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Evaluating Impact of Different Parameters in Additive Manufacturing for Complex Situations

Suresh Raju Alase[1], Prof. A. S. Bharule[2]

[1]*M.Eng. Student of Mechanical Engineering Department*
[2]*Mechanical Engineering Department*
[1 2]Shri Sant Gajanan Maharaj College of Engineering, Shegaon

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Abstract - Additive manufacturing (AM) has emerged as an effective method for fabricating parts with internal complex features. However, optimizing process parameters to achieve desired mechanical properties for such complex geometries remains a challenge. This research aims to systematically evaluate the influence of AM process parameters on the tensile strength of PLA plus specimens containing a rectangular channel integrated inside the gauge section. A Taguchi L9 orthogonal design of experiments was formulated with four control factors - printing temperature, layer height, wall line count and infill percentage. Tensile testing specimen of standard ASTM D638-Type I containing a rectangular channel of 1.5x5x50mm was printed on an FDM machine. Tensile testing determined the ultimate tensile strength and percentage of elongation as the response. Signal- to-noise ratio analysis revealed optimized levels as 210°C, 0.20mm, 3 wall lines and 100% infill. Tensile testing of specimens printed at these conditions yielded average UTS of
34.58 MPa.
Adopting Taguchi methodology, this study aims to improve understanding of interplay between key AM parameters and mechanical properties for PLA plus specimens with complex internal geometry. Optimized settings aid quality fabrication of functionally graded parts with intricate designs using this sustainable FDM material. Statistical design of experiments serves as an efficient evaluation approach.

Key Words: Additive Manufacturing, Fused Deposition Modelling, PLA, Tensile Test Specimen

1. INTRODUCTION

Additive manufacturing, also known as Rapid prototyping or 3D printing, is described as a quick process for creating a prototype based on design data with the aid of a computer. Since the introduction of 3D printing technology in the 1980s, the term “3D printing” has been used in many industries such as the automotive, aerospace, electronics and biomedical industries. 3D printing was developed in the 1980s when Charles W. Hull invented the early 3D printing prototype called Stereolithography (SLA), which was based on laser technology and a photo-curable polymer. Since then, many other scientists and researchers have been developing other forms of 3D printing technologies such as SLS by Deckard, FDM by Crump and many other technologies. Fused deposition modeling (FDM) [1] is the most common and simplest techniques in 3D printing technology that was developed by Stratasys in 1989. Fused deposition modeling uses a wide range of thermoplastics, such as ABS, nylon, PLA and their blends [2]. The FDM process starts when a thermoplastic filament is melted in a liquefier at a temperature above its melting point and then pushed through a nozzle of a given diameter. As the nozzle moves, the molten thermoplastic filament is deposited layer by layer in the horizontal direction on a heated bed (Fig.1). Once the first layer is printed, the nozzle starts printing the second layer on top of preceding layer and continuing until the completion of the objects.

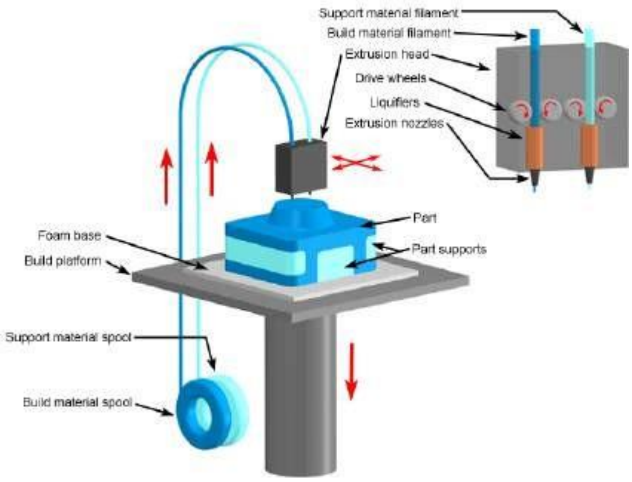

Fig -1: Fused Deposition Modeling Technology

2. LITERATURE REVIEW

A number of studies have investigated the effect of layer thickness on mechanical properties of FDM parts. Jin et al [3] evaluated ABS specimens fabricated with layer thicknesses ranging from 0.1 to 0.3 mm. Tensile strength was highest at 0.15 mm. Ahn et al.[4] reported similar trends for PLA, with strengths reducing significantly above 0.2 mm layers. Bellini and Guceri et al. [5] performed rheological modeling to analyze flow behaviors at varying deposition rates corresponding to different layer thicknesses. Their results provided mechanistic insights into property variations. Agarwala et al. (1996)[6] studied the influence of nozzle

