EXPERIMENTAL INVESTIGATIONS OF TENSILE STRENGTH AND PRINTING TIME OF 3D PRINTED SPECIMENS BY USING TAGUCHI ROBOST DESIGN METHODOLOGY

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Abstract - Fusion Deposition Modelling (FDM) is a filament extrusion based process that integrates CAD system, materials science, computer numerical control, and the extrusion process to fabricate 3D parts directly from a CAD model. In the basic FDM process, a plastic filament is drawn into a liquefier head, where the filament is heated to a semi liquid state and then extruded through a nozzle to deposit roads or beads to fill each layer of the part on to a platform in a temperature-controlled chamber. The computer controlled head moves in X–Y plane while the platform moves in the z-direction as required by the selected layer thickness. The main process parameters include slice height (layer thickness), model tip diameter, model build temperature, part fill style, part interior style, raster width, raster angle, and raster air gap. In this work the effect of FDM parameters, viz., layer thickness, print temperature, infill density and infill pattern on tensile strength and printing time of Carbon fiber PLA will be studied. The printing process will be done by considering three levels for each parameter and a full factorial design of experiments (34) will be conducted. The tensile test data will be analysed by conducting ANOVA and Regression Equation will be generated to obtain optimum tensile strength and optimum printing time.

Key Words: 3D Printing, Fused Deposition Modelling, Tensile strength, Taguchi Methodology, ANOVA.

1. INTRODUCTION

The method of producing an object layer by layer is known as additive manufacturing. It is the reverse of subtractive manufacturing, which involves removing little amounts of a solid block of material at a time until the finished item is produced. Technically, the term "additive manufacturing" can apply to any procedure that involves building up a product, like moulding, although it usually refers to 3-D printing. In the 1980s, prototypes made using additive manufacturing for the first time were often non-functional, because it enabled for the creation of a scale model of the final product fast and without the usual setup time and expense associated with producing a prototype, this method was known as rapid prototyping. Rapid tooling, which was used to make moulds for finished items, was added to the uses of additive manufacturing as technology advanced. Early in the new millennium, practical goods were being made via additive manufacturing. Recently organizations like Boeing and General Electric have started integrating additive manufacturing into their operational procedures.

The most popular polymer materials for 3D printing and their tensile strengths are as follows:

ABS	33MPa,	4,700psi
Nylon	48MPa,	7000psi
PLA	50MPa,	7250psi
PC	68MPa,	9800psi
PEI	81MPa,	11,735psi

Fused Deposition Modelling (FDM)

A kind of 3D printing known as fused deposition modeling (FDM) comes within the broad category of material extrusion. These procedures include heating a thermoplastic substance to a pliable condition before depositing it layer by layer onto a build plate or printer bed. The word Fused Filament Fabrication (FFF) is often used to refer to Fused Deposition Modeling (FDM), while the latter term is more frequently connected with industrial production equipment. FFF is frequently used to refer to less costly, home-use 3D printers. FDM machines often used heated printer chambers, but FFF printers did not have this feature in order to provide a more affordable design. This is another difference between these two terminologies. Stratasys, the company that created it, has trademark and patent protection for the first FDM name. However, since these patent protections have expired, the lines between the names FDM and FFF have become much more hazy, and in many cases, they now effectively refer to the same fundamental technique.

Most individuals initially come across an FDM printer while learning about 3D printing. These machines, which were among the first kinds of 3D printers on the market and now rule the industry as a cheap but very powerful additive manufacturing tool. FDM printers are programmable extrusion devices that convert CAD models into actual physical components. They do this by first converting CAD files into file formats that are compatible with 3D printers, typically .STL files that split the model into layers (this is also accomplished by specialized software known as "slicers" or slicing software). Then, one at a time, these layers are printed onto a build platform using a meltable material and a controlled nozzle. The construction platform descends gradually after each layer is placed to make room for the next layer. Once every layer has been printed, the component is complete, and the user is left with a 3D part that corresponds to their CAD file.

