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Abstract. The 3D printing method (additive manufacturing) is one of the manufacturing technologies for producing parts with faster, more flexible, and relatively lower-cost procedures compared to conventional methods, one of which is Fused Deposition Modeling (FDM). A primary challenge often encountered during the 3D printing process using the FDM method is the engineers' lack of knowledge in optimizing three machining parameters (nozzle temperature, printing speed, and infill pattern) to enhance the mechanical properties and quality characteristics of FDM-type 3D printed parts. The hybrid Taguchi method is employed in this paper to obtain optimal printing parameters. The L9 (33) orthogonal array layout is selected and utilized to obtain optimal printing response results. The outcomes indicate that the maximum Tensile test achieved is 20.7 MPa with a combination of parameters: nozzle temperature of 280°C, printing speed of 40 mm/s, and a grid infill pattern.

Keywords: additive manufacturing, FDM, Taguchi, mechanical properties of materials

1. Introduction

Nowadays, the use of 3D printing methods in the manufacturing industry makes it possible to manufacture parts with procedures that are faster and more flexible than conventional manufacturing processes such as CNC-based machine tools. This method is known as additive manufacturing with a working system of stacking materials to create 3-dimensional objects. One of the 3D printing methods that is often used is Fused Deposition Modeling (FDM) as explained 1. Apart from that, this method can also be used to create objects with high complexity at relatively low cost 4. The results of 3D printing products can also be used as final products and not just as prototypes 5. Various manufacturing industries such as automotive, aerospace, medical, mechanical, electrical, electronics, education, and many others are now also taking advantage of 3D printing. 6.

One material that is often used in 3D printing is nylon carbon fiber filament because it combines strength and lightweight. The addition of carbon fiber can significantly increase the strength, stiffness, and hardness of nylon, so it can replace metal materials in many applications 8.

An important mechanical specification of 3D printing is tensile strength. Tensile strength whose value is known by tensile testing is the most common among other mechanical property tests 9.

Parameters that influence the tensile strength of 3D printing products include raster orientation, raster width, air gap, infill density, number of shells, layer thickness, build orientation, infill pattern, print speed, and extrusion temperature 10. The results of the initial investigation carried out are presented in the form of a fishbone diagram in Figure 1.

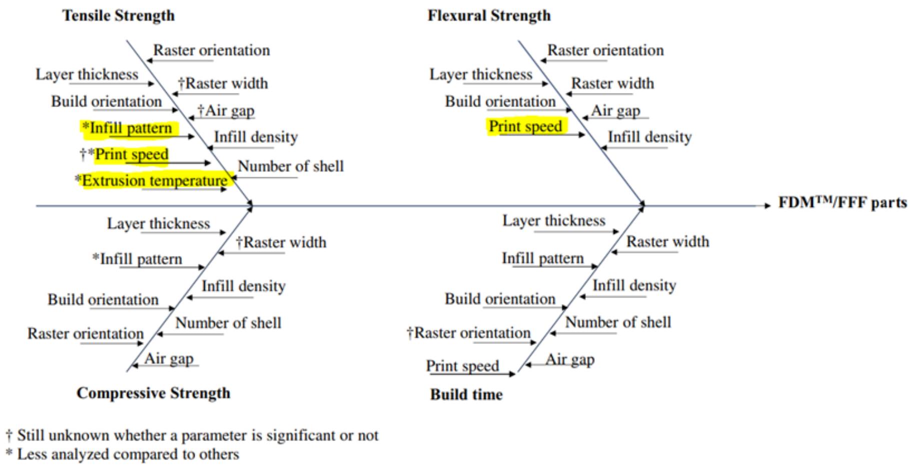


Fig 1. Parameters Influence of FDM 3D printing

On all 3D printing machines, nozzle temperature has a significant effect on tensile strength. The results showed that the tensile strength increased with increasing nozzle temperature. This shows that the melting temperature of the filament affects the filament bonding 1012.

The printing speed parameter influences the melting and hardening process of the filament. In addition, printing speed affects the extrusion rate, placement of the melted polymer, and the quality of the printed part. Setting a suitable printing speed can improve the layer bonding and mechanical strength of the printed product 1415.