temperature on dimensional accuracy and strength of ABS parts. An optimal processing window between 190-210°C was observed. Subramanian et al. (1995)[7] also investigated temperature effects on PLA, finding ductility peaked between 185-195°C. Jin et al. (2016) [8] studied warpage in PLA components printed at varying temperatures from 180-220°C using a Design of Experiment approach. Minimized distortions were noted between 195-205°C. Infill density influences properties by modulating bulk density and surface area. Tymrak et al. (2014)[9] found ABS and PLA moduli and strengths rose significantly with increasing fill from 10-100% in 10% increments. Mansoor et al. (2016)[10] determined honeycomb patterns provided maximum strength for a given fill percentage. To enhance strength, parts are built with thicker perimeter walls surrounding infill. Ahn et al. (2009)
[11] evaluated ABS specimens having one to four perimeter shells, reporting consistent strength improvements by adding extra wall lines. Muammel M. Hanon et al. [12] obtained results show that the highest Young's modulus and ultimate tensile strength values were observed in the On-edge orientation samples (1.896 ± 0.044 GPa and 49.12 ± 0.78 MPa, respectively). Meanwhile, the best elongation at break was found in the 0.1 mm layer thickness specimen (3.13%). Further, it was noticed that the hardness and tensile strength are in a proportional relation when the print orientation parameter is the variable. Kuldeep Sharma et al [13] experimental study investigates the effect of different process parameters viz. layer height, raster angle, nozzle temperature and surrounding pressure on thickness of the final part for Poly Lactic Acid (PLA) filament. Experiments, based on Taguchi’s L9 orthogonal array, were performed and subsequently experimental data have been analysed by ANOVA. It has been observed that the layer height is the most significant factor in order to achieve the dimensional accuracy.

In summary, past studies have significantly enhanced understanding of individual effects of common FDM process parameters like layer thickness, temperature, infill etc. on mechanical properties. However, a few knowledge gaps still remain:

i. Most investigations considered simple rectangular tensile test specimens without complex interior geometries. Practical additively manufactured parts often incorporate multiple enclosed cavities.

ii. Limited literature exists evaluating the influence of various parameters simultaneously using a systematic experimental design approach for parts with internal features.

iii. There is lack of standardized process parameter protocols and tensile performance benchmarks specifically for load-bearing AM components with complex multi-cavity designs.

iv. Detailed empirical studies are needed to bridge the gap between desirable properties and process settings required to fabricate topologically complex geometries with structural integrity.

2.1 Aim of the Research work

i. To characterize the effect of key FDM process parameters on the tensile properties of 3D printed PLA Plus specimens containing an embedded channel.

ii. To investigate the influence of parameters like printing temperature, layer height, Infill density and wall line count on the formation of voids/defects within the channel region

iii. To optimize the FDM process settings for achieving maximum tensile load capacity of printed PLA Plus specimens with void-free internal channels.

2.2 Objective of the Research work.

i. Design tensile test specimens incorporating a rectangular channel inside as a representation of complex internal geometry.

ii. Identify key FDM parameters (layer thickness, temperature, infill, walls etc.) affecting mechanical performance based on literature.

iii. Fabricate PLA plus specimens as per design of experiments employing different parameter settings on a desktop FDM system.

iv. Conduct tensile testing of specimens as per ASTM D638 standard and record properties such as ultimate strength.

v. Analyze experimental results using statistical tools to quantify parameter effects and recognize optimal settings.

vi. Recommend guidelines for additive manufacturing of prototypes and load-bearing components incorporating complex internal cavities.

3. METHODOLOGY

Additive manufacturing (AM) techniques have gained prominence as an effective fabrication approach for prototype development and tooling applications. Fused deposition modeling (FDM) is one of the most widely used polymer-based AM technologies. However, optimizing process parameters to achieve consistent mechanical properties for complex part designs remains a challenge.

This research aims to characterize the tensile behaviour of FDM printed polylactic acid (PLA+) specimens with enclosed internal channel geometry. A systematic approach is adopted involving design of experiments, fabrication, testing and statistical analysis. The findings will provide guidelines for additive manufacturing of prototypes and load-bearing components incorporating internal cavities.

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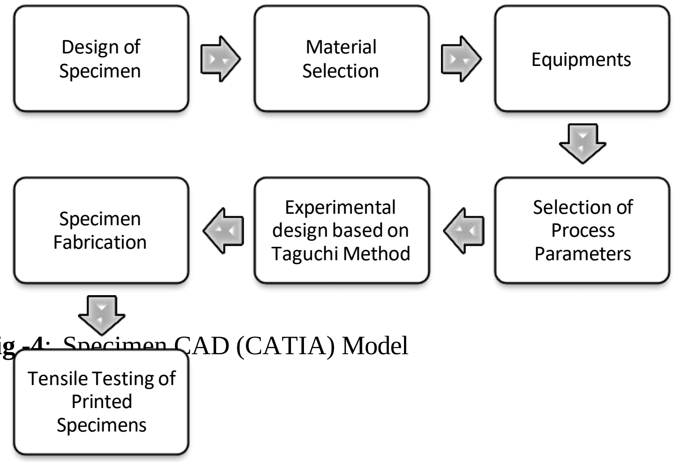

Fig -2: Framework of the proposed method for the study

3.1 Design of Specimen

A specimen is designed using CATIA software for experiments, i.e. tensile test specimen following the ASTM D638 type-I but inserted the rectangular channel inside it for complex geometries as shown in Fig. The specimen helps for investigating impacts of FDM building parameter settings on mechanical properties like Ultimate Tensile strength, percentage of elongation at break.

