

# Comparative Analysis of 3D Printed Material Properties Through Optimization of FDM Process Parameters

Kiran A Gund<sup>1</sup>, Prasad M. Patare<sup>2</sup>, Dilip A. Patil<sup>3</sup>

Department of Mechanical Engineering, Sanjivani College of Engineering, Kopergaon.

Autonomous Engineering By UGC & SP Pune University;

Department of Mechanical Engineering, Sanjivani KBP Polytechnic College , Kopergaon.

**Abstract** - Additive Manufacturing (AM), particularly Fused Deposition Modelling (FDM), has emerged as a widely adopted technology for producing complex polymer components with reduced manufacturing time and cost. However, the mechanical performance of FDM-printed parts is significantly influenced by process parameters and material selection. This study investigates the effect of five key parameters—material type, wall thickness, infill pattern, infill density, and layer height—on the tensile properties of FDM-printed specimens. Three commonly used thermoplastic materials, namely PLA, ABS, and PETG, were selected for experimentation. An L27 orthogonal array based on the Taguchi design method was employed to optimize the process parameters and minimize the number of experimental trials. ASTM standard tensile specimens were fabricated using an FDM printer and tested on a Universal Testing Machine (UTM) to evaluate Ultimate Tensile Strength (UTS), Yield Strength (YS), and Percentage Elongation. The experimental results revealed that PLA exhibited the highest tensile strength of 17.75 MPa, while PETG demonstrated a comparable tensile strength of 17.58 MPa with superior ductility, achieving 14.66% elongation. ABS showed lower tensile strength but greater deformation characteristics before failure. Among all tested combinations, the specimen fabricated using PLA material, 1 mm wall thickness, cubic infill pattern, 30% infill density, and 0.2 mm layer height exhibited the best tensile performance. The study concludes that material selection and optimization of printing parameters play a crucial role in enhancing the mechanical properties of FDM-printed components, with PETG offering the best balance between strength and ductility and PLA providing the highest tensile strength.

**Keywords**- fused deposition modelling; additive manufacturing; evolutionary algorithms; Multi objective optimization; Design of experiment.

## I INTRODUCTION

Additive manufacturing (AM) has raised interesting awareness from society as state-of-the-art technology, in which engineers can build and adjust 3D complex geometry objects quickly to satisfy changes of customer's requirements and market. Several existing technologies with varying material types and forms have been developed intensively in AM field. Some commonly used AM techniques can include fusing of molten filament material (FDM), selective laser sintering/melting (SLS/M), electron beam melting (EBM), laser-photo resin curing (SLA), and laser cutting of sheet material (LOM). FDM was first introduced in 1992 by American company Stratasys. Currently, FDM technology, works with specialized 3D printers, allows producing accurate parts with geometries and cavities complexity [1]. Nowadays, small commercial machines with FDM based technology have a very reasonable price and become popular appliances in education organization, company and even at home. The main FDM materials are PLA, ABS, PET, Nylon, TPU (flexible) and PC. This research works with PLA (polylactic acid) which are the most popular material in the market today. PLA

provides good visual quality for products. However, it is quite rigid and brittle. Like 3D printing with other materials, FDM 3D printing using PLA is currently facing many problems about parameters control. The default setting of printing process parameters given by the manufacturers cannot ensure the quality of printing products because many parameters can affect the printing process. Wrong initial set up for printing parameters can result in excessive time, unnecessary weight and low tensile strength, and thus raise the production cost, waste material and make difficulties for individual users. In recent years, there are many research publications for optimizing the parameter setup, which concentrates on FDM 3D printing with PLA. Tymrak, et al. investigated the impact of printing parameters at different values, i.e., pattern orientation and layer thickness to tensile strength and modulus elasticity of PLA and ABS parts. In similar research topic, Singh Bual and Kumar found that the surface finish of plastic patterns made by FDM could improve by choosing proper build orientation and reducing layer thickness. Zaldivar et al. researched the print orientation effects on the mechanical and thermal properties, and the strain field behaviors of ULTEM 9085. They concluded that build orientation affects the tensile strength, failure strain, Poisson's ratio, coefficient of thermal expansion and modulus significantly, Johansson (2016) concluded that the main factors affected the quality of

