# OPTIMIZATION OF PROCESS PARAMETERS FOR IMPROVING MECHANICAL STRENGTH OF PLA PLASTICS USING TAGUCHI METHOD

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**Abstract -** *Fused Deposition Modelling (FDM) is one of the most widely used additive manufacturing process to produce the prototypes from CAD model that empowers the development of three-dimensional objects through a computer aided or driven manufacturing process. The present study focuses on the process parameter effects for the rigidity of FDM part. Hence, two parameters such as infill density and printing pattern and three levels (80, 90, 100 and line, hexogen, triangle) are examined for the experimental design. L9 orthogonal array has been used for this project. The Poly Lactic Acid (PLA) material is used as filament in FDM process. The specimens are fabricated using FDM technology as per D638 standards. Using UTM machine. To maximize the tensile strength of FDM printed PLA parts MINITAB software is used concerned with optimisation.*

***Key Words***: **Optimization, Design of Experiments, Poly Lactic Acid, Fused deposition modelling, Tensile Strength.**

## 1. INTRODUCTION

Additive manufacturing is a procedure of addition of materials for creating three dimensional solid objects from a CAD model. The 3D printing is a method of implementing the material addition by layer until the final model is obtained, thus producing a three-dimensional physical product that has the structure as 3D model data. Fused Deposition Modelling (FDM) is building a component in layers by material deposition from a digital 3D designed data file. PLA is a most popular material for 3D printing owing to its excellent bio-compatibility and sustainability. The melting point for PLA material is very low (160-170°C). Due to its characteristics, PLA is a most common material for FDM 3D printing. The honeycomb structure has the highest strength when compared to lattice shaped structures. The specific tensile strength showed that the 3D printed samples with lattice-shaped structure provides the adequate strength with decreased mass [1]. The low mechanical properties may cause several defects such as high porosity, poor compaction and adhesion between filament layers in sample parts. PLA, wood and carbon fibre-based PLA materials has better printing formability than ceramic, copper and aluminum-based PLA in upright orientation [2]. Full factorial experimental design is used in investigation of influencing process parameters namely air gap, raster width, raster angle, contour number and contour width. The raster angle has vital role on the tensile strength of FDM parts [3]. The Reverse CAD model is the virtual replica of the parts printed with specific printing parameters with layer thickness and infill density. The algorithm is well suitable for precise modelling and analysis of the FDM printed part behaviour [4]. Formation of air pores during printing process reduces the properties of printed parts in FDM, and 80% properties of injection moulding parts were obtained from the optimization of PEEK and PEI parts [5]. FEA indicates that increase in layer thickness increases the elongation and tensile stress varies by decreasing first and then increases [6]. Taguchi method is an experimental design used to determine significance of the parameters for stereolithographic 3D printing. The post cure temperature considerably has an effect on flexural strength and hardness, while the exposure resolution significantly influenced on the error of width of the 3D-printed objects. An orthogonal array technique is used that can minimize the number of experiments and thus results in reduction in time and cost [7]. In FDM parts the strength difference occurs due to weaker bonds present between the layers. To obtain higher bond strength of specimen post heat treatment is applied on 3D printed objects [8]. The different parameters of prints mainly print orientation and infill ratio that finds the amount of material inside printed part [9].

The present study focuses on influences of process parameters such as printing pattern and infill density on tensile strength of the FDM printed parts. The experimental design is determined using design of experiments. The 3D printing of PLA specimens is carried out using Instabot 3D S2 machine. Then, the tensile test is performed using UTM machine. The optimization is performed to obtain the maximum tensile strength of PLA specimen using taguchi method.

## 2. EXPERIMENTAL DETAILS

### 2.1 Design of experiments

Design of Experiments is an experimental strategy for examine the consequence of multiple factors by running tests at various levels of the factors simultaneously. Taguchi has formulated a systematic method to make use of the Design of Experiments (DOE) method to improve the product quality and processes. DOE is a substantial statistical procedure for product/process design improvement and solving problems occurring during production of parts. By implementing the Taguchi Parameter Design techniques, the performances of designed product is improved and process designs enhance the stability of functioning and it is cost effective Build insensitivity (Robustness) regarding un controllable factors.

**Table – 1** Parameters and its levels.

| Parameters | Levels | | |
|---|---|---|---|
| | Low | Medium | High |
| Infill Density (%) | 80 | 90 | 100 |
| Printing Pattern | Line | Triangle | Hexagon |

The selected process parameters and its levels are mentioned in Table. In this work the parameters such as infill density and printing pattern are considered affecting the mechanical properties of 3D printed specimens.

### 2.2 Orthogonal Array

The L9 orthogonal array is designed for two parameters and three levels by applying design of experiments. Hence, an experiment plan to fabricate a total of 9 samples as dog bone shape for conducting tensile test.