3.1.1 Design Calculation

As per ASTM D638 Type-01 the dimensions of specimen are as follows:
Overall Length=165mm
Length of narrow grips=115mm Length of narrow section= 57mm Gage Length = 50mm
Gage Width= 13mm Overall Width= 19mm Thickness= 3mm

Internal Channel design calculation:
Length= 50mm
Width= 5mm
Thickness= 1.5mm

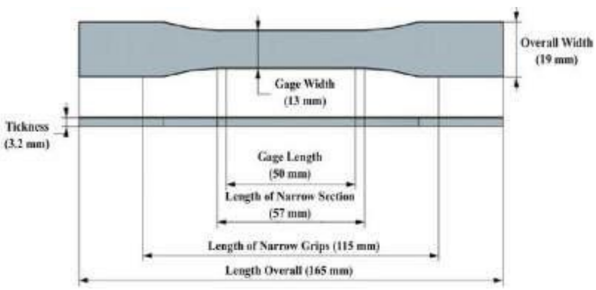

Fig -3: ASTM D638-01 Tensile Specimen

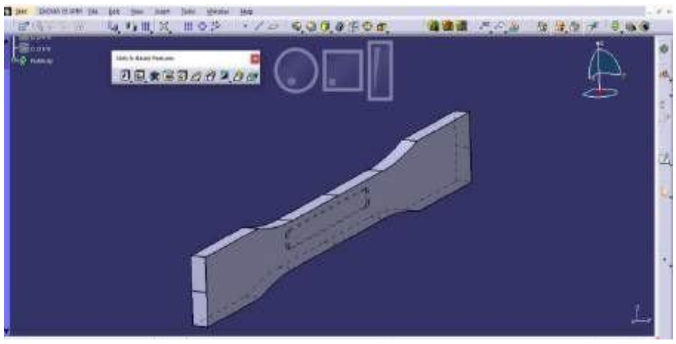

Fig -4: Specimen CAD (CATIA) Model

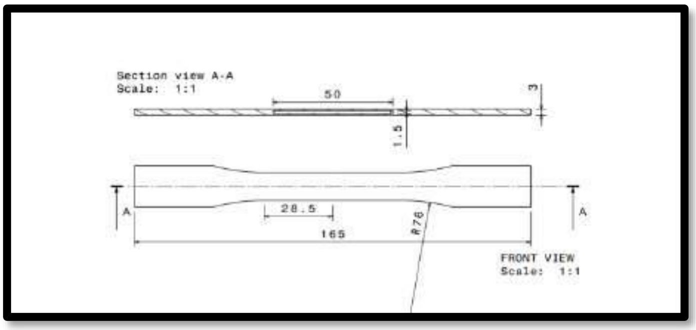

Fig -5: Specimen 2D Drawing (Front View and Its Section View), dimensions in mm

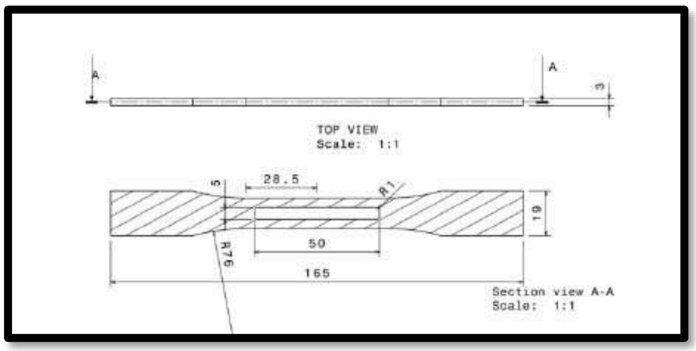

Fig -6: Specimen 2D Drawing (Top View and Its Section View), dimensions in mm

3.2 Material

The filament material used for 3D printing is Poly Lactic Acid Plus (PLA+) obtained from NuMakers. PLA+ is an enhanced form of Polylactic acid (PLA) which is a thermoplastic polyester derived from renewable plant sources like corn starch or sugarcane

The PLA+ filament used has the following specifications as provided by the manufacturer:

- Material: PLA+
- Diameter: 1.75 mm
- Color: Pure White
- Specific Gravity: 1.24 g/cc

- Melt Flow Rate: 6 g/10min (210°C, 2.16kg)
- Tensile Strength: 50MPa
- Glass Transition Temperature: 30-60°C
- Print Temperature: 200-230°C

3.3 Equipments.

3.3.1 3D Printer

The Creality Ender 3 3D printer was used for fabricating all the PLA+ specimens. It is a low-cost desktop FDM system equipped with a single extruder.

The key technical specifications of the printer are:

- Brand & Model: Creality Ender 3
- Build Volume: 220 x 220 x 250 mm
- Nozzle Diameter: 0.4 mm
- Nozzle Temperature Range: 180-250°C
- Bed Temperature Range: 50-110°C
- Layer Thickness: 0.1-0.4 mm
- Positioning Accuracy: ±0.1 mm
- Positioning Repeatability: ±0.02 mm
- Print Head Travel Speed: 180-200 mm/s
- Build Platform: Hinged magnetic removable plate
- Filament Diameter: 1.75 mm
- Connectivity: USB port

Fig -7: 3D Printer (Creality Ender 3) Setup

3.3.2 Tensile Testing Machine

A Vector model universal testing machine with a 10 kN (1000kg) load cell was used for tensile testing as per ASTM D638 standards. It has the following specifications:

- Load Capacity: 10 kN
- Crosshead Speed Range: 0.5-800 mm/min
- Accuracy: ±0.5% of displayed value
- Speed Control: Servomotor with servo controller
- Data Sampling Rate: 1000 Hz

Fig -8: Universal Testing Machine

3.4. Selection of Process Parameters

Based on literature, it was analysed that the process parameters such as layer height, printing temperature, wall line count and infill density greatly affect the dimensional accuracy and mechanical properties of printed parts. In this study, the specimen with channel inside it is considered as in actual the various parts contains channels or cavities inside it but still no any research has been done with channel or cavity, so in this project work considered cavity and modified standard ASTM D638 type 1 specimen for evaluating its effect on dimensional accuracy, bridging and mechanical properties. Three levels of parameters are considered for sample preparation because Taguchi L9 method is being used for process parameter selection in this study. The levels of these parameters were selected with the help of machine manual and performing the preliminary test on a 3D printer.