printing product is printing temperature, printing speed, and layer height. Printing at 250 °C can help to increase seven times of load capacity than printing at 190 °C. In term of layer height, 91% load capacity was boosted when printing at 0.1mm layer height instead of 0.4mm. Besides, 10 mm/sec printing speed illustrates better bonding connection than 130 mm/sec printing speed. Other concerned printing parameters such as infill rate, density, raster angle also are studied in current years. In this research, four common printing parameters, i.e., layer height, infill percentage, printing temperature, printing speed, were investigated to show their effects to weight, printing time and tensile strength of printed parts produced by FDM 3D printer using PLA material. Choosing parameter set to optimize Multiobjective for 3D printing was studied and suggested by analyzing experiments and regression models [3].

The potentials of additive manufacturing (AM) to produce the parts for various applications including prosthetics, automotive, intelligent structure and defense show its increasing recommendations. It is able to fabricate the parts using a variety of materials ranging from plastics to metals. Many AM systems are commercially available such as stereo lithography apparatus (SLA), selective laser sintering (SLS), fused deposition modeling (FDM) and three-dimensional printing (3DP) for advanced applications. Among all available AM systems, FDM technology is the most widely used process for polymeric material. The major advantages of FDM technology are material availability, material diversity, cheaper, compact size and low working temperature. Based on the literature survey many studies also revealed some disadvantages of FDM technology such as surface properties, slow process and limits of dimensions. Researchers also performed the optimization of process parameters for avoiding limitations of FDM process. Therefore, this study inspired to analyze the potential of bio-inspired infill patterns through additive manufacturing

## II METHODOLOGY

### 1. Design Selection:

A standard design (ASTM D638 Type VI) will be chosen for printing. The design should be simple enough to conduct break tests.

### 2. Printing:

1. Print 27 copies of the selected design, with 9 copies made from each of the three materials.
2. Use diverse slicing parameters for each print. Parameters to vary include: Layer height, Print speed, Infill density, Print temperature.
3. Document the slicing parameters used for each print.

### 3. Testing:

1. Conduct a break test on each printed part to measure the maximum stress it can handle. This test will help determine the strength of each part.
2. Record the print time for each part.

#### 4. Analysis:

1. Compare the results to identify trends and correlations between slicing parameters and the three main performance metrics (UTS, Yield strength, Elongation %).
2. Determine the optimal set of slicing parameters for each material that balances fast printing and high strength.

### III METHOD OF SELECTION OF ARRAY

**1. Taguchi method:-** The Taguchi method of quality control is an approach to engineering that emphasizes the roles of research and development (R&D), and product design and development in reducing the occurrence of defects and failures in manufactured goods.

Today many engineers are using Taguchi's catalog of orthogonal arrays to plan industrial experiments. But Taguchi provides either no information or insufficient information on the methods that were used to construct these arrays. Moreover, Taguchi displays orthogonal arrays in forms that are different from the way these arrays are usually displayed in the statistical literature. It is, therefore, difficult to discern the links between Taguchi's arrays and their counterparts published elsewhere. Recent advertisements and testimonials of the efficacy of experiments based on Taguchi's orthogonal arrays increase the confusion by giving an impression that these arrays are something other than fractional factorials and classical plans of experiments.

Taguchi's catalog contains 20 arrays. However, only 18 of these arrays are orthogonal arrays. These 18 orthogonal arrays are the focus of this paper, and they have been classified into eight groups defined in such a way that the orthogonal arrays in each group can be constructed by a common method. The subsequent eight sections are devoted to these eight specific groups. In these sections, first the constructions of Taguchi's orthogonal arrays are described and then these arrays are related to fractional factorials and other well-known orthogonal arrays.

