Optimization of 3D Printing Process Parameters of Poly Lactic Acid Materials by Fused Deposition Modeling Process

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Abstract - Additive Manufacturing (AM), also referred to as 3D printing involves manufacturing a part by depositing material layer by layer. There is a wide array of different AM technologies, Fused Deposition Modeling (FDM) is one of the most common techniques used for 3D printing. In this work, a customized FDM system was developed for Poly Lactic Acid (PLA) material printing. The present research is to investigate the influence of the printing temperature, printing speed, layer thickness and filling ratio on the mechanical properties of the PLA specimens. Optimum FDM process parameters of PLA material, the tensile test were carried out with filling ratio and without filling ratio (100%) and the specimens were selected by the orthogonal test of four factors and three levels for varying filling ratio and the orthogonal test of three factors and three levels for 100% filling ratio along with the printing temperature, printing speed, layer thickness and filling ratio.

Index Terms - Additive Manufacturing, 3D printing, Fused Deposition Modeling, Poly Lactic Acid.

I. INTRODUCTION TO RAPID PROTOTYPING

Prototype making is the one of the most important step in finalizing a design of a product before going to mass production. In olden days prototyping is done by skilled craftsman by manually it is an old practice. Second stage of prototyping is started around 1970, where soft prototype is modeled by 3D cures and surfaces and tested them in virtual environment conditions. 3rd and latest technology is Rapid prototyping which is denoted simply by symbol “RP”. Rapid prototyping is layer by layer depositions process, just like arranging the Lego blocks one over the other. Rapid prototyping techniques have been advancing rapidly since the commercialization of the first method, stereo lithography, in the late 1980s, which utilizes a laser to cure successive layers of a liquid polymer into the desired structure [1]. Rapid prototyping is started early in the year 1980 because of enormous growth in CAD/CAM technology. The historical development is shown in below Table 1. The additive manufacturing technologies, recently emerged as an innovative set of technologies to produce 3D products, may offer a viable and simpler alternative to fabricate these constructs while controlling efficiently their architecture.

Table1. Historical Development of Rapid Prototyping.

Year of Inception	**Technology**
1770	Mechanization
1946	First computer
1952	First numerical control (NC) machine tool
1960	First commercial laser
1961	First commercial robot
1963	First interactive graphics system(early version of computer aided design)
1988	First commercial rapid prototyping system

Rapid prototyping is additive manufacturing where material is going add layer by layer according to program given in the form of G-codes. In this process material is going to deposit on pervious layer until final shape of the model is obtained. Whereas lathe, Milling, grinding comes under the metal removal process in which metal is going to remove in small chips until final shape is obtained. In commercial rapid prototyping machines material is deposited consciously in X-Y planes where Z-axis moment is controlled by bed height, the bed is going downwards according the program and next layer is going to deposit on pervious layer this process is continues until final shape of the model is reached.

II. RAPID PROTOTYING TECHNOLOGIES

Rapid Prototyping Technologies are classified as follows:

