"Enhancing PLA Material Performance in FDM 3D Printing: Investigating Tensile Strength and Surface Roughness through Taguchi Methodology for Optimized Infill, Orientation, and Pattern Parameters."- A Comparative Study of FDM Material using 3D Printer

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ABSTRACT- *This study shows the effects of orientation, pattern and infill on tensile strength of PLA (polylactic acid) material 3D-printed parts produced by Fused Deposition Modelling (FDM) technology. This study investigates the effect of infill and orientation changes on the roughness and tensile strength of solid 3D-printed samples with a systematic experimental approach. The Taguchi method, famous for its efficiency in optimisation of design, simplifies the experimental design and explores the correlations between various process settings. Nine experiments are performed, focusing on key process variables like fill angle, part orientation angle and layer thickness. Their impact on response properties, such as cycle duration, surface roughness and tensile strength are the purpose of this study. The Taguchi method uses a L9OA orthogonal array, and has different parameter possibilities and levels for every experiment. The results of the experiment tell us which set of parameters is best to optimize in order to increase the tensile strength of 3D printed PLA pieces. This research is especially relevant to rapid prototyping because the cost factor of producing prototypes remains a high hurdle. In the case of 3D printing technologies based on FDM, the Taguchi method's ability to simplify experimental designs and test parameter interactions is absolutely critical to achieving effective design optimization.*

Keywords: **3D printing, FDM technology, PLA material, Taguchi method, Design Optimization, Rapid Prototyping**

1. INTRODUCTION

Additive Manufacturing (AM), also referred to as 3D printing, is a revolutionary approach that departs from conventional subtractive manufacturing techniques by building objects layer by layer. Additive manufacturing, layer manufacturing, additive procedures, additive techniques, and freeform fabrication are examples of synonyms. Global methods to product design and manufacture are greatly impacted by additive manufacturing (AM), which finds its main uses in design and modelling, fit and function prototyping, and direct part production.

When utilised properly, additive manufacturing (AM) turns out to be a time and money-saving technique that completely transforms the traditional schedules for design, development, and production. Businesses all across the world attest to the significant weeks—or even months—that AM has saved them in these processes, highlighting the avoidance of expensive mistakes and enhancements in product quality.

The objective of this work is to present a comprehensive analysis of Additive Manufacturing, examining its diverse aspects and uses. A vital component is the division of AM systems according to the original material form, which results in a broad classification into Liquid-Based, Solid-Based, and Powder-Based systems. The next sections will examine the specifics of each category, highlighting their distinct contributions to the changing field of additive manufacturing.

1.1 Conceptual Framework

Fused Deposition Modelling: The additive manufacturing technique known as fused deposition modelling (FDM) or fused filament fabrication (FFF) is a member of the material extrusion family. Layer by layer, an object is constructed using FDM by carefully depositing melted material along a predefined route. The materials are thermoplastic polymers, which are available as filaments.

The most popular 3D printing technology is FDM, which has the most installed base of printers worldwide and is frequently the first technology that people are exposed to. The fundamental ideas and important features of the technology are discussed in this article.