**Table 1- Taguchi Designs Table**

| n\k | 3    | 4    | 5      | 6     | 7       | 10       | 11    | 12 | 13      | 15    |
|-----|------|------|--------|-------|---------|----------|-------|----|---------|-------|
| 4   | L4/2 |      |        |       |         |          |       |    |         |       |
| 8   |      |      |        |       | L8/2    |          |       |    |         |       |
| 9   |      | L9/3 |        |       |         |          |       |    |         |       |
| 12  |      |      |        |       |         |          | L12/2 |    |         |       |
| 16  |      |      | L16b/4 |       |         |          |       |    |         | L16/2 |
| 18  |      |      |        |       | L18/3.6 |          |       |    |         |       |
| 25  |      |      |        | L25/5 |         |          |       |    |         |       |
| 27  |      |      |        |       |         |          |       |    | L27/3.2 |       |
| 32  |      |      |        |       |         | L32b/3.2 |       |    |         |       |

#### 2. Selected Array for experiment (L27 Array)

As we studied all the possibilities of an Orthogonal Array, we came up with some testing parameters and we selected what material should be we going to use. We used PLA, ABS and PETG material.

Process parameters like wall thickness, infill percentage, infill pattern and layer height were selected. Wall thickness was selected as 0.712, 0.8, 1 while infill pattern was as cubic, hexagonal, and triangular. Infill percentage was 10%, 20%, and 30% so to get better results and good surface finish.

Layer height was dependent on wall thickness so we did necessary calculations and Obtained as 0.178, 0.2, and 0.25.

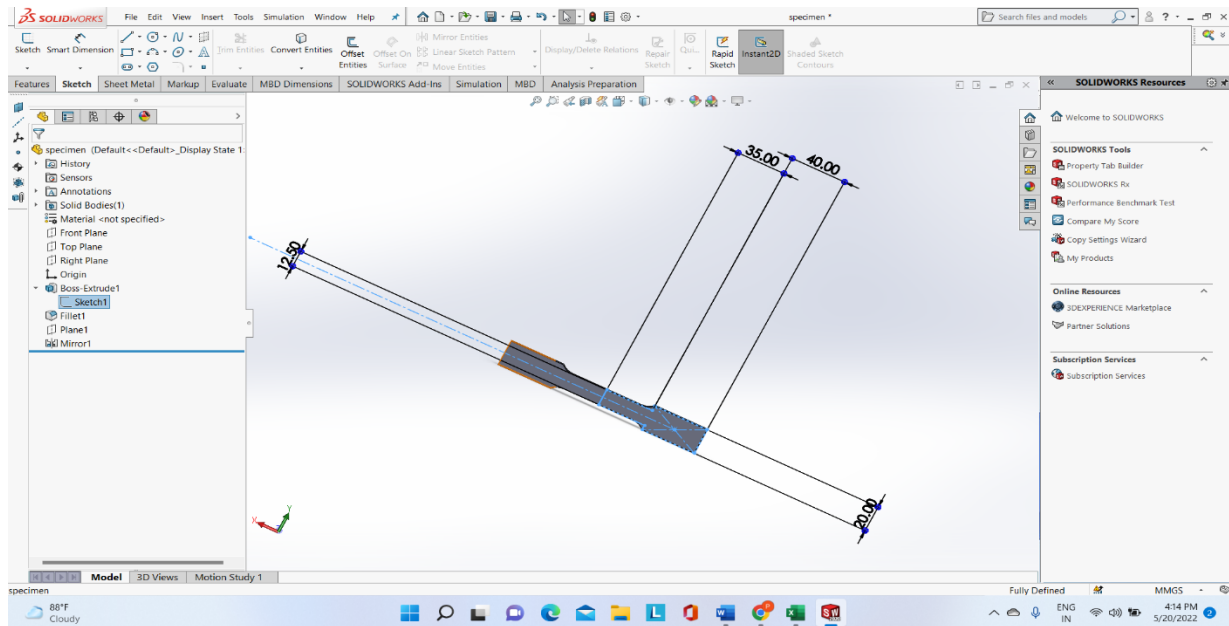
Considering all this parameter and values we created a table for all 3 materials and According to Taguchi method our array of 27 samples was created.