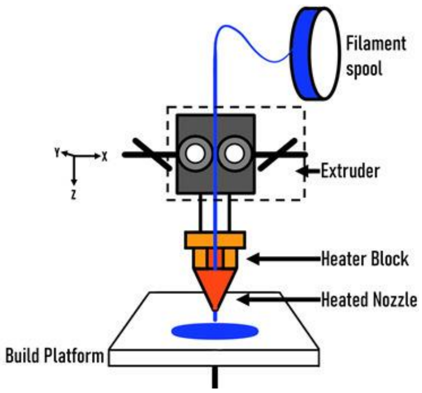

Figure: 1.1: Fused Deposition Modelling

The most popular 3D printing filament for FDM machines is Poly Lactic Acid (PLA), which is also a biodegradable filament. The most common source of PLA is poly lactic acid. Printing with PLA is relatively simple and doesn't need a heated bed. Because PLA has a limited strength capability under stress, it was chosen above alternative brittle materials [5]. Polylactic Acid (PLA) characteristics PLA is tougher than ABS, melts at a lower temperature (2100 C) than ABS, heated beds are not required, and nozzle temperatures are kept between 190 and 2150 C. Physical characteristics are crucial; one has to be aware of the needed dimensions, sizes, and weights for a desired component or product. For instance, if employed by a surgeon, it must be light enough to handle exactly because lighter materials make implementation more simpler and less dangerous.

2. LITERATURE REVIEW

Ankita Jaisingh Sheoran and Harish Kumar (1) Title: Fused Deposition modeling process parameters optimization and effect on mechanical properties and part quality: Reviewing recent research and reflecting on it. In order to improve mechanical characteristics, construction time, component quality, and other output reactions, this article will examine recent research on statistical and experimental design methodologies. Only certain values, not any value, within a specified range of minimum and maximum layer thickness, are permitted for FDM machines' layer thickness. Some particular standard values for layer thickness include, for instance, 0.127 mm, 0.1778 mm, 0.25 mm, 0.35 mm, etc. The extruder nozzle tip sizes are standard for FDM machines as well, therefore any random intermediate value cannot be taken into account for optimization.

Cristina Vălean. et. Al (2) Title: Effect of manufacturing parameters on tensile properties of FDM printed specimens. The tensile characteristics of specimens 3D produced using FDM printing are investigated experimentally in this work. Investigated were the effects of size effect (various thickness) and spatial printing orientation (0°, 45°, 90°) on key mechanical parameters. All tensile tests were conducted using dog bone specimens made of polylactic acid (PLA). Observational experiments were conducted in accordance with ISO 527-1 Standard at room temperature. It was shown that the spatial orientation has a greater impact on tensile strength and less impact on the Young's modulus. Additionally, as the number of layers increases, the tensile strength and Young's modulus also decrease.

Atefeh Rajabi Kafshgar et. al. (3) Title: Optimization of Properties for 3D Printed PLA Material Using Taguchi, ANOVA and Multi-Objective Methodologies. Using design of experiments (DOE) techniques, this study intends to shed light on how FDM process factors affect the mechanical characteristics of printed items. Infill density, extrusion temperature, raster angle, and layer thickness are some of the input design factors that are taken into consideration as variables in order to explore the impact of process parameters on the tensile qualities of 3D printed Polylactic Acid (PLA) material. The relationship between mechanical properties (like ultimate tensile stress, yield strength, modulus of elasticity, toughness, and elongation at break) and process parameters is investigated using the Taguchi optimization methodology and ANOVA. Finally, the investigated mechanical properties were optimized, and the suitable levels of printing process parameters were suggested by regression equations and mathematical modeling. The optimal 3D printing input parameters for the tensile strength and toughness values were found to be an infill density of 60%, an extrusion temperature of 200oC, a raster angle of 45/-45, and a layer thickness of 0.2mm. Similar to this, 60%, 220°C, 0/90, and 0.1mm were found to be the ideal input values for optimizing the other examined strength attributes.

Jasgurpreet Singh Chohan et. al (4) Title: Optimization of FDM Printing Process Parameters on Surface Finish, Thickness, and Outer Dimension with ABS Polymer Specimens Using Taguchi Orthogonal Array and Genetic Algorithms. In this research, acrylonitrile butadiene styrene (ABS) is printed using an FDM printer to examine the impacts of different altering factors on surface roughness and thickness measurement, including nozzle temperature (° C), infill pattern, and printing speed (mm/s). The Taguchi L9 orthogonal array technique and the ANOVA approach are used in the experiment design. The component that contributes the most to an increase in surface roughness is printing speed (83.41%), while the influence of nozzle temperature is 9.04%. Reduced printing speed improves surface smoothness, and results are almost consistent for all printed samples' thickness and exterior dimensions. The single-objective equations are created using regression analysis, and the values of the process parameters are optimized using a genetic algorithm (GA).