Table -1: Setting of levels for parameters

Parameters	Symbols	Levels		
		I	II	III
Printing Temperature (^{0}C)	A	200	210	220
Layer Height (mm)	B	0.1	0.15	0.2
Wall Line Count	C	2	3	4
Infill Density (%)	D	50	75	100

Table -2: List of fixed parameters

Sr. No.	Parameters	Fixed Value
1	Build Plate Temperature	50 ºC
2	Printing Speed	40 mm/s
3	Retraction Distance	2 mm
4	Building Orientation	Flat

3.5 Design of Experiment based on Taguchi Method

A L9 orthogonal array chosen for the experimentation in which 9 rows corresponding to the number of experiments, with 4 columns at three levels as shown in Table 3. The experiments were performed for each combination of rows as per selected L9 orthogonal array.

Table -3: L9 Orthogonal Array Design

Experiment No.	A	B	C	D
1	200	0.1	2	50
2	200	0.15	3	75
3	200	0.2	4	100
4	210	0.1	3	100
5	210	0.15	4	50
6	210	0.2	2	75
7	220	0.1	4	75
8	220	0.15	2	100
9	220	0.2	3	50

3.6 Specimen Fabrication

The tensile test specimen was designed using CAD (CATIA V5R20) software as per ASTM D638 type 01 standard and added a rectangular channel inside it for complex situations as not all the parts are solid some parts may contain channels or cavities inside it, this study aims to investigate the impact of parameters in additive manufacturing for PLA plus 3D printed parts with the integrated channel inside it. The channel has specifications as 1.5*5*50 mm and is given a fillet of R01 to minimize stress concentration at the sharp edge.

The designed specimen file is converted into an STL file for the 3D printing process with Cura slicing software to be incorporated for slicing the specimen design and generating G-code for further 3D printer execution.

As there is no report on the optimal printing condition to fabricate high strength test specimen with channel inside it using PLA plus such as nozzle temperature, layer height, wall line count and infill density, three specimens per experiment were fabricated to investigate the effect of these parameters to fabricate a specimen.

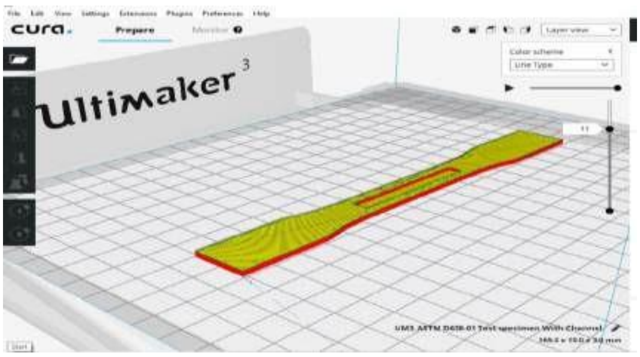

Fig -9: Flat orientation of the tensile sample imported and placed in Ultimaker Cura.(Haft sliced Specimen showing channel inside)

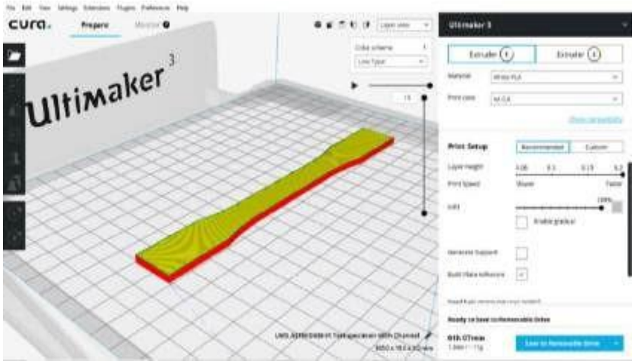

Fig -10: Flat orientation of the tensile sample imported and placed in Ultimaker Cura.

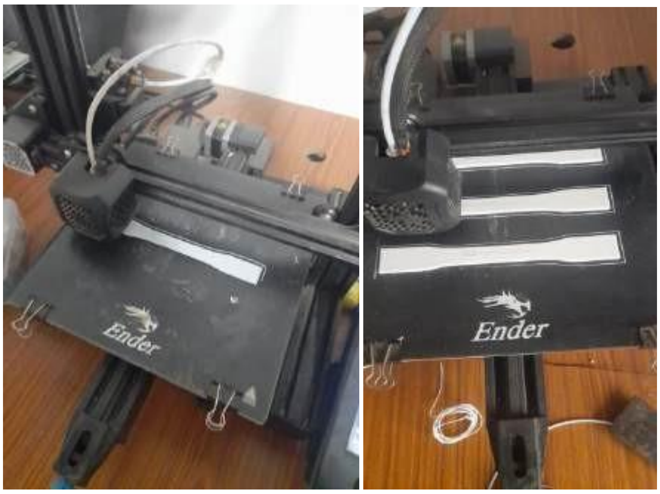

Fig -11: Fabrication of Specimen on 3D Printer

Fig -12: Printed Specimens with 3 replicates

3.7 Mechanical Testing

A 10kN capacity Hounsfield UTM was used for testing. It was interfaced with Trapezium X software for automatic data logging. The software recorded load, extension and time data at 1 second intervals