Table 2- L27 Array Tables

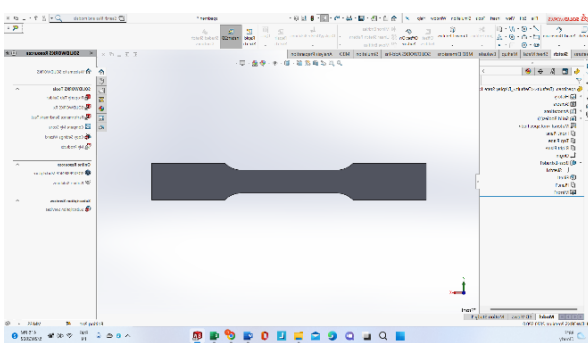
| No | X1 = Material | X2 = Wall Thickness | X3 = Infill Pattern | X4 = %Infill | X5 = Layer Height |
|----|---------------|---------------------|---------------------|--------------|-------------------|
| 1  | PLA           | 0.712               | cubic               | 10           | 0.178             |
| 2  | PLA           | 0.712               | hexagonal           | 20           | 0.2               |
| 3  | PLA           | 0.712               | triangular          | 30           | 0.25              |
| 4  | PLA           | 0.8                 | cubic               | 20           | 0.25              |
| 5  | PLA           | 0.8                 | hexagonal           | 30           | 0.178             |
| 6  | PLA           | 0.8                 | triangular          | 10           | 0.2               |
| 7  | PLA           | 1                   | cubic               | 30           | 0.2               |
| 8  | PLA           | 1                   | hexagonal           | 10           | 0.25              |
| 9  | PLA           | 1                   | triangular          | 20           | 0.178             |
| 10 | ABS           | 0.712               | cubic               | 20           | 0.25              |
| 11 | ABS           | 0.712               | hexagonal           | 30           | 0.178             |
| 12 | ABS           | 0.712               | triangular          | 10           | 0.2               |
| 13 | ABS           | 0.8                 | cubic               | 30           | 0.2               |
| 14 | ABS           | 0.8                 | hexagonal           | 10           | 0.25              |
| 15 | ABS           | 0.8                 | triangular          | 20           | 0.178             |
| 16 | ABS           | 1                   | cubic               | 10           | 0.178             |
| 17 | ABS           | 1                   | hexagonal           | 20           | 0.2               |
| 18 | ABS           | 1                   | triangular          | 30           | 0.25              |
| 19 | PETG          | 0.712               | cubic               | 30           | 0.2               |
| 20 | PETG          | 0.712               | hexagonal           | 10           | 0.25              |
| 21 | PETG          | 0.712               | triangular          | 20           | 0.178             |
| 22 | PETG          | 0.8                 | cubic               | 10           | 0.178             |
| 23 | PETG          | 0.8                 | hexagonal           | 20           | 0.2               |
| 24 | PETG          | 0.8                 | triangular          | 30           | 0.25              |
| 25 | PETG          | 1                   | cubic               | 20           | 0.25              |
| 26 | PETG          | 1                   | hexagonal           | 30           | 0.178             |
| 27 | PETG          | 1                   | triangular          | 10           | 0.2               |

#### IV DESIGN OF STANDARD SPECIMEN (MODELING)

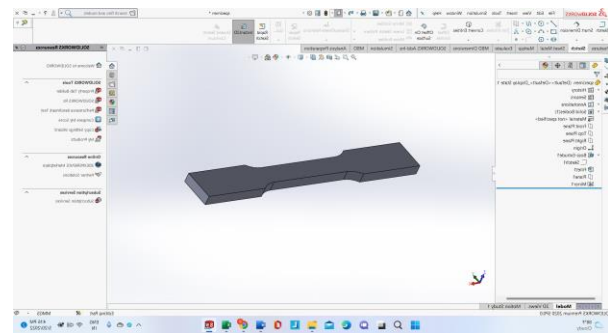
The FDM process was conducted with an in-house FDM Ultimaker S5 three-dimensional (3D) printer with a heated build plate maintained at 60 °C. The layer resolution can range from 20 to 300 microns depending on the nozzle diameter. The environmental conditions of air pressure, air temperature, and humidity were recorded and within 1% variability. A raster orientation of 45 degrees was used for all the samples. The Ultimaker Curve was used to slice and prepare the CAD model for printing. During each experimental run, an energy meter was used to measure the energy consumption. The sample dog bone shape was based on the ASTM E8M-08 Type IV standard, which is used for the tensile testing of plastic materials. The dimensions of the dog bone shape sample are shown in Figure 1, and the 3D printed sample is shown in Figur