Ge Gao et. al. (5) Title: Parametric Optimization of FDM Process for Improving Mechanical Strengths Using Taguchi Method and Response Surface Method: A Comparative Investigation. : The Taguchi method and the response surface method (RSM), two popular optimization techniques for fused deposition modeling (FDM), were compared in the current work. Tensile strength and compressive strength were chosen as the response, and four operational parameters—extrusion temperature, layer thickness, raster width, print speed, and their interaction terms—were defined as control variables with three levels. Taguchi and RSM experiments were conducted using L27 orthogonal array and face-centered central composite design (FCCCD), respectively. The ideal FDM parameter combination and the primary factor affecting the performance of the PLA samples were determined using the signal-to-noise (S/N) ratio and analysis of variance (ANOVA). The findings concerning the important ranking of parameters on the FDM process from these two methodologies were found to be different based on the experimental results. However, compared to the control groups, both the Taguchi technique and RSM are successful in forecasting improved outcomes. Additionally, the RSM's best combinations for tensile strength and compressive strength were, respectively, 2.11% and 8.15% greater than those from the Taguchi approach.

Abhinav Chadha et.al (6) Title: Effect of fused deposition modelling process parameters on mechanical properties of 3D printed parts. This study examines how the bed temperature, primary layer thickness, and infill pattern (rectilinear, honeycomb, triangular) affect the mechanical properties of tensile strength and bending strength of 3D printed parts. The findings show that as bed temperature increases, tensile strength and flexural strength increase initially before decreasing. Tensile strength and flexural strength both rise with a main layer's thickness increase. Triangular and honeycomb infill designs have higher tensile and flexural strengths than other types of infill patterns.

Marcelo Tulio Piovan & Patricio G. Riofrío (7) Title: Behavior of Influencing Parameters of the Fused Deposition Modeling Process in Dissimilar Combinations: Polymer-3D Printer. In this study, two distinct material and FDM printer combinations are used to analyze the mechanical characteristics of common polymers, comparing a low-cost combination with a more expensive one. Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) polymers' modulus of elasticity and tensile strength are assessed using standardized ASTM and ISO tests that take into account the impact of the infill density, layer thickness, and filament color. It was primarily discovered that the influence of filament color produces the largest range of variation, between 3% and 19% in the mechanical properties, and that the increase in layer thickness generates appreciable reductions in the modulus of elasticity and tensile strength in the range of 12-17% considering the two polymers. The greatest values in the preceding ranges correlate to PLA polymer, and the lowest values to ABS polymer; this may be because the two polymers are of different quality levels.

3. METHODOLOGY

To ensure that the experimental data is collected under the best possible circumstances, this study employs the Taguchi robust design technique. Results for the Analysis of Mean (ANOM) and Analysis of Variance (ANOVA) are obtained using the statistical program Minitab 15.0. In order to authenticate the findings, the confirmation test is carried out under ideal circumstances. The foundation of the engineering design activity is knowledge of scientific phenomena and prior experience with comparable product designs and production techniques. However, a lot of engineering work is expended on carrying out experiments (either with hardware or by simulation) to generate the data necessary to inform these decisions. These decisions relate to the specific design, the process architecture, and the parameters of the manufacturing processes. Meeting marketing deadlines, keeping development and production costs low, and having high-quality goods all depend on how efficiently this information is produced. An engineering technique called robust design aims to increase productivity throughout design and development so that high-quality goods may be manufactured affordably.

Signal-to-Noise ratio (S/N ratio):

To assess a system's performance, Dr. Taguchi created the notion of the Signal-to-Noise ratio in resilient design. This is a translation of the data to a different value that represents a measurement of the level of variation. The S/N ratio shows how predictable a process or product performs in the presence of noise effects. The variation of predictable performance and the variance of unexpected performance are combined into a signal measure via the S/N ratio.

In order to make performance less vulnerable to noise effects and hence increase product quality, robust design improves the S/N ratio in the area of control factor. Depending on the kind of feature, there are three significant forms of S/N ratios.