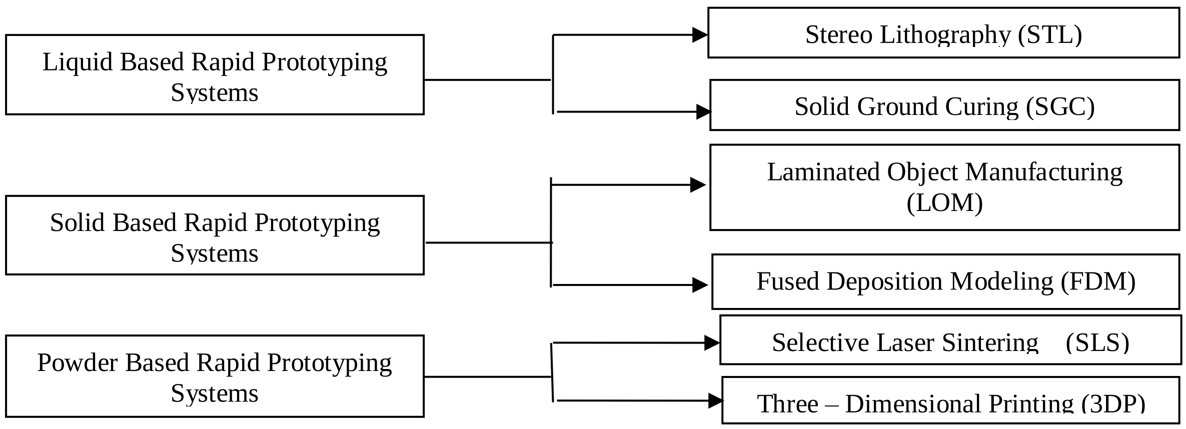

Fig.1 Classification of Rapid Prototyping Techniques

III. FUSED DEPOSITION MODELING

FDM is the most widely used RP technique used for producing 3D models. The basic construction of machine is as shown in fig.2. In FDM machine a plastic filament of standard Diameter 1.75mm is used. For industrial grade the filament diameter is 3 mm. these filament is heated in nozzle, the extruder deposits these melted Filament into layer by layer form as per the program given to system. Additive Manufacturing (AM) Technologies meet the requirements by creating products with complex, customized, and even assembled geometries, in a much faster and more economical way, difficult to manufacture by other technologies in a single step. An example of such technology is the Fused Deposition Modeling (FDM) [2]. The printing process is driven by the controlled planar translation of a print head in stacked layers that determines the spatial accumulation of material. Depending on the process, the print head typically either deposits material by fused deposition modeling [3]. The AM process usually takes a stereo lithography (STL) file as the raw data, which is the triangulated surface representation of a 3D object. To build an object in a layer by layer fashion, the shape of the cross section at each layer is required. The process to obtain the geometric property of the cross section area for each layer is usually termed as slicing [4] is shown in below figure.3.

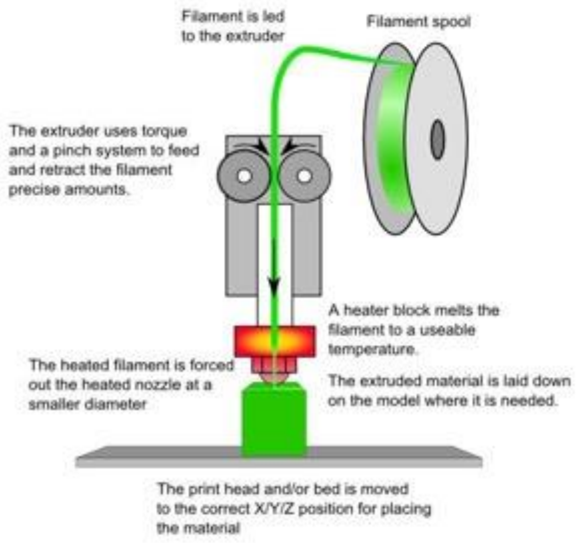

Fig.2 FDM Process

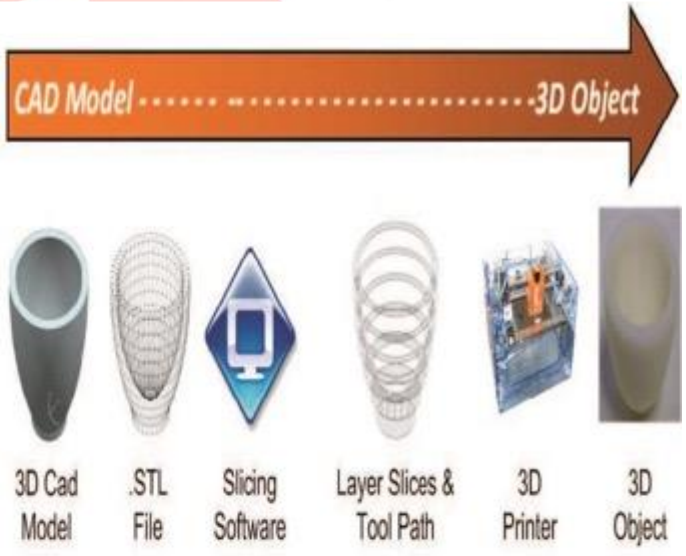

Fig.3 Generalized FDM Process

Poly Lactic Acid (PLA) is most common 3D printed filament used in FDM machine, and PLA is a bio degradable filament PLA is generally produced from Poly lactic acid. PLA is very easy to print which doesn’t required heated bed. The reason why PLA was selected among other brittle materials is, it exhibit a low strength capacity in tension [5]. Properties of Poly lactic Acid (PLA): 1) PLA is harder than ABS, 2) PLA melts at lower temperature than ABS i.e. 210^0 C, 3) Heated bed is not mandatory, 4) Nozzle temperature is maintained at 190 to 215^0 C. Physical properties are important; one must know the dimensions, size, and weight requirements for a desired part or product. For example, if used by a surgeon, it must be light enough to handle precisely as implementation of material also becomes much easier and less hazardous when lighter [6].