**Figure 1- Design and Dimensions of ASTM E8M-08**



**Figure 2- Front view of ASTM**



**Figure 3- Side view of ASTM**

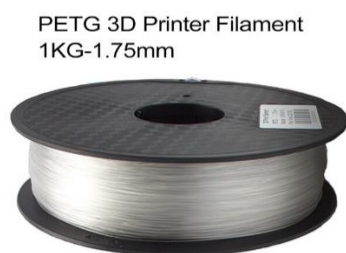
### Dimensions of Specimen

Width – 20mm  
 Height – 06mm  
 Handle length – 40mm  
 Mid-length – 70mm

Each experimental run was conducted two times, making it a total of 27 samples to allow for residual analysis. The samples were carefully labeled and stored in a vacuum-tight storage bin for further evaluation of their dimensional tolerances, followed by weight measurements. After the nondestructive quality characteristics evaluations of the samples were completed, the final destructive tensile tests were conducted on the 27 samples to evaluate their tensile strength properties.

### Material Used

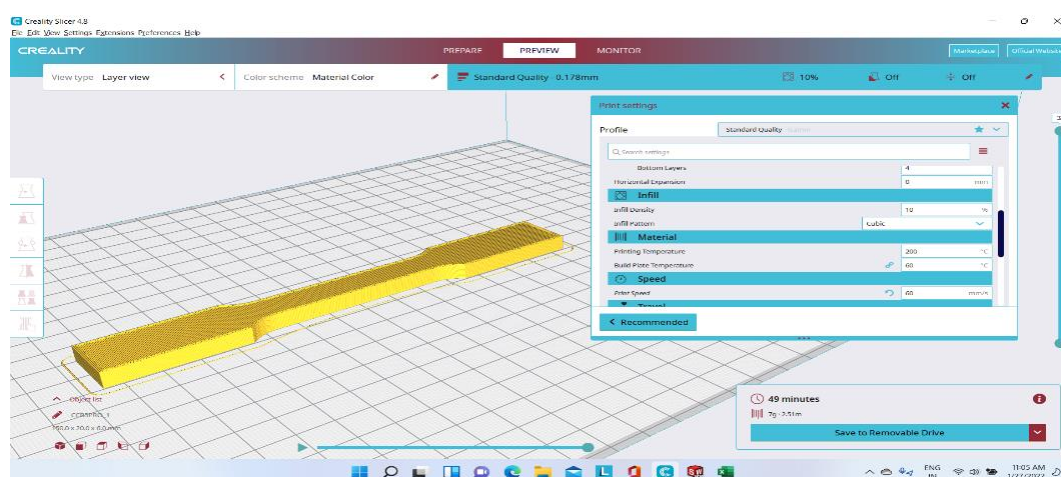
- Acrylonitrile butadiene styrene (ABS)
- Polylactic acid (PLA)
- Polyethylene terephthalate glycol (PETG)



**Figure 4. – PLA, ABS, PETG Materials**

### Slicing of model designed

When you have a designed model, you can use specific slicing software such as idea Maker to slice the model. The purpose of slicing is to allow the 3D printer to calculate the route and the amount of filament required when printing the model. Just like building a house, you need to calculate the steps to build and the amount of wood needed. idea Maker will generate a G-Code file, which is essentially a long list of instructions, and then the 3D printer will read the G-Code instruction to build the model. idea Maker is a powerful slicing software, which can create personalized configurations according to different printers, filaments, and models, it can also automatically create precise support structures. Therefore, idea Maker will provide you with more possibilities for creativity.



**Figure 5 – Slicing of designed ASTM std**

### Printing parts

After slicing is complete, you can upload the slice file to the printer, and calibrate the printer to prepare for printing. The extruders and the printing base need to be calibrated, to improve the accuracy of printing. During the printing process, you can observe the printing process through the transparent panel of a Raise3D Pro2 Series printer, or you can also monitor the printing progress remotely through our APP Raise Cloud in real-time. You will have a more intuitive and deeper understanding of the principles of 3D printing in this way. It will be a wonderful thing to observe the process of filaments accumulate layer by layer and monitor the printing progress.