- Smaller the better
- Larger the better
- Nominal the best

Smaller-the-better type:

The quality attribute in this case is continuous and non-negative, meaning that it may take any value between 0 and. Zero is the preferred value. Examples of this kind include the number of surface flaws, air pollution from power plants, EM radiation from telecommunications networks, and metal corrosion, among others.

$$\text{S/N ratio } (\eta) = -10\log_{10}(\text{mean square quality characteristic})$$

$$-10\log_{10}\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n} {y_i}^2\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

where,

n: no. of tests in trial (no. of repetitions regardless of noise levels);

yi: is the ith observation of the quality characteristic.

Larger-the-better type:

The quality attribute in this case is constant and non-negative. The optimum value should be as high as it can be. There is no adjustment factor present. Examples of this kind are the miles travelled per gallon of gasoline for a vehicle carrying a certain amount of weight and the mechanical strength of a wire per unit cross-section area. By taking into account the reciprocal of the quality feature, this issue may be converted into a smaller, better sort of problem.

$$\eta = -10\log_{10}\ (\text{mean square reciprocal quality characteristic})$$

$$\eta = -10\log_{10}\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}\left(\frac{1}{{y_i}^2}\right)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

Nominal-the-best type:

The quality characteristic of this type is continuous, non-negative, and may take any value between 0 and ; nevertheless, its goal value must be non-zero and finite. When the mean for these types of issues equals zero, the variances likewise equal zero. Engineering designs commonly have issues of this kind. To obtain a desired paint thickness on the surface is an example of this kind.

The S/N ratio for nominal-the-best is given by:

The S/N ratio for nominal-the-best is given by:

$$\eta = 10\log_{10}\left[\frac{\mu^2}{\sigma^2}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

where, $\mu = \frac{1}{n}\sum_{i=1}^{n} y_i$ & $\sigma = \frac{1}{n}\sum_{i=1}^{n}(y_i - \mu)^2$

Minitab software:

Minitab is often a statistical software program. Researchers Barbara F. Ryan, Thomas A. Ryan, and Brian L. Joiner created it at Pennsylvania State University in 1972. A statistical analysis application developed by NIST, Minitab originally came in a lite form. Minitab Inc., a privately held firm with its headquarters in State College, Pennsylvania, and subsidiaries in Coventry (Minitab ltd.), Paris (Minitab snarl.), and Sydney (Minitab pty.), distributes Minitab. Today, Six Sigma, CMMI, and other statistics-based process improvement techniques are often utilized in combination with Minitab. Seven languages are supported by Minitab 16, the most recent version of the program: English, French, German, Japanese, Korean, simplified Chinese, and Spanish. Two further items made by Minitab Inc. complete Minitab 16. The quality companion 3 is an integrated tool for managing Six Sigma and lean manufacturing projects that enables the combination of Minitab data with project management and governance tools and documents. Quality trainer is an e-learning package that teaches statistical tools and concepts in the context of quality improvement and integrates with Minitab 16 in order to simultaneously develop the user's statistical knowledge and proficiency with the Minitab software.

Uses of Minitab:

- File and data management, including a spread sheet for improved data analysis.
- Analysis of regression
- Tables and graphs, power, and sample size
- Multivariate analysis, which encompasses correspondence analysis, cluster analysis, and factor analysis.
- Tests that is nonparametric, such as the song test, runs test, Friedman test, etc.
- Time series and forecasting are tools that assist in identifying data patterns and making future value predictions. Exponential smoothing, trend analysis, and time series charts.
- Statistical process control • Analysis of measurement systems
- Variance analysis to ascertain the variation between data points.

The Minitab program is utilized in the current study to generate regression models and produce ANOVA (mathematical modeling is done using multiple regression analysis).

Minitab instructions: ANOVA

The Minitab program has a number of options for obtaining ANOVA. The next section includes a step-by-step description and an example of the tools needed to produce an ANOVA using Minitab software.

Step 1: open Minitab: To launch Minitab, double-click the icon.

1) Results are shown in the session window.
2) The spreadsheet is where the unprocessed data from Figure came from.

The worksheet columns have already been filled with the soft data from the ANOVA: complete factorial design instruction.

- Each row corresponds to a test (or run).
- The first grey row represents the column labels.
- One variable is represented by each column.

Step 2: ANOVA: Go to stat >> ANOVA >>general linear models

- As illustrated in Figure 3.4, double-click "c6 results" while the cursor is in the "responses:" area.
- Position the cursor in the "model:" field, then double-click factors a, b, and c. • Use the * symbol to see all 2-way interactions.