IV. PROJECT METHODOLOGY FLOW CHART

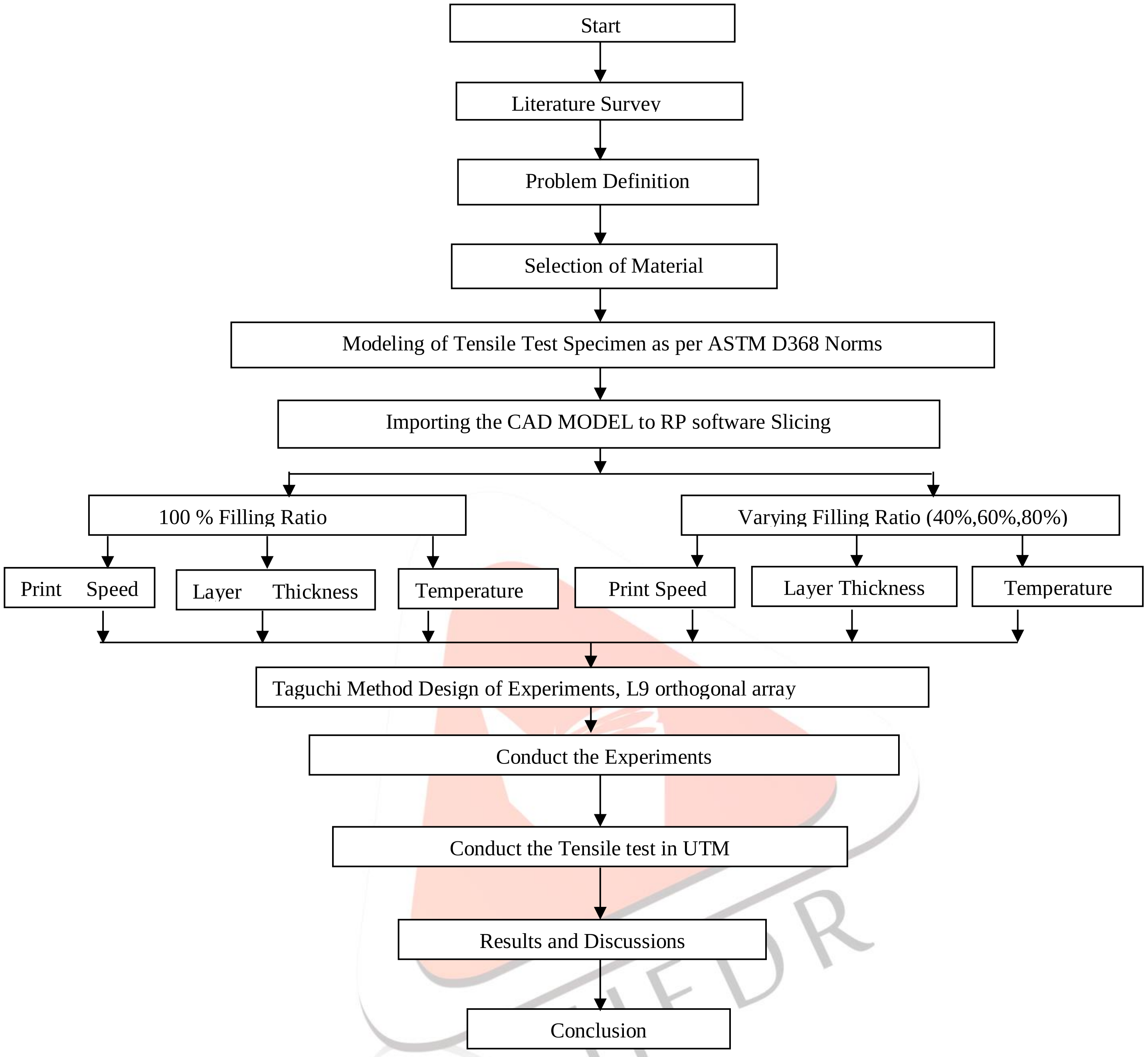

Fig.4 Flow Chart of Project Methodology

V. INTRODUCTION TO 3D PRINTING METHODLOGY

In the present study, the interactions among four parameters were neglected in order to simplify the test. The orthogonal factor level table is shown in Table 2. Optimum FDM process parameters of PLA tensile specimens were selected by the orthogonal test of four factors and three levels, with the printing temperature, printing speed, layer thickness and filling ratio[7], is for with filling ratio and Table 3.3 is for without filling ratio(i.e.,100%). L9 orthogonal array design was selected to improve experimental efficiency, as shown in Table 3.2. The Tensile properties of the PLA specimens were measured with the universal testing machine (Dak System Inc Test Bench, MSME, HYDERABAD, 250KN) by ASTM D638 Standards The Orthogonal factor levels and L9 Orthogonal arrays are listed in table 2 and 3 respectively.

Table.2. Orthogonal Factor Level (4x4) Table for PLA FDM

Levels	Print Speed(mm/s)-A	Layer Thickness(mm)-B	Filling Ratio(%)-C	Temperature(^{0}C)-D
1	40	0.15	20	205
2	60	0.20	40	210
3	80	0.25	60	215

Table.3. Orthogonal Factor Level (3x3) Table for PLA FDM (100% Filling Ratio)

Levels	Print Speed(mm/s)-A	Layer Thickness(mm)-B	Temperature(0C)-C
1	40	0.15	205
2	60	0.20	210
3	80	0.25	215

Table-4. L9 Orthogonal Array Design for PLA FDM

FACTORS				
Sl. No	A	B	C	D
1	40	0.15	20	205
2	40	0.20	40	210
3	40	0.25	60	215
4	60	0.15	40	215
5	60	0.20	60	205
6	60	0.25	20	210
7	80	0.15	60	210
8	80	0.20	20	215
9	80	0.25	40	205

Table-5. L9 Orthogonal Array Design for PLA FDM (100% Filling Ratio)

FACTORS			
FACTORS			
Sl. No	A	B	C
1	40	0.15	205
2	40	0.20	210
3	40	0.25	215
4	60	0.15	210
5	60	0.20	215
6	60	0.25	205
7	80	0.15	215
8	80	0.20	205
9	80	0.25	210