**Finished Sample for testing:** When all the above process is done with this we are ready with our finished parts.



**Figure 6– Final printed parts**

## V EXPERIMENTAL SETUP

**Testing on UTM machine** The set-up and usage are detailed in a test method, often published by a standards organization. This specifies the sample preparation, fixturing, gauge length (the length which is under study or observation), analysis, etc.

The specimen is placed in the machine between the grips and an extensometer if required can automatically record the change in gauge length during the test. If an extensometer is not fitted, the machine itself can record the displacement between its cross heads on which the specimen is held. However, this method not only records the change in length of the specimen but also all other extending elastic components of the testing machine and its drive systems including any slipping of the specimen in the grips.

Once the machine is started it begins to apply an increasing load on specimen. Throughout the tests the control system and its associated software record the load and extension or compression of the specimen.

Machines range from very small table top systems to ones with over 53 MN (12 million lbf) capacity.



**Figure 7- Specimen clamped in the UTM**



**Figure 8- Elongated PLA material part no 21**

After performing the testing, we get values of stress Vs strain, Load Vs Displacement and the graphs were generated and are as follows

**Table 3- Testing Values of UTS**

| Sr. | UTS (MPa)    | YS (MPa)    | % Elongation | % Reduction Area | YS Load N      | Break Load N | Ultimate N  |
|-----|--------------|-------------|--------------|------------------|----------------|--------------|-------------|
| 1   | 16.21        | 15.11       | 12.76        | 15.89            | 1221.64        | 1050         | 1277        |
| 2   | 15.09        | 14.9        | 8.42         | 22.96            | 1210.95        | 910          | 1227        |
| 3   | 17.39        | 16.58       | 11.94        | 22.96            | 1347.6         | 520          | 1414        |
| 4   | 17.47        | 16.64       | 13.74        | 23.51            | 1352.11        | 1257         | 1420        |
| 5   | 16.99        | 15.73       | 9.8          | 13.8             | 1258.43        | 1340         | 1359        |
| 6   | 12.78        | 12.06       | 6.96         | 22.8             | 964.42         | 817          | 1022        |
| 7   | <b>17.75</b> | <b>16.7</b> | <b>12.96</b> | <b>22.96</b>     | <b>1357.41</b> | <b>1229</b>  | <b>1443</b> |
| 8   | 14.56        | 14.05       | 9.32         | 22.96            | 1141.98        | 1162         | 1184        |
| 9   | 15.63        | 14.61       | 7.92         | 23.15            | 1168.67        | 313          | 1251        |
| 10  | 10.86        | 10.67       | 11.66        | 38.65            | 840            | 212          | 856         |
| 11  | 10.29        | 9.88        | 5.2          | 38.55            | 751.45         | 363          | 713         |
| 12  | 10.13        | 9.54        | 13.7         | 23.64            | 939.18         | 627          | 785         |
| 13  | 10.75        | 10.34       | 8.74         | 16.09            | 801.18         | 126          | 833         |
| 14  | 9.03         | 8.84        | 11.14        | 23.64            | 684.64         | 277          | 700         |
| 15  | <b>12.67</b> | <b>12.2</b> | <b>4.94</b>  | <b>23.64</b>     | <b>945.39</b>  | <b>860</b>   | <b>982</b>  |
| 16  | 11.9         | 18.42       | 5.46         | 55.62            | 884.47         | 675          | 922         |
| 17  | 11.56        | 11.33       | 3.62         | 23.64            | 877.9          | 536          | 896         |
| 18  | 10.39        | 8.83        | 9.72         | 31.29            | 761.55         | 381          | 805         |
| 19  | <b>17.58</b> | <b>17</b>   | <b>14.66</b> | <b>23.94</b>     | <b>1317</b>    | <b>133</b>   | <b>1341</b> |
| 20  | 14.87        | 14          | 11.66        | 2.44             | 1095           | 163          | 1133.56     |
| 21  | 16.26        | 16          | 17.9         | 2.44             | 1196           | 126          | 1238.99     |
| 22  | 14.97        | 14          | 26.14        | 6.5              | 1077           | 115          | 1140.76     |
| 23  | 15.29        | 15          | 5.98         | 2.44             | 1126           | 948          | 1165.42     |
| 24  | 17.06        | 17          | 6.28         | 2.44             | 1272           | 890          | 1299.94     |
| 25  | 17.03        | 16          | 14.44        | 8.74             | 1214           | 130          | 1298.19     |
| 26  | 16.54        | 16          | 11.6         | 4.86             | 1242           | 126          | 1260.69     |
| 27  | 13.7         | 13          | 14.66        | 6.5              | 1013           | 583          | 1044.66     |

## VI RESULT & DISCUSSION

The tensile properties of three commonly used FDM materials (PLA, ABS, and PETG) were experimentally evaluated and compared. The average values obtained from the tensile tests indicate significant differences in mechanical performance.