A total of 27 specimens were tested (9 experimental runs x 3 repeats). The 9 experimental runs consisted of combinations from the L9 OA as shown in Table 3. For each run, specimens were printed at 0°orientations (Flat). This resulted in 3 repeats for mechanical property determination to account for build variability. 9 sets of samples corresponded to the 9 experimental runs. Within each set, specimens were built at on flat surface. 3 identical specimens from each run-orientation group were tested. This provided 3 repeats of measurement for statistical analysis.

The 27 specimens were carefully removed from storage packs. Specimen surfaces were lightly sanded to remove any defects. Each specimen was labeled with run number and repeat number for identification. A pneumatic wedges of the UTM were used to hold the specimens firmly. The specimens were centered in the grips ensuring alignment with the load cell. For 0° orientation, the specimens long axis was kept parallel to the load cell. Care was taken to avoid any bending load on the specimens during mounting. Figure shows a specimen mounted and ready for testing

Fig -13: Specimen Mounted on UTM

This process was followed consistently for all 27 specimens to be tested. The gripping method ensured uniform stress distribution on the gage section. Any slack was carefully adjusted to avoid pre-loading before the actual test. Proper mounting maintained specimen integrity and facilitated failure in the gage as per standards

4. RESULTS AND DISCUSSION

The objective of this study was to optimize the 3D printing process parameters for PLA Plus specimens using Taguchi methodology. Tensile testing was conducted to determine mechanical properties as response variables. This chapter discusses the results of tensile testing and statistical analysis carried out to meet the objectives.

In first run process parameters used are Printing temperature of 200°C, layer height of 0.1mm, wall line count of 2 (layer thickness of 0.8mm), infill density of 50%. There was warping observed when bridging/printing overhangs above the channel/hole in the dumbbell samples. With the selected process parameters, proper bridging/printing of overhanging features above the channel/hole was not achieved.

Fig -14: Sample 01 (Front view and Back View)

In second run process parameters used Printing temperature 200°C, Layer height 0.15mm, Wall line count 3 (layer thickness of 1.2mm), Infill density 75%. There was still warping when bridging/printing overhangs above the channel. Bridging was initiated but did not complete filling the bridge space over the channel.

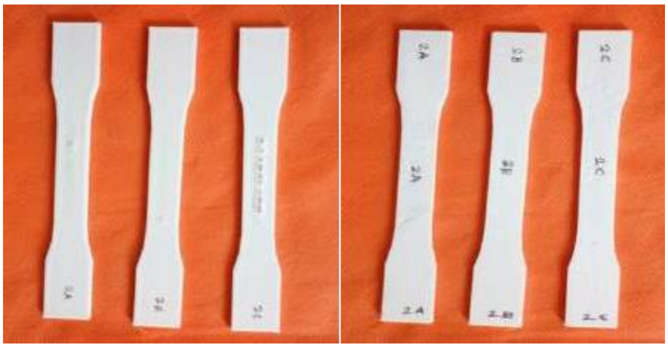

Fig -15: Sample 02 (Front view and Back View)

In third run process parameters used are printing temperature 200°C, Layer height 0.2mm, Wall line count 4 (layer thickness of 1.6mm), Infill density 100%. There was no warping observed when bridging/printing overhangs above the channel. The cavity or channel was completely filled by the bridging material. A smooth surface finish was achieved when bridging.

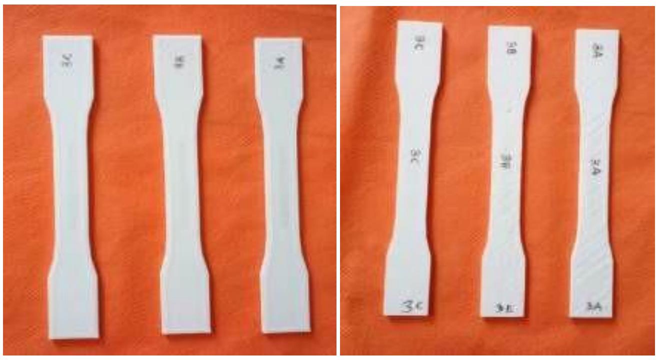

Fig -16: Sample 03 (Front view and Back View)

In fourth run process parameters used Printing temperature 210°C, Layer height 0.1mm, Wall line count 3 (layer thickness of 1.2mm), Infill density 100%. There was warping seen when bridging/printing overhangs above the channel. Proper bridging of the gap over the channel was not achieved.