VI. FDM MACHINE HARDWARE

Fig.5. Flash Forge Finder Printer Fused Deposition Modeling Machine

FDM machine is the one the type of 3D printing machine, in which the thermoplastic filament is going to heated in the nozzle and passed through the extruder. In the extruder drive wheels are present to control the speed of the filament. This heated filament is going to form object by depositing layer by layer according the slicing parameters which is given in Flash print software.

Table.6 3D Printer Specifications

Name	Finder
Number of Extruder	Single
Print Technology	Fused Deposition Modeling(FDM)
Screen	3.5"color IPS Touch Screen
Build Volume	140*140*140mm
Layer Resolution	0.1-0.5mm
Build Precision	+/- 0.1mm
Position Precision	Z axis 0.0025mm, XY0.011mm
Filament Diameter	1.75mm
Nozzle Diameter	0.4mm
Build Speed	24CC/hr
Software	Flash print
Support Formats	Stl, obj
Operating System	Windows, Mac OS
Device Size	420 × 420 × 420mm
Weight	10.75Kg
AC Input	100-240V, 50-60Hz, 100W
Connectivity	USB cable, USB stick, WIFI

VII. SAMPLE PREPARATION PROCESS

Tensile test specimen is designed according ASTM D638 [8] standards, for that designed model in CATIA V5 R20, then these model is saved in STL format. These STL file is imported into Flash print software and divided into number of layers this process is called slicing. According to code generated in Flash print software the 3D printer is going to print the part. Tensile testing on the filament alone without having been extruded through the printing process was also tested. Several displacement rates were used to test the filament [9]. Inside fill pattern was made of honeycomb structure, this structure gives more strength than any other pattern [10]. In the below figure 8, the STL Tensile test specimen file is sliced into 30 layers with fill density as 100%.