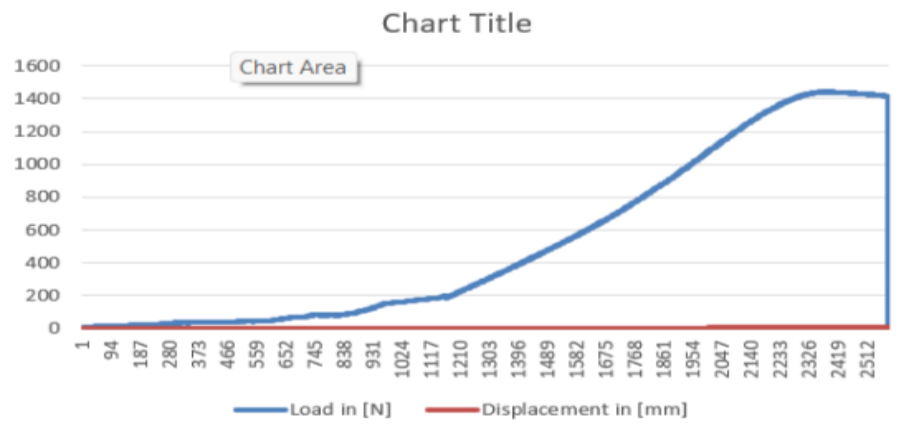


Figure 9- Load Vs Displacement of PLA specimen 7

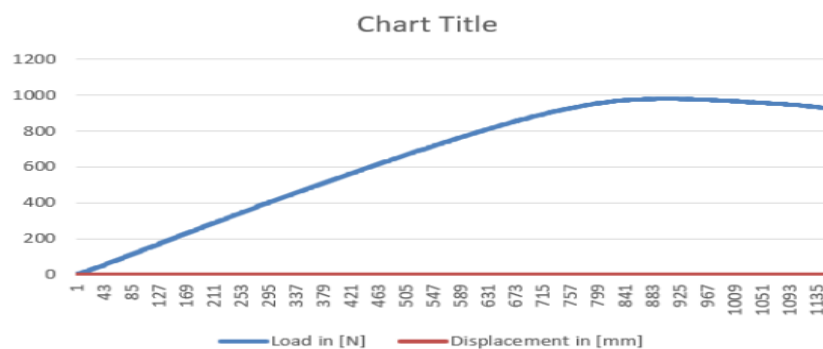


Figure 10-Load Vs Displacement of ABS specimen 15

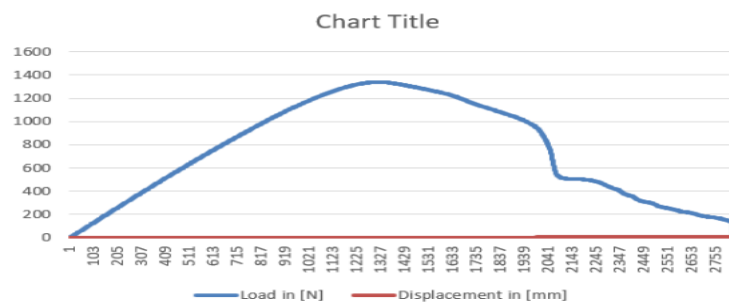


Figure 11- Load Vs Displacement of PETG specimen 19

Table 4- Comparative Results

| Material | UTS (MPa) | Yield Strength (MPa) | Elongation (%) | Reduction in Area (%) |
|----------|-----------|----------------------|----------------|-----------------------|
| PLA      | 17.75     | 16.7                 | 12.96          | 22.96                 |
| ABS      | 12.67     | 12.2                 | 4.94           | 23.64                 |
| PETG     | 17.58     | 17                   | 14.66          | 23.94                 |

The tensile properties of three commonly used FDM materials (PLA, ABS, and PETG) were experimentally evaluated and compared. The average values obtained from the tensile tests indicate significant differences in mechanical performance.

