired properties and qualities [3].

Design of experiments (DOE) methods are used to systematically vary the printing parameters and analyse their effects on the obtained mechanical properties, such as hardness, tensile strength, and fatigue life [4]. Taguchi method, analysis of variance (ANOVA), and multi-objective methodologies were also used to optimize properties of 3D printed PLA parts including ultimate tensile strength (UTS) and elongation at break, while minimizing weight and printing time [5]–[7]. Finite element analysis (FEA) was utilized to mimic the printing process and determine the mechanical properties based on the material behaviour and printing parameters [8]. Neural networks and support vector regression were utilized to establish empirical models of the mechanical properties of printed parts as a function of particular printing parameters [9].

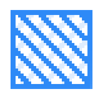
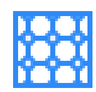
Multi-criteria decision making (MCDM) methods can be used to identify the most appropriate printing parameters for achieving desired qualities of printed parts while considering multiple attributes simultaneously [10]. Analytical hierarchy process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods were used to optimize the printing parameters of FDM for printing a gear model [11]. A VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)-based decision model was introduced to optimize printing parameters of infill percentage, layer thickness, speed, and bed temperature with multiple objectives such as filament weight, length and printing time [12]. VIKOR was also used to optimize layer thickness, infill percentage, and speed while considering printing time, filament length, and weight [13]. VIKOR approach was employed to select a 3D printer for a particular product [14].

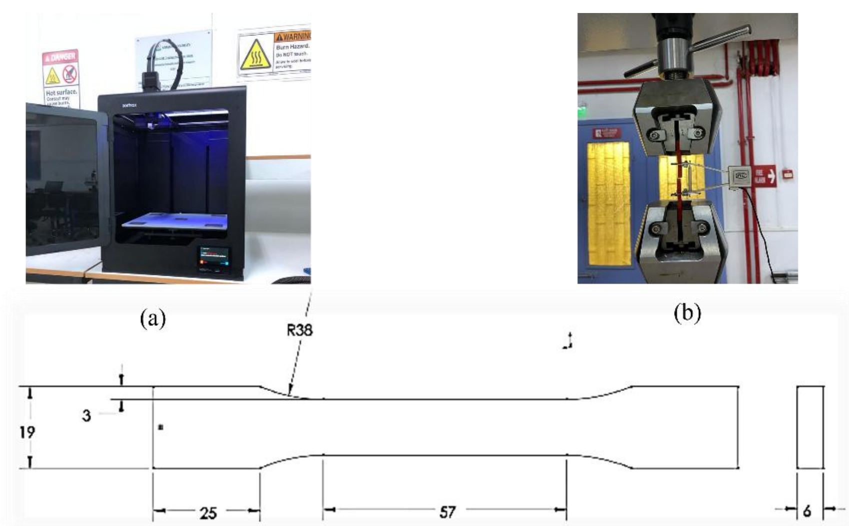
In this paper, the effects of layer thickness, material type, and infill pattern will be investigated with insights into the resulting mechanical properties, mass, and printing time. After then, VIKOR technique will be used to select the best printing setting.

2. Methodology

A 2^3 experiment was designed with two levels for each printing parameters as shown in Table I. This design resulted in eight distinguished combinations of printing parameters with three specimens printed together under each combination. The specimens were printed using Zortrax M300 plus printer with an infill density of 50% for all specimens. The printed specimens were then tensile tested for the determination of the mechanical properties. Printing time and mass were estimated by the printer. The experimental setup is shown in Figure 1.

TABLE I: Levels of Printing Factors.

Factor	**Low level**	**High level**
Layer thickness	0.14 mm	0.29mm
Infill pattern	 Regular	 Honeycomb
Plastic type	ABS	PLA



(c)

Fig 1. Experimental setup: (a) Zortrax M300 plus printer (b) Tensile testing machine (c) Standard specimen [15]; all dimensions in mm

Table II shows the responses collected for each specimen. ANOVA will be conducted to investigate the impact of printing parameters on these responses. After then, VIKOR method will be applied to select the most suitable combination of printing parameters leading to the best overall performance of printed parts. Detailed steps of VIKOR can be found in [16].

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TABLE II: Responses and their Definitions.

Response	Definition
Printing Time	Time taken to print three specimens
Weight	Weight of the printed specimens
UTS	Maximum stress the specimen can withstand before breaking
Ductility	A measure of the specimen's ability to undergo plastic deformation
Elasticity	The ability of the specimen to restore its original shape after deformation
Yield Strength	The stress at which the specimen begins to deform plastically

3. Results

ANOVA was carried out to investigate the effect of printing parameters on performance measures. Proper transformation was used based on the Box-Cox method to attain normality assumptions if needed. The main effects of each parameter on all responses are shown in Table III. P-values less than 0.05 indicate a significant effect while P- values between 0.05 and 0.1 indicate marginal significant effect. For each parameter with significant effect, response values were compared at the two levels. As for the printing time, it was shown that increasing the layer thickness reduced printing time. Using the regular infill structure resulted in lower printing time. In addition, the use of ABS as printing material resulted in lower printing time compared to PLA.