Step 3: Validating model (Fisher assumptions):

- Produce residual plots to demonstrate the independence and normal distribution of the sampling errors.
- In the general linear models box, click OK.

4. EXPERIMENTAL DESIGN AND SETUP

The impacts of significant factors, such as layer thickness, printing temperature, infill density, and infill pattern, were examined in this research using the Taguchi technique.

Table No.: 4.1 Process Parameters

FACTORS	LEVELS		
	1	2	3
Layer Thickness (A)	0.12	0.2	0.25
Printing Temperature (B)	210	220	230
Infill density (C)	80	85	90
Infill pattern (D)	Triangular	Cubic	Quarter cubic

Table 4.2: The L9 orthogonal array with parameters values

Exp.	**L.T.**	**P.T.**	**I.D.**	**I.P.**
1	0.12	210	80	Triangles
2	0.12	220	85	Cubic
3	0.12	230	90	Quarter Cubic
4	0.2	210	85	Quarter Cubic
5	0.2	220	90	Triangles
6	0.2	230	80	Cubic
7	0.25	210	90	Cubic
8	0.25	220	85	Quarter Cubic
9	0.25	230	80	Triangles

Test Specimens

Figure 4.1: 3D printed Tensile specimens

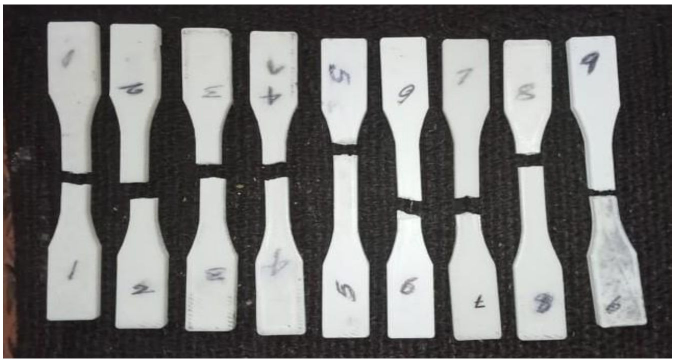

Figure 4.2: Tensile specimens after testing

Table 4.3: Tensile test Results

No. of Exp.	Layer Thickness (A)	Printing Temperature (B)	Infill Density (C)	Infill Pattern (D)	Tensile strength (MPa)	
					Trail 1	Trail 2
1	0.12	210	80	Triangles	29	28.5
2	0.12	220	85	Cubic	29	31
3	0.12	230	90	Quarter Cubic	30	28.75
4	0.2	210	85	Quarter Cubic	27.5	28
5	0.2	220	90	Triangles	30	28.75
6	0.2	230	80	Cubic	28.5	27.5
7	0.25	210	90	Cubic	26.75	25.75
8	0.25	220	85	Quarter Cubic	27.75	25.5
9	0.25	230	80	Triangles	27.5	26.25

Table 4.4: Results related to Printing time

No. of Exp.	Layer Thickness (A)	Printing Temperature (B)	Infill Density (C)	Infill Pattern (D)	Printing time	
					Trail 1	Trail 2
1	0.12	210	80	Triangles	9.0	9.5
2	0.12	220	85	Cubic	8.5	9.0
3	0.12	230	90	Quarter Cubic	8.0	8.5
4	0.2	210	85	Quarter Cubic	7.0	7.5
5	0.2	220	90	Triangles	7.5	7.0
6	0.2	230	80	Cubic	7.5	7.0
7	0.25	210	90	Cubic	6.0	6.5
8	0.25	220	85	Quarter Cubic	6.0	6.0
9	0.25	230	80	Triangles	6.5	6.5

5. DATA ANALYSIS

5.1: Tensile Strength

Table 5.1: Analysis of Variance of Tensile strength

Factor	S.S	D.O.F	M.S.S	F-ratio (data)	F-ratio (Table)	Percentage contribution
Layer thickness	24.0069	2	12.0035	900.26	4.26	82.3626483
Printing Temp.	2.5444	2	1.2722	95.42	4.26	8.729303755
Infill density	0.9653	2	0.4826	36.20	4.26	3.311742224
Infill pattern	0.9444	2	0.4722	35.42	4.26	3.440038699
Error	0.1200	9	0.0133			1.061694879
S_t	29.1478	17				

Table 5.2: Summary of S/N ratios of Tensile strength

Factors	Level 1	Level 2	Level 3
Layer Thickness (LT)	**29.35805**	28.40833	28.49172
Printing Temperature (PT)	28.80675	**29.13573**	28.96323
Infill Density (ID)	28.90096	28.97091	**29.03384**
Infill Pattern (IP)	**29.03976**	28.9558	28.91015

5.1.1: Selection of optimum parameters for Tensile strength:

The optimum conditions are layer thickness at level 1 (0.12 mm), Printing temperature at level 2 (220°C), Infill density at level 3 (90 %) and Infill pattern at level 1 (Triangles). Thus, the optimum condition obtained.