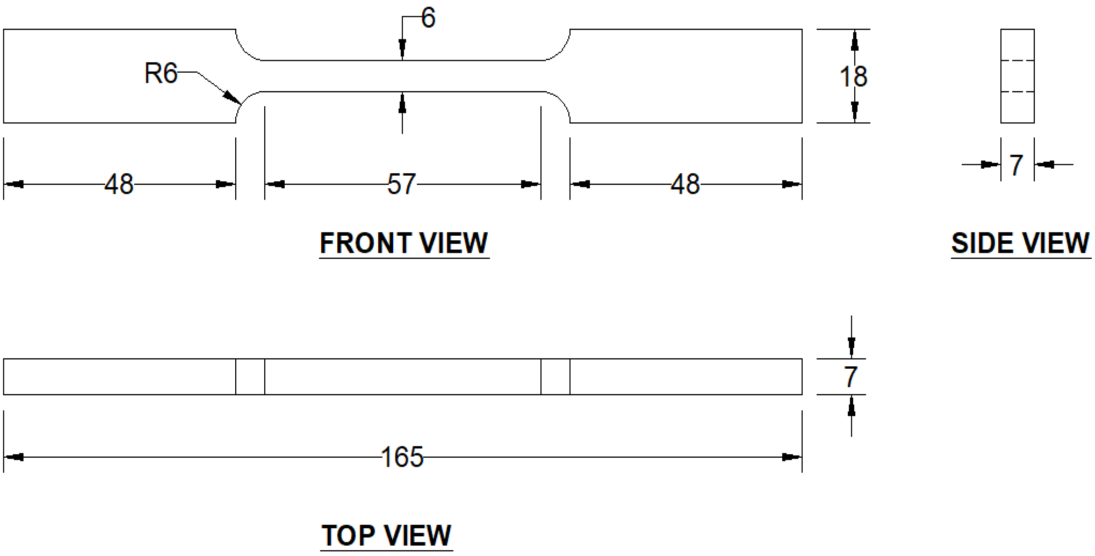

Fig.6. 2D Diagram of tensile specimen

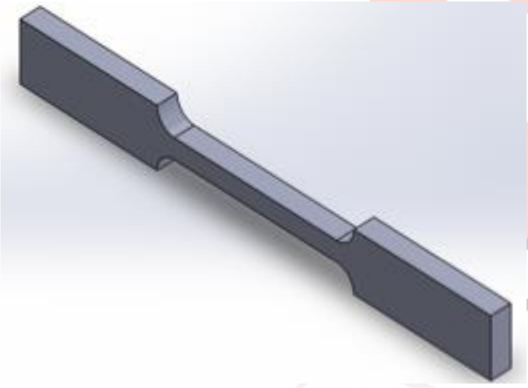

Fig.7. 3D diagram of tensile test specimen

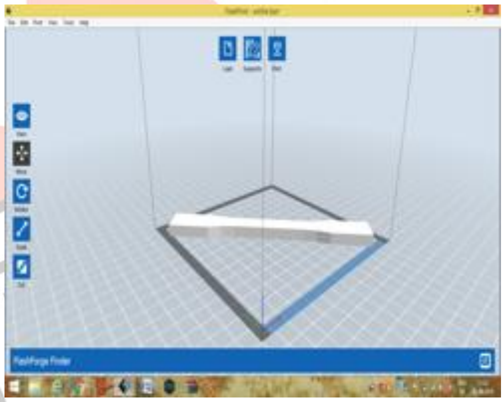

Fig.8. STL file imported to Flash Print software

Similarly by making important settings and changing settings in flash print software like Print Speed, Infill Ratio, Layer Thickness and Temperature by seeing the Table 4,5 respectively we get the specimens which shown in below figures 9, 10 respectively.

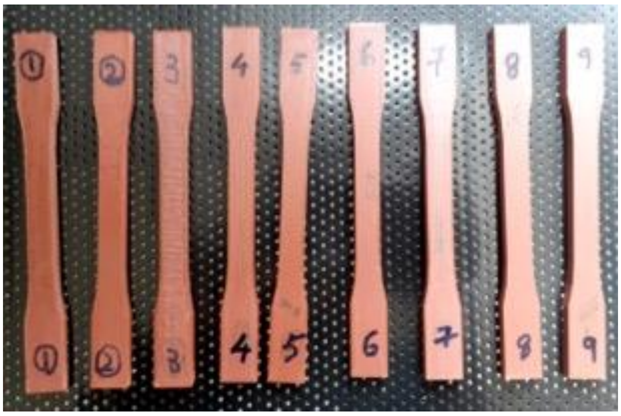

Fig.9. Final Tensile Specimens from 1-9 no's

Fig.10.Final Tensile Specimens (100% Filling Ratio) from 1-9 no's

VIII. MECHANICAL TESTING OF FDM PRINTED SPECIMENS

Table 7.Input Data of All Tensile Specimens

INPUT DATA	
Specimen shape	Flat
Material type	Plastic (PLA)
Specimen description	Tensile PLA-1
Specimen width	13mm
Specimen thickness	7mm
Gauge length for % Elongation	50 mm
Pre load value	0 KN
Max. load	250KN
Max. Elongation	200mm
Specimen cross section area	91mm^2