The infill pattern parameters also influence the production of hollow products that are lighter, cheaper, faster to make, and still have the required mechanical properties. The infill pattern allows control over the level of stiffness of the printed object. In some applications, such as prototyping or structural components, different levels of stiffness may be required. Some infill patterns can provide additional rigidity, while others produce more flexible objects 1617

Because AM technology is affected by many process parameters and currently has high costs, the quantity and cost of full factorial method experiments would be quite large, the Taguchi method has been widely used to optimize process parameters in product design through comprehensive experimental investigations 18. The Taguchi experimental design method was applied to reduce the number of experiments and find optimal parameters for maximum mechanical properties, minimum weight, and minimum printing time 19. Auffrey, et.al. (2022) conducted research using DoE Taguchi to analyze the 7 parameters that most influence Young's modulus, namely infill pattern, layer height, infill density, printing velocity, raster orientation, outline overlap, and extruder temperature 11. Meanwhile, Timoumi, et.al. (2021) used Taguchi to examine the influence of nozzle, bed, and radiant temperatures as well as printing speed and layer thickness on the tensile properties of three-dimensional printed polyether ether ketone 20.

However, several previous studies 919 indeed state that nozzle temperature, printing speed, and infill pattern are important parameters that influence the mechanical properties of 3D printing results, but no one has focused on doing this simultaneously on nylon-carbon fiber filament material.

This paper comprehensively aims to identify and determine optimal machining parameter optimization on a 3D print-type FDM machine with NCF material to obtain maximum tensile strength.

2. Material and Methods

The samples were produced using FFF carbon fiber reinforced nylon (ePA-CF) produced by Shenzhen Esun Industrial Co., Ltd. The filament had a print temperature specification ranging between 260 ℃ and 300 ℃ and had a diameter of 1.75 mm 10. The experiment was conducted using the standard specimen and test method for tensile properties of plastics from ASTM D638-10 as shown in Figure 2.

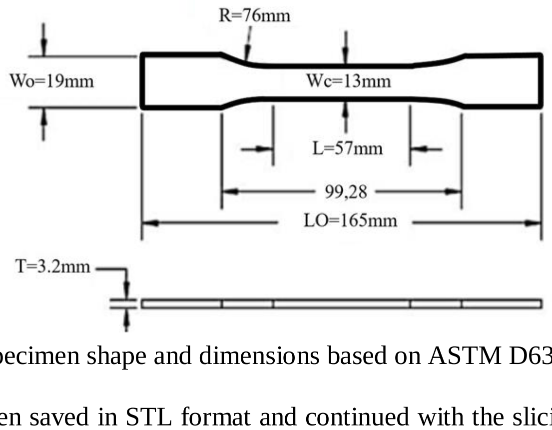


Fig 2. Specimen shape and dimensions based on ASTM D638 standards

The image is then saved in STL format and continued with the slicing process using

Prusa Slicer. The constant parameter applied to the printing process is the nozzle diameter of 0,4 mm and 80 °C of bed temperature with pre-drying treatment of the filament at a temperature of 70°C for 12 hours before and during the printing process. Three 3D print FDM machining parameters play an important role in improving material characteristics in this paper, namely: nozzle temperature, printing speed, and infill pattern. The printing parameters recommended by the material are with nozzle temperature of 260-300 °C and a printing speed of 40-100 mm/s. Because the nozzle temperature and printing speed are still a range, this is why in this paper an investigation is carried out to obtain the best parameter values. The parameters to be tested are shown in Table 1.

Table 1. Printing parameters

Parameter	***Nozzle Temperature***	***Printing Speed***	***Infill Pattern***
	°C	**mm/sec**	***type***
Level 1	260	40	*Triangle*
Level 2	280	70	*Grid*
Level 3	300	100	*Honeycomb*

Lay out the experimental design in this paper using the hybrid Taguchi method by entering 3 machining parameters (extruder temperature, printing speed, and pattern type) as independent variables that will influence the measured response data. Orthogonal Array (OA) L_9 (3^3) in Table 2 was selected and determined in this experiment to obtain response data in tensile strength.