**Table – 2** Orthogonal Array

| S. No | Infill Density (%) | Printing Pattern |
|---|---|---|
| 1 | 80 | Line |
| 2 | 90 | Line |
| 3 | 100 | Line |
| 4 | 80 | Triangle |
| 5 | 90 | Triangle |
| 6 | 100 | Triangle |
| 7 | 80 | Hexagon |
| 8 | 90 | Hexagon |
| 9 | 100 | Hexagon |

The L9 orthogonal array is designed for two parameters and three levels using design of experiment.

### 2.3 3D Printing Process

The STL file type is the standard format implemented in industries for 3D Printing process. The Computer Aided Design file format must convert into STL format. The designed model is then modified into G-code, the machine language through slicing process and is set to print. The STL file format reconstruct the relative arrangement of the parts of a solid model through a series of liked triangles. The G code file instructs the 3D printer where to start the printing point in each layer and the route that the nozzle or print head will follow in laying down the material. Program slicing can be used in debugging to locate the source of error accurately. The 3D models are sliced into layers initially and then the 3D printer prints the model by depositing the material layer by layer. The slicing algorithm plays a vital role in the 3D printing process. The most common technique for slicing is to make contour data from STL files. The Ultimaker Cura software which is widely used software which help to convert STL file format to G-code for the given geometry and properties. This mould was printed by using the INSTABOT 3D S2. The bed size of this machine is 240x240x300 mm. The nozzle diameter and layer thickness of this machine is fixed and it cannot be changed.

The following properties are given while generating the G-code in the Cura software. The printing properties are 0.28mm layer height, $215^0$ C bed temperature and $40^0$ C printing temperature.

The layer height in this fused deposited modelling machine is fixed and it varies with reference to the machine. For this insta bot 3D S2 series the layer height is 0.28 mm. Infill density refers to amount of material to be filled while printing. Infill density relate to the strength of print which defines the internal structure of the print. We can print the object complete hollow by setting the infill density to 0% and printing temperature depends upon the material usage. PLA is harder than ABS which has a glass transition temperature of 60-60 $^0$C and melts at lower temperature around 180°C to 220°C. The nozzle temperature must be more than the melting point, so that while printing the material melt and form new structure. Thermal expansion of concerned material is low when compared to other materials. The degradation rate is very slow in ambient temperatures.

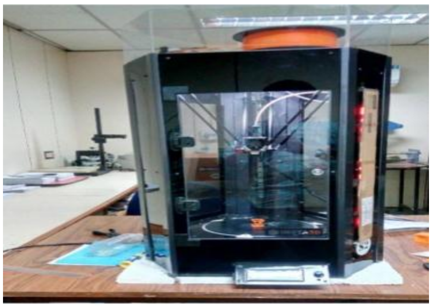

Fig – 1 : FDM machine

The FDM machine used of fabricating 3D parts is shown in figure. In FDM the material is heated in nozzle and so deposited layer by layer. The nozzle can travel horizontally through the platform and it moves up and down vertically after each new layer has deposited.

## 2.4 Tensile test

Tensile test specimen is made according ASTM D638 standards, for that model is designed in SOLIDWORKS, then these models is saved in STL format. The mechanical behaviour of a part is the way that the material reacts to a mechanical stress. The deformation of the component is mainly depend on the direction of the applied force and the mechanical properties and size of the component geometry.

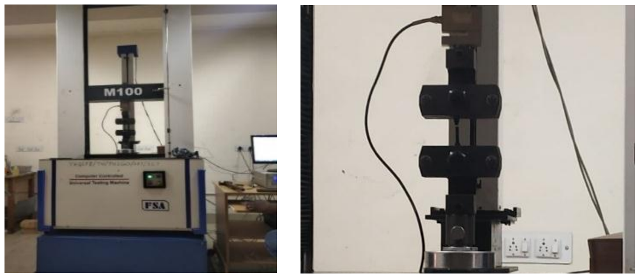

Fig – 2 Universal Testing Machine

The UTM machine for tensile test is shown in figure. There is no postprocessing of test specimens. Tensile tests are made according to ASTM D638, at an ambient temperature of 23°C and 50% relative humidity. The velocity is 5 mm/min and the specimens are loaded until the failure. For this test a load cell of 5KN is used.

## 3 RESULTS AND DISCUSSION

The input data for tensile test is described as follows:

Specimen Shape : Flat

Specimen Type : Plastic

Specimen Width : 10 mm

Specimen Thickness : 5 mm

Initial G.L. For % elong : 80 mm

Pre Load Value : 0 kN

Max. Load : 30 kN

Max. Elongation : 1000 mm

Specimen Cross Section Area: 50.000 $mm^2$

The tensile tests were made to find the effect on strength of FDM specimens. Using universal testing machine tensile tests were undergone. The load is applied to the cross section of the specimens, and changes are observed. The specimen samples with dimensions such as 10 mm width and 5 mm thickness is selected for tensile testing.