TABLE III: The ANOVA Table for P-Values of the Factors.

Responses	P-value of the factors		
	Layer thickness	Infill pattern (structure)	Plastic type
Printing time	< 0.0001*	0.0002*	0.0010*
Weight	0.0903**	0.0903**	0.0193*
UTS	0.0911	0.0993	< 0.0001*
Ductility	0.5198	0.1506	< 0.0001*
Elasticity	0.0084*	0.4097	0.0206*
Yield strength	0.1041	0.0198*	< 0.0001*

As for the weight of printed specimens, the low level of layer thickness, a honeycomb infill structure, and the use of ABS material produced lower weight of printed specimens. The plastic type was the only factor with significant effect on the UTS and ductility with higher values record at PLA type. As for elasticity, lower layer thickness resulted in higher magnitude. The use of ABS resulted in higher elasticity compared to PLA. Infill pattern and plastic type had significant effect on the yield strength with higher magnitude resulted from regular infill structure and PLA plastic.

Each printing parameter is shown to affect at least one response, indicating the viability of building alternative combinations based on these parameters' levels. To further understand the effect of printing parameters on performance measures, all possible combinations of parameters were evaluated. Table IV shows the best combination for each response with the associated average value. This helps users select the best printing setting for a particular performance measure. It is shown that no combination can enhance all responses simultaneously. This indicates the need for a method to identify the combination of printing parameters leading to the best overall performance.

TABLE IV: Best Combinations of Factors for the Desired Responses.

Response	Best Combination	Average Value
Printing time	ABS, 29, Regular	144 min
Weight	ABS, 14, Honeycomb	38 g
UTS	PLA, 29, Regular	21.701 MPa
Ductility	PLA, 14, Regular	8.606
Elasticity	ABS, 14, Regular	10.085 MPa
Yield strength	PLA, 29, Regular	21.623 MPa

To determine the combination with the best overall performance, VIKOR method is applied. Table V shows the ranked alternatives; the smaller value of Qi is associated with the best alternative combination. The combination of PLA, 0.14 mm layer thickness, and regular infill structure outperforms the remaining combinations, as it possesses the best overall performance in terms of fulfilling necessary requirements. This combination can be classified as the most efficient option with respect to the overall performance measure.

TABLE V: Best Combinations of Factors in VIKOR Approach.

Best Combination	Qi	Rank
PLA, 0.14, Regular	0	1
PLA, 0.14, Honeycomb	0.166909	2
PLA, 0.29, Regular	0.384615	3
ABS, 0.14, Regular	0.518431	4
PLA, 0.29, Regular	0.538462	5
ABS, 0.29, Honeycomb	0.692308	6
ABS, 0.14, Honeycomb	0.846154	7
ABS, 0.29, Regular	1	8

4. Discussion and Conclusions

A 2^3 experiment was conducted to explore the effect of printing parameters on performance measures of UTS, ductility, elasticity, yield strength, printing mass, and printing time. Additionally, VIKOR decision-making technique was employed to select the best combinations of printing parameters. Printing time increases when the layer thickness was set to 0.14 mm, indicating that precision and finer details come at a cost of longer printing time. Regular infill pattern required less time than the honeycomb, demonstrating that choosing the appropriate infill pattern can help speed up the printing process. ABS material was reported to take lesser printing time than PLA. Lighter printed specimens were produced by using ABS material, honeycomb infill structure, and low layer thickness. This suggests that users might build lightweight parts by modifying these parameters to suit applications where weight reduction is essential.

In fact, the problem of selecting an alternative combination of printing parameters is a complex problem with multiple contradicting performance measures. For instance, using the regular infill pattern leads to reduce the printing time while increasing printing weight. A layer thickness of 0.14 mm needs longer printing time and results in higher UTS. Given the fact that no combination can optimize all responses simultaneously, as shown in Table 4, trade-offs should take place in case of having multiple performance measures. VIKOR can deal with such problem effectively with an ability to rank combinations of printing parameters in a wise manner. The best combination was to use PLA material, 0.14 mm, and regular infill pattern. Layer thickness of 0.14 mm can improve the structural integrity and strength of the printed specimens. Additionally, compared to other plastic types, PLA can result in better UTS, ductility, and yield strength.

This study provides a guideline on how various printing parameters affect the properties of 3D-printed parts. A systematic approach for selecting the best combination of printing parameters was employed. The results can aid in enhancing the quality and functionality of 3D-printed components in a variety of applications and industries.

The study was limited to three printing parameters with two levels for each. The use of the 2^3 factorial design, however, was adequate for the purpose of the study to explore the behaviour of performance measures with printing parameters. For future work, more printing parameters with more levels can be considered. Sensitivity analysis can also be conducted to further understand the effect of user's preferences on the process of selecting a combination of parameters for a particular application.

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