Table 2. Design of L_9 (3^3) orthogonal array

No.	**Nozzle Temperature**	**Printing Speed**	**Infill Pattern**	**UTS Mean**	**STDev**	**S/N Ratio**
	°C	**mm/sec**	***type***	***Mpa***		***MPa***
1	260	40	*Triangle*	19,4	0,29	25,7620
2	260	70	*Grid*	20,1	0,63	26,0517
3	260	100	*Honeycomb*	18,6	0,44	25,3827
4	280	40	*Grid*	20,7	0,89	26,3045
5	280	70	*Honeycomb*	19,6	0,26	25,8518
6	280	100	*Triangle*	19,8	0,39	25,9458
7	300	40	*Honeycomb*	20,0	0,16	26,0024
8	300	70	*Triangle*	19,0	0,68	25,5764
9	300	100	*Grid*	20,2	0,46	26,1004

In general, the methodology flowchart of this paper can be presented in Figure 3.

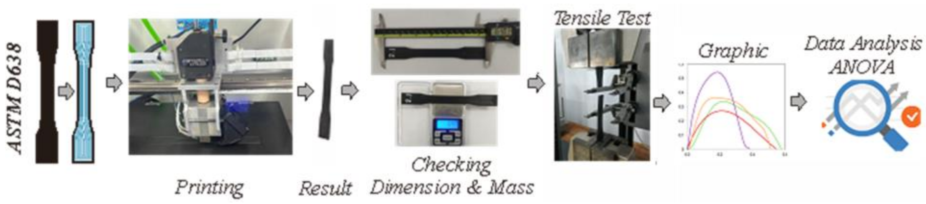


Fig 3. Flowchart of experiment

3. Result & Discussion

From Table 2 it can be seen that the response measured is ultimate tensile strength by calculating the S/N ratio in the larger is better category. The table also shows that the standard deviation is quite large. This happened because there were quite significant deviations in the test results for each of the 5 samples. The minimum and maximum test results are quite far apart, so they overlap with the test results of other specimens. The S/N ratio graph along with the standard deviation value is shown in Figure 5.

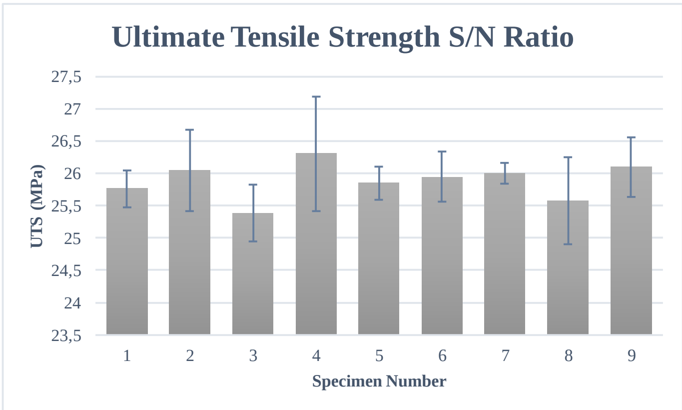
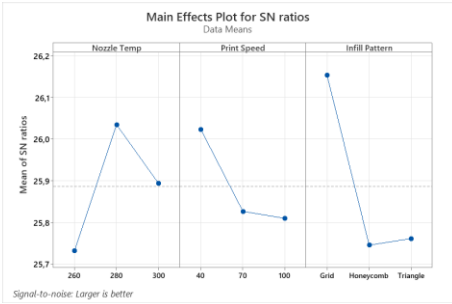