Table 5.3: Optimum set of control factors for Tensile strength

Factors/ Levels	Layer Thickness (mm)	Printing Temperature (°C)	Infill Density (%)	Infill Pattern
Optimum	0.12	220	90	Triangles

5.2: Printing Time

Table 5.4: Analysis of Variance of Printing time

Factor	S.S	D.F	M.S.S	F-ratio (data)	Percentage contribution
Layer thickness	19	2	9.55	97.71	89.94083
Printing Temp.	0.25	2	0.125	1.29	1.183432
Infill density	0.25	2	0.125	1.29	1.183432
Infill pattern	0.15	2	0.075	0.77	0.710059
Error	0.875	9	0.0972		4.142012
S_t	21.125	17			

Table 5.5: Summary of S/N ratios of Printing time

Factors	Level 1	Level 2	Level 3
Layer thickness	-18.8343	-17.2119	**-15.9153**
Printing Temp.	-17.4875	**-17.2062**	-17.2678
Infill density	-17.5987	-17.2062	**-17.1565**
Infill pattern	-17.5987	-17.3267	**-17.036**

5.2.1: Selection of optimum parameters for Printing time:
The optimum conditions are layer thickness at level 3 (0.25 mm), Printing temperature at level 2 (220°C), Infill density at level 3 (90 %) and Infill pattern at level 3 (Quarter-cubic). Thus, the optimum condition obtained.

Table 5.6: Optimum set of control factors for Printing time

Factors/ Levels	Layer Thickness (mm)	Printing Temperature (°C)	Infill Density (%)	Infill Pattern
Optimum	0.25	220	90	Quarter-cubic

6. RESULTS AND DISCUSSIONS

The larger-the-better sort of quality characteristic has been chosen for the response because the performance qualities of tensile strength must be maximized.

6.1. Optimization of process parameters for Tensile strength:
In order to boost the Tensile strength for better performance, Taguchi's robust design technique has been effectively used to determine the ideal parameters from chosen process parameters and their levels. The ideal process parameters were discovered after data from the resilient design tests were analyzed.

Table 6.1: Optimum Parameters for Tensile strength

Layer Thickness (LT)	0.12 mm
Printing Temperature (PT)	220 °C
Infill Density (ID)	90 %
Infill Pattern (IP)	Triangles

6.2. Factor response plot for performance characteristics:
The level of parameter with the highest S/N ratio is the optimal level. The individual factors effect on Tensile strength has found to be significant, Layer thickness (LT) has major contribution of (82.36%) followed by Printing temperature (8.72%), Infill pattern (3.44%), infill density (3.31%).

Figure 6.1: Main effect plots for Tensile strength

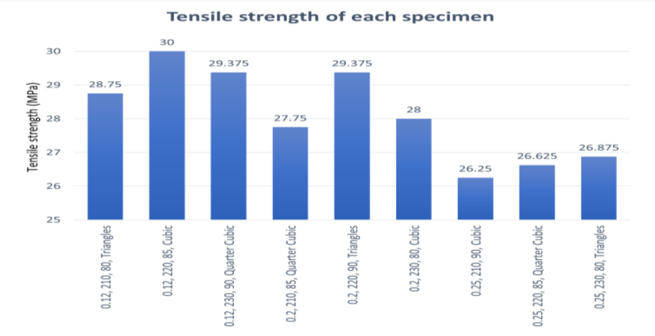

Figure 6.2: Tensile strength of each specimen

The significance of each factor chosen for this experiment is high. The layer thickness (LT), which contributes roughly 85%, is the main factor. The most important component that may affect the output parameter is layer thickness. The same outcome is obtained by other researchers. Only the layer thickness is recommended as an optimal setting by the UltimakerCura program. Therefore, the only significant factor affecting the strength of a component created by 3D printing is layer thickness. More layers must be deposited to get the required component since thinner layers have greater strength. To fulfill the necessary thickness component, only few layers are needed if the layer thickness is higher.