Fig.11. UTM machine

Fig.12. PLA Specimen-1 During Testing

In this project for testing of 3D printed specimen of PLA used UTM machine of load 250kN is used.

Fig.13. PLA Tensile Test Specimens After Testing

Fig.14. PLA tensile test specimens (Filling Ratio 100%)

IX. RESULTS AND DISCUSSIONS:

The following table represents the output tensile test results of specimen-1.

Table 8.Output Obtained for PLA Specimen-1

Output Data	Results
Peak Load(N)	1345.68
Tensile Strength (N/mm^2)	14.78
Elongation (%)	0.6
Elongation (mm)	26.52

Yield Stress (N/mm^2)	3.95
Yield Strain (mm)	22.45
Final Gauge Length (mm)	50.3

Table.9. Output obtained for PLA specimens 1-9 with 100% filling ratio

SAMPLE No.	TENSILE STRENGTH (N/mm^2)	LOAD (KN)
1	49.197	4.720
2	35.276	3.280
3	39.754	4.000
4	38.572	3.640
5	28.520	2.680
6	42.744	4.000
7	29.014	2.680
8	19.642	1.800
9	39.805	3.760

Table.10. Response Table for Signal to Noise Ratio

Level	Print Speed(mm/sec)	Layer Thickness(mm)	Temperature(C)
1	31.70	31.05	30.22
2	31.15	28.64	31.56
3	29.04	32.20	30.11
Delta	2.67	3.56	1.44
Rank	2	1	3

Form the above set of combination of varying filling ratios the optimum theoretical tensile strength is obtained as 30.5411 N/mm^2 and the experimental tensile strength is obtained as 29.014 N/mm^2 and the difference between theoretical and practical is 1.5271 N/mm^2.

Form the above set of combination of 100% filling ratios the optimum theoretical tensile strength is obtained as 48.283 N/mm^2 and the experimental tensile strength is obtained as 49.197 N/mm^2 and the difference between theoretical and practical is 1.5271 N/mm^2.

X.CONCLUSIONS

The Effect of FDM process parameters of temperature, print speed, layer thickness, and Filling Ratio PLA material was first systematically investigated in this study and also tensile test was performed. The influences of printing temperature, filling rate, layer thickness and printing speed on tensile properties were analyzed by L9 orthogonal array of four factors and three levels. The range analysis indicated that the optimal combination of tensile strength is printing speed of 60 mm/s, layer thickness of 0.25 mm, printing temperature of 210°C and filling rate of 60%. From the above set of combination the optimum tensile strength is obtained as 29.014 N/mm^2. Then further we tested same as keeping filling ratio as 100% and remaining parameters like Print speed, layer thickness and temperature will vary according orthogonal L9 array design of experiments and tensile tests were performed. The range analysis indicated that the optimal combination of tensile strength for filling ratio 100% is printing speed of 40 mm/s, layer thickness of 0.25 mm, printing temperature of 210°C. From the above set of combination the optimum tensile strength for 100% filling ratio is obtained as 49.197 N/mm^2. Comparing with normal varying filling ratio tensile specimen, the 100% filling ratio tensile specimen has more tensile strength.

XI. FUTURE SCOPE

We can do same work on other materials like Acrylonitrile Butadiene styrene (ABS), High impact poly styrene (HIPS), Carbon fiber Filament (CFF), Metal Composition Filament (MCF), etc. We can perform and find other mechanical tests like flexural test, impact test, etc with same PLA and other than PLA materials. We can do ANSYS work and analyze where the stresses and strains were acting on each individual specimen and compare the strengths of structural and solid specimens. We can do same work on different build orientation types of infill hexagonal patterns like 30^0, 45^0, 60^0, 90^0 and find the solid and structural tensile strengths.

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