- **PLA** exhibited the highest Ultimate Tensile Strength (UTS) of **17.75 MPa**, demonstrating superior strength characteristics among the tested materials.
- **PETG** showed a comparable UTS of **17.58 MPa** and the highest elongation of **14.66%**, indicating improved ductility and toughness.
- **ABS** exhibited the lowest UTS (**12.67 MPa**) but showed the highest reduction in area (**23.64%**), suggesting greater plastic deformation before fracture.
- PETG demonstrated the best balance between strength and ductility, while PLA provided the highest tensile strength with moderate elongation.
- ABS specimens showed lower tensile strength but better energy absorption capability due to their higher deformation characteristics.

## VII CONCLUSION

In this project, five FDM printing parameters—material, wall thickness, layer height, infill density, and infill pattern—were analysed at three levels using the Taguchi L27 orthogonal array, resulting in 27 test specimens. Among the PLA samples, specimen 7 (1 mm wall thickness, cubic infill, 30% infill density, and 0.2 mm layer height) showed the highest ultimate tensile strength. Specimen 15 exhibited the best tensile strength among the ABS samples, while specimen 19 achieved the highest tensile strength among both the PETG samples and all 27 specimens tested. The experimental results provide useful reference data for future studies and rapid prototyping using Creality FDM printers. Overall, PLA offers the highest tensile strength and is suitable for rigid structural applications, PETG provides the best balance of strength and ductility for engineering applications, and ABS is more suitable for impact-resistant components due to its higher deformation capability. Therefore, PETG is recommended where both strength and toughness are required, whereas PLA is preferred when maximum tensile strength is the primary requirement.

## VIII REFERENCE

- [1] Saty Dev, Rajeev Srivastava." Experimental investigation and optimization of FDM process parameters for material and mechanical strength. Materials Today: Proceedings (2019) 1-10
- [2] V.H. Nguyen, T.N. Huynh, T.P. Nguyen and T.T. Tran -Single and Multi-Objective Optimization of Processing Parameters for Fused Deposition Modelling in 3D Printing Technology. International Journal of Automotive and Mechanical Engineering (LIAME) (2019)5-8
- [3] N.A. Fountas, J.D. Kechagias, D.E. Manolakos, N.M.Vaxevanidis - 30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021) 15-18 June 2021, Athens, Greece. Single and multi-objective optimization of FDM-based additive manufacturing using metaheuristic algorithms. (2021)1-8
- [4] D.M. D'Addona; Sunil J Raykar; Dharmendra Singh; Davorin Kramar – 4th CIRP Conference on Intelligent Computation in Manufacturing Engineering, CIRP ICME '20 Multi Objective Optimization of Fused Deposition Modeling process parameters.2020
- [5] Ian Gibson and Dongping Shi – “Material properties and fabrication parameters in selective laser sintering process”. Department of Mechanical Engineering, Bangalore Institute of Technology, Bangalore, India, 10.2478/adms-2020-0003
- [6] Ferry P.W. Melchels, Jan Feijen, Dirk W. Grijpma - A review on stereolithography and its applications in biomedical engineering. (2010)
- [7] Chamil Abeykoon, Pimpisut Sri-Amphorn, Anura Fernand- Optimization of fused deposition modeling parameters for improved PLA and ABS 3D printed structures. (2019),11:200=207, DOI:10.1007/s11804-012-1123-4,2012, Pp. 1-7
- [8] N.A. Fountas, J.D. Kechagias, D.E. Manolakos, N.M.Vaxevanidis - 30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021) 15-18 June 2021, Athens, Greece. Single and multi-objective optimization of FDM-based additive manufacturing using metaheuristic algorithms. (2021)1-8

- [9] Todd Letcher, Behzad Rankouhi, Sina Javadpour- Proceedings of the ASME 2015 International Mechanical Engineering Congress and Exposition IMECE2015, Experimental study of Mechanical properties of additively manufactured ABS plastic as a function of layer parameters Pp. 3-7