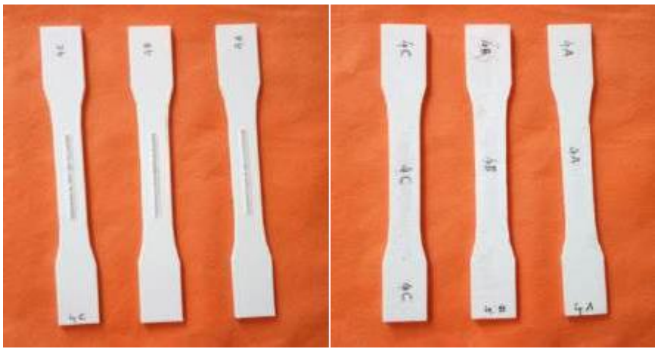

Fig -17: Sample 04 (Front view and Back View)

In fifth run process parameters used Printing temperature 210°C, Layer height 0.15mm, Wall line count 4 (layer thickness of 1.6mm) and Infill density: 50%. Warping occurred when bridging/printing overhangs above the channel. The bridge was not completely filled Despite optimizing some parameters from the 4th run that is decreased layer height to 0.15mm and increased wall count to 4 layers.

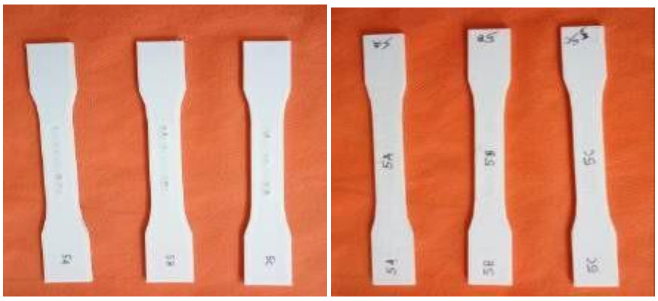

Fig -18: Sample 05 (Front view and Back View)

In sixth run process parameters used printing temperature 210°C, Layer height 0.2mm , Wall line count 2 (layer thickness of 0.8mm) and Infill density 75%. There was no warping seen when bridging over the channel. A smooth surface finish was obtained in the bridged region. The cavity/channel was completely filled by the bridging material. The results indicate that for this material and printer, these process parameters in the sixth run successfully bridged the dumbbell samples without defects. Further validation tests could be done.

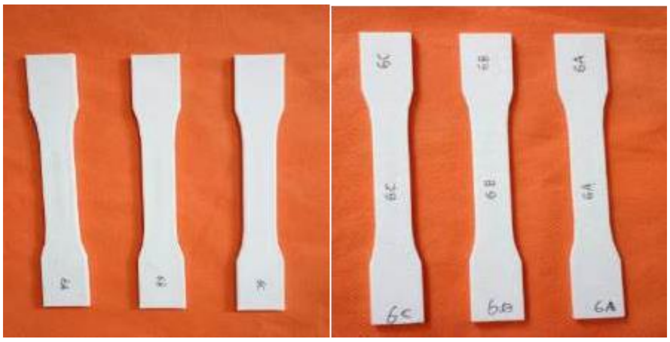

Fig -19: Sample 06 (Front view and Back View)

In seventh run parameters taken printing temperature 220ºC, Layer height 0.1mm, wall line count 4 (1.6mm of layer thickness) and 75% of infill density. It was found that there is warpage when bridging above the channel, not completely fills the bridge when selected above parameters

Fig -20: Sample 07 (Front view and Back View)

In eighth run parameters taken printing temperature 220ºC, Layer height 0.15mm, wall line count 2 (0.8mm of layer thickness) and 100% of infill density. It was found that there is warpage when bridging above the channel, not completely fills the bridge when selected above parameters.

Fig -21: Sample 08 (Front view and Back View)

In the ninth run Process parameters used printing temperature 220°C, Layer height 0.2mm, Wall line count 3 (layer thickness of 1.2mm) and Infill density 50%. There was no warping seen when bridging over the channel. A smooth surface finish was obtained in the bridged region. The cavity/channel was completely filled by the bridging material.

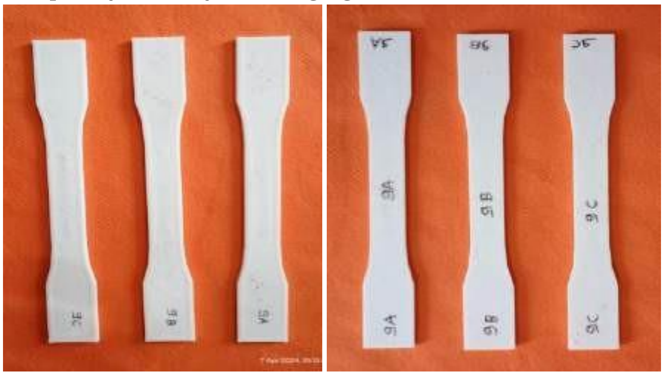

Fig -22: Sample 09 (Front view and Back View) From all

the runs of experiments it was observed that-

Upon visual inspection post-printing, some specimens exhibited warpage to varying degrees:

a. Specimens from Run 2, 5, 7 and 8 displayed minor warp of corners/edges due to internal stresses developed during the cooling process after printing.

b. No bridging was observed in the channel feature for Run 1 and 4 specimens, indicating incomplete filling possibly due to low infill density and temperature.

c. For Run 3, 6 and 9 specimens, the channel bridging was completed smoothly with a clear surface, demonstrating optimal material flow at these printing conditions.

4.1 Tensile test results of taguchi matrix

The tensile stress–strain plots for each sample in the Taguchi L9 orthogonal array are presented in figure 23 Ultimate tensile strength and percentage elongation for all the samples are tabulated in Table 4. It is observed that sample number 8 has the highest ultimate tensile strength, while sample number 1 has the lowest UTS.