Table 6.2: Optimum Parameters for printing time

Layer Thickness (LT)	0.25 mm
Printing Temperature (PT)	220 °C
Infill Density (ID)	90 %
Infill Pattern (IP)	Quarter Cubic

Factor response plot for performance characteristics:
The ideal level of a parameter is the one with the greatest S/N ratio. Layer thickness (LT), which has a considerable impact of (89.94%), is followed by Infill density (1.183%), Printing temperature (1.183%), and Infill pattern (0.71%) in terms of the individual components' effects on tensile strength.

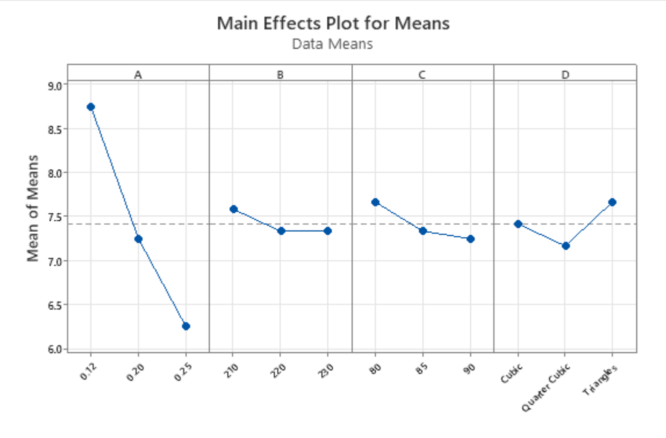

Figure 6.3: Main effect plots for printing time

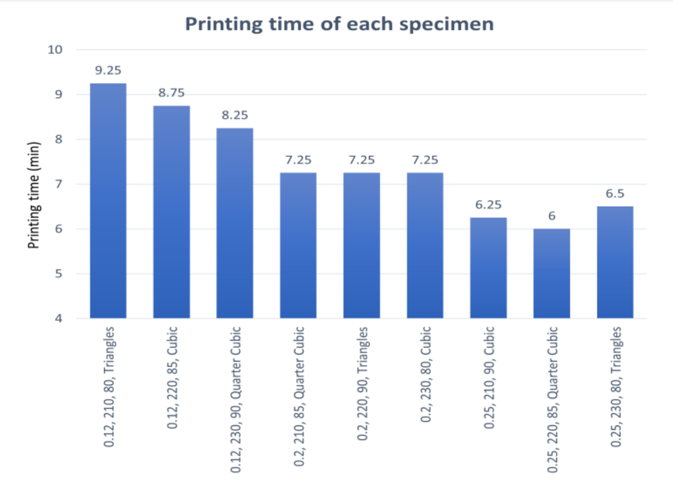

Figure 6.4: Printing time of each specimen

The layer thickness significantly affects how long each specimen takes to print. The impact of the other variables on printing time is minimal. If the layer thickness is exceedingly thin, numerous layers must be deposited to achieve the component's required form. If the layer thickness is really high, the bare minimum of layers is required to provide the specified thickness component. Layer thickness is shown to have a substantial influence on the component's printing time. The component's printing time is not significantly impacted by the printing temperature, infill density, or infill pattern.

7. CONCLUSIONS

• In conditions where layer thickness is 0.12 mm or less, the maximum tensile strength is seen; in conditions where layer thickness is 0.2 mm or more, the average tensile strength is seen; and in conditions where layer thickness is highest, very little tensile strength is seen.

• In comparison to other process factors, layer thickness has a significant impact. No other factor is significantly significant.

• The ideal level of a parameter is the one with the greatest S/N ratio. Layer thickness (LT) makes up the majority of the (85%) contribution to the tensile strength of the 3D printed specimen among the individual parameters whose effects on impact strength were determined to be significant.

• Printing takes longer when the layer thickness is low than when the layer thickness is higher. When layer thickness is average, a moderate printing time is seen.

• In comparison to other process variables, layer thickness has a significant impact on printing time. No other factor is significantly significant. While some criteria are negligible, others are crucial.

• The influence of each individual element on tensile strength was found to be considerable. In the printing of tensile specimens, layer thickness (LT) contributed the most (89.94%), followed by infill density (1.183%), printing temperature (1.183%), and infill pattern (0.71%).

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