Fig 4. SN Ratio of ultimate tensile strength

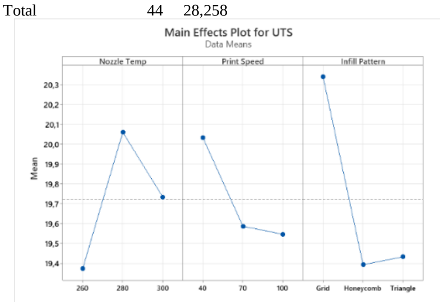
Based on the graph, it is found that the UTS value from 3D printing for nylon carbon fiber filament material is at an average value of 18.6 – 20.7 MPa. The highest UTS results were obtained for specimens number 4, 9, and 2, all of which have the same type of infill pattern in the form of a grid with varying nozzle temperature and printing speed values. ANOVA was used to examine the importance of each process parameter as well as the relationships between the factors that were evaluated. Specifically, ANOVA is utilized to ascertain the significance of the model, the impacts of individual elements, and their interactions, finally assessing the accuracy of the generated model. 2122. Data analysis uses Anova to help draw conclusions. The results of the Anova analysis are shown in Figure 6.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Nozzle Temp	2	0,13691	0,06846	1,49	0,402
Printing Speed	2	0,08435	0,04217	0,92	0,521
Infill Pattern	2	0,31827	0,15913	3,46	0,224
Error	2	0,09187	0,04593		
Total	8	0,63140			



(a)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Nozzle Temp	2	3,539	1,7696	4,83	0,014
Print Speed	2	2,190	1,0949	2,99	0,062
Infill Pattern	2	8,599	4,2996	11,73	0,000
Error	38	13,930	0,3666		
Lack-of-Fit	2	1,990	0,9949	3,00	0,062
Pure Error	36	11,940	0,3317		
Total	44	28,258			



(b)

Fig 5. Analysis of Variance and Main effects plot for a. S/N ratio and b. Data Mean

Figure 6 shows that the p-value calculation between the S/N Ratio value and the average value is different. In the S/N ratio, the three parameters, namely nozzle temperature, printing speed, and infill pattern, have P-values far exceeding 0.05 with a confidence interval of 95% so that all parameters do not have a significant effect on the tensile test results. However, if based on the average value, the p-value of the nozzle temperature and infill pattern is better, namely <0,05, only the print speed exceeds 0.05. This value was obtained by analyzing all tensile test measurement results, namely 45 test samples. Lack of fit also shows a fairly high number with a p-value of 0.062 which can be caused by other important parameters that determine the tensile strength value but are not regulated in the controlled parameters.

The main effects plot for both, namely the SN Ratio value and the average value, shows the same analysis results, namely the large influence of nozzle temperature, printing speed, and infill pattern on tensile strength. The right nozzle temperature affects the bond strength of nylon with carbon fiber which will increase the tensile strength value 22. From this data, it can be concluded that to achieve maximum UTS, the recommended printing parameters are nozzle temperature 280°C, printing speed 40 mm/s, and infill pattern in the form of grid. An increase in tensile strength can be achieved by reducing printing speed. A high printing speed setting may result in inadequate layer bonding, reducing the product's mechanical strength 21. Meanwhile, the infill pattern in the form of grid is the most suitable type of infill pattern for maximum resistance to tensile forces, this is in accordance with previous research conducted by Ambati, et.al. (2022) 24.

4. Conclusion

It is crucial to understand the relationship between process variables and the mechanical performance of nylon carbon fiber filament. This study examined the effects of various printing parameters in combination, with the tensile strength of specimens based on ASTM D638 standard. These parameters—(i) nozzle temperature (ii) printing speed (iii) infill pattern—were chosen for this work based on the literature reviews. The L_9 (3^3) Taguchi orthogonal array was utilized in conjunction with a three-level fractional factorial design to minimize the number of experimental runs.

1) The apparent tensile strength of all the various permutations of the L_{27} array had minimum and highest mean values of 18,6 – 20,7 MPa, respectively.
2) It was demonstrated that the interaction between the process parameters for tensile strength named nozzle temperature, printing speed, and infill pattern was important to achieve the maximum tensile strength.
3) To achieve the maximum tensile strength, the recommended printing parameters are a nozzle temperature of 280°C, a printing speed of 40 mm/s, and a grid infill pattern.

Numerous 3D process technologies can be readily integrated with the methodology employed in this paper. Potential directions for future research include developing a model to help designers achieve custom-made or robust mechanical qualities with little volatility and uncertainty. The evaluation of specimen mechanical characteristics is contingent upon the consideration of scalability effects, as FDM/FFF printing parts are composed of highly orthotropic materials. These are the paths that further research will take.

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