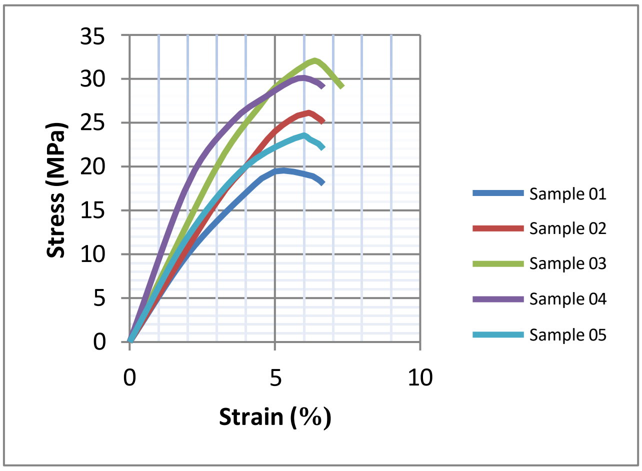

Fig -23: Stress-Strain Curve (Sample 01- Sample 05)

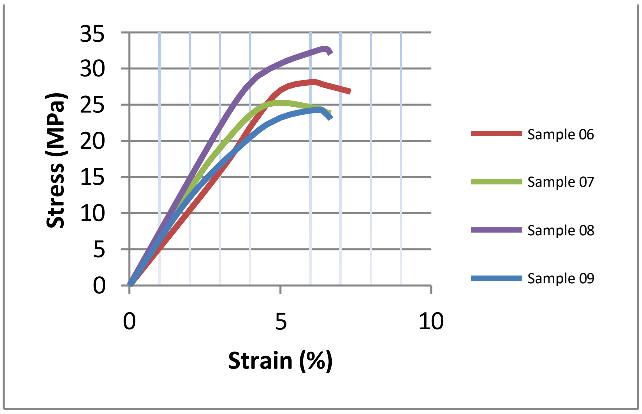

Fig -24: Stress-Strain Curve (Sample 06- Sample 09)

Table-4: Ultimate tensile strength and percentage elongation of the samples

Sample No.	Ultimate Tensile Strength MPa				Percentage Elongation %			
	A	B	C	Avg	A	B	C	Avg
1	18.46	20.9	19	19.45	8	6	6	6.67
2	26.11	25	27.16	26.09	6	6	8	6.67
3	31.09	31.07	33.64	31.93	6	8	8	7.33
4	29.5	30.17	30.5	30.06	6	6	8	6.67
5	23.68	23.89	22.98	23.52	6	6	8	6.67
6	28.31	28.2	27.84	28.12	8	6	8	7.33
7	25.17	24.7	25	24.96	8	6	6	6.67
8	34.11	32.96	31.14	32.74	6	6	6	6.00
9	22.88	24.77	25.3	24.32	6	8	6	6.67

4.2 Signal/Noise Ratio Analysis

The effect of FDM process parameters and the annealing treatment on the mechanical properties was assessed by computing the signal-to-noise (S/N) ratio for every sample in the orthogonal L9 Taguchi array (as shown in Table 4.2). The S/N ratio calculated using Minitab software facilitates data analysis and identifies the optimum values of process parameters for the desired output. In the present work, the larger-the-better criterion was selected to maximize the UTS and percentage elongation.

The main effect plot for the UTS means S/N ratio values as generated by the statistical software is represented in Figure 25. Table 5 shows the corresponding values for mean S/N ratios and the maximum effectiveness rank for each processing factor. These ranks are calculated based on delta values for each factor, where the delta represents the variance/scatter between the highest and lowest average response for the respective processing factor.

Table-5: Signal/noise ratios for UTS and % Elongation calculated using Minitab software

Sample No.	UTS (MPa)	S/N Ratio	% Elongation	S/N Ratio
1	19.45	25.77987	6.67	16.47818
2	26.09	28.32948	6.67	16.47818
3	31.93	30.08488	7.33	17.30602
4	30.06	29.55883	6.67	16.47818
5	23.52	27.42753	6.67	16.47818
6	28.12	28.97929	7.33	17.30602
7	24.96	27.94374	6.67	16.47818
8	32.74	30.3007	6.00	15.56303
9	24.32	27.71809	6.67	16.47818

Fig -25: Plot of S/N ratios for UTS mean responses

Table-6: S/N ratio analysis for UTS and effectiveness rank of process parameters.

Parameters	Printing Temperature (^{0}C)	Layer Height (mm)	Wall Line Count	Infill Density (%)
Level				
1	28.06	27.76	28.35	26.98
2	28.66	28.69	28.54	28.42
3	28.65	28.93	28.49	29.98
Delta	0.59	1.17	0.18	3.01
Rank	3	2	4	1
Criterion:	Larger is better			

Table-7: S/N ratio analysis for % elongation and effectiveness rank of process parameters

Parameters	Printing Temperature (0C)	Layer Height (mm)	Wall Line Count	Infill Density (%)
Level				
1	16.75	16.48	16.45	16.48
2	16.75	16.17	16.48	16.75
3	16.17	17.03	16.75	16.45
Delta	0.58	0.86	0.31	0.31
Rank	2	1	3.5	3.5
Criterion:	Larger is better			

It is evident from Figure 4.21 that printing temperature and layer height have a positive correlation with the UTS. Therefore, it is clearly inferred that a higher value of layer thickness (0.20 mm) and maximum printing temperature of 220 °C would optimize the UTS. Contrary to this, the infill density was seen to have a direct relation with the increase in UTS. Moreover, wall line count of 3 were observed to be the most suitable levels for the processing factors. Furthermore, it is evident from Table 7 that the infill density having the highest delta value is the most significant processing parameter, followed by the layer height, while the wall line count was measured to be the least influential of the four processing parameters.