**Table – 3** Tensile strength for printed samples

| S. No | Infill Density (%) | Printing Pattern | Tensile Strength (MPa) |
|---|---|---|---|
| 1 | 80 | Line | 19.320 |
| 2 | 90 | Line | 20.664 |

| | | | |
|---|---|---|---|
| 3 | 100 | Line | 28.020 |
| 4 | 80 | Triangle | 19.896 |
| 5 | 90 | Triangle | 20.652 |
| 6 | 100 | Triangle | 28.404 |
| 7 | 80 | Hexagon | 19.994 |
| 8 | 90 | Hexagon | 21.000 |
| 9 | 100 | Hexagon | 28.872 |

The tensile strength for nine 3D printed samples are shown in table.

### 3.1 Optimization

Optimization of process parameters are carried out using taguchi method. The response table for SN ratio and means are shown in Table.

**Table – 4** Response table for SN ratio

| Level | Infill Density | Printing Pattern |
|---|---|---|
| 1 | 27.04 | 25.94 |
| 2 | 27.11 | 26.35 |
| 3 | 27.22 | 29.08 |
| Delta | 0.18 | 3.3 |
| Rank | 2 | 1 |

**Table – 5** Response table for Means

| Level | Infill Density | Printing Pattern |
|---|---|---|
| 1 | 22.77 | 19.82 |
| 2 | 22.98 | 20.77 |
| 3 | 23.27 | 28.43 |
| Delta | 0.50 | 8.61 |
| Rank | 2 | 1 |

From the Table it is identified that maximum SN ratio for infill density is 27.22 at 3rd level. The maximum SN ratio for printing pattern is 29.08 at 3rd level. The delta value for infill density is 0.18 and the delta value for printing pattern 3.13. Hence, the optimized parameters to maximize the tensile strength of specimens were obtained from the response table. The maximum tensile strength can be obtained at the infill density of 100% and hexagonal printing pattern.

The Figure exhibits the main effect plots for SN ratio and means. Also it shows that the infill density is least influencing parameter which affects the tensile strength of FDM specimens. Because the infill density delivers less variation when the level of parameter changes.

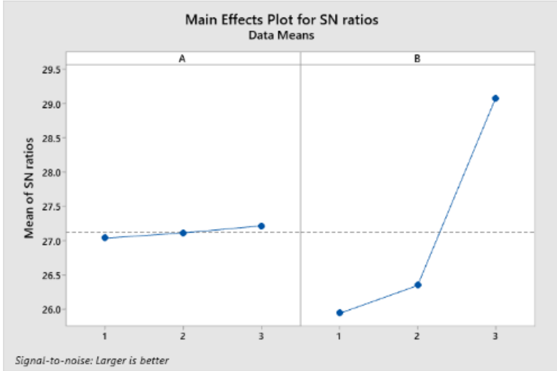


Fig – 3 Main effects plots for SN ratios

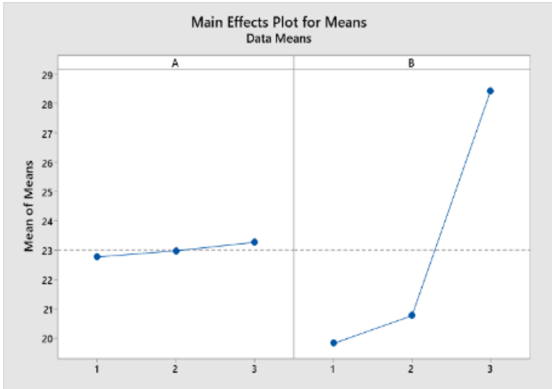


Fig – 4 Main effects plots for Means

The Figure shows the main effect plots for SN ratio and main effect plot for means. The printing pattern is the most influencing parameter affecting the tensile strength of FDM printed PLA specimens. And the parameter of hexagonal printing pattern is major influencing parameter that affecting the tensile strength of FDM specimens. Because the printing pattern exhibits more variation when the level of parameter changes.

## 4. CONCLUSION

The Effect of FDM process parameters such as infill density and printing pattern of PLA material was first systematically investigated in this study and also tensile test was performed. Effect of printing pattern, infill density on tensile properties were analysed by L9 orthogonal array of two factors and three levels. The range analysis indicated that the optimal combination of tensile strength is hexagonal printing pattern and filling rate of 100%. From the above set of combination, the optimum tensile strength is obtained as 28.872 N/mm2. Comparing with normal varying filling ratio tensile specimen, the 100% filling ratio and hexagonal printing pattern tensile specimen has more tensile strength. The printing pattern is the most influencing parameter affecting the tensile strength of FDM specimens.

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