The main effect plot for the % Elongation mean S/N ratio values as generated by the statistical software is represented in Figure 26. Table 7 shows the corresponding values for mean S/N ratios and the maximum effectiveness ranks for each processing factor. In light of the S/N ratio plot, it is evident that higher layer height of 0.20 mm, highest infill density of 75%, lowest printing temperature of 200 °C and higher wall line count of 4 as printed sample are the optimized processing parameters required to achieve maximum ductility. Barkhad et al., in their research on the annealing treatment of melt-extruded PLA, have also revealed that it significantly increased the PLA’s stiffness and compressive strength while reducing its ductility. Consequently, layer height was the most influential process parameter affecting the ductility, followed by the printing temperature.

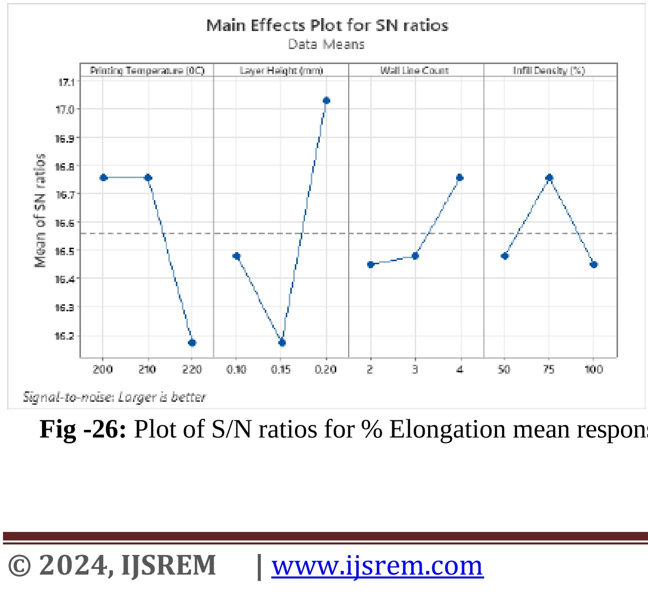

Fig -26: Plot of S/N ratios for % Elongation mean responses

In light of the tensile test results of the L9 orthogonal array, the maximum tensile strength was measured to be 32.74 MPa, and the highest % Elongation was 7.33% for the sample 03. With reference to S/N ratio plots, the optimized process parameters for UTS and % Elongation are tabulated in Table 4.14. However, samples using these conditions were not part of the original L9 orthogonal design array. Therefore, the next step was to conduct confirmatory tests using the best parameters, i.e., sample 10 and sample 11. The tensile stress/strain plots of the two samples are presented in Figure 4.23. Tensile tests on sample 10 resulted in a maximum UTS value of 34.58 MPa. Similarly, sample 11 was the most ductile sample, with a strain percentage value of 7.93%.

Table-8: Optimized Processing Parameters for maximum UTS and % Elongation

UTS Optimized Parameters				
Sample No.	Printing Temperature (^{0}C)	Layer Height (mm)	Wall Line Count	Infill Density (%)
10	210	0.20	3	100
% Elongation Optimized Parameters				
Sample No.	Printing Temperature (^{0}C)	Layer Height (mm)	Wall Line Count	Infill Density (%)
11	210	0.20	4	75

5. CONCLUSIONS

In this study, the effect of various FDM process parameters on the mechanical properties of 3D printed PLA plus samples are investigated. Parameter combinations involving printing temperature, layer height, wall thickness and infill density are evaluated. A Taguchi L9 Orthogonal Array design of experiments is employed to methodically study the process parameter effects. Tensile strength and percentage elongation are chosen as the critical response variables representing part quality. Specimen geometries contains complex bridged channel is 3D printed as per the experimental design. S/N ratio analysis is performed to determine the optimal parameter settings for maximum tensile strength and elongation. These samples are subjected to tensile testing to determine the mechanical properties Through the identification of these key parameters, the following conclusions are made:

1. The result from the L9 tensile tests has achieved a highest tensile strength of 32.74 MPa and 7.33% elongation for Sample 3. Thus, the optimized settings from S/N analysis improved the mechanical performance.
2. Signal-to-noise ratio analysis showed that maximum tensile strength achieved with 210 ^{0}C printing temperature, 0.20 mm layer height, 100% infill density and wall line count (Number of shells) of 03.
3. Samples 10 and 11 printed using these optimized parameters showed maximum tensile strength and elongation values of 34.58 MPa and 7.93% respectively based on UTM testing.
4. The inclusion of bridged channels in the specimen design added an element of geometric complexity similar to real functional components. The channel bridging done completely when uses 0.20mm layer height, channel not been filled with other layer height.
5. This work demonstrated that the Taguchi design approach coupled with S/N ratio analysis provides an effective means to determine robust printing conditions for FDM of complex parts. The optimized parameters ensured reproducible quality for PLA plus materials in terms of strength as well as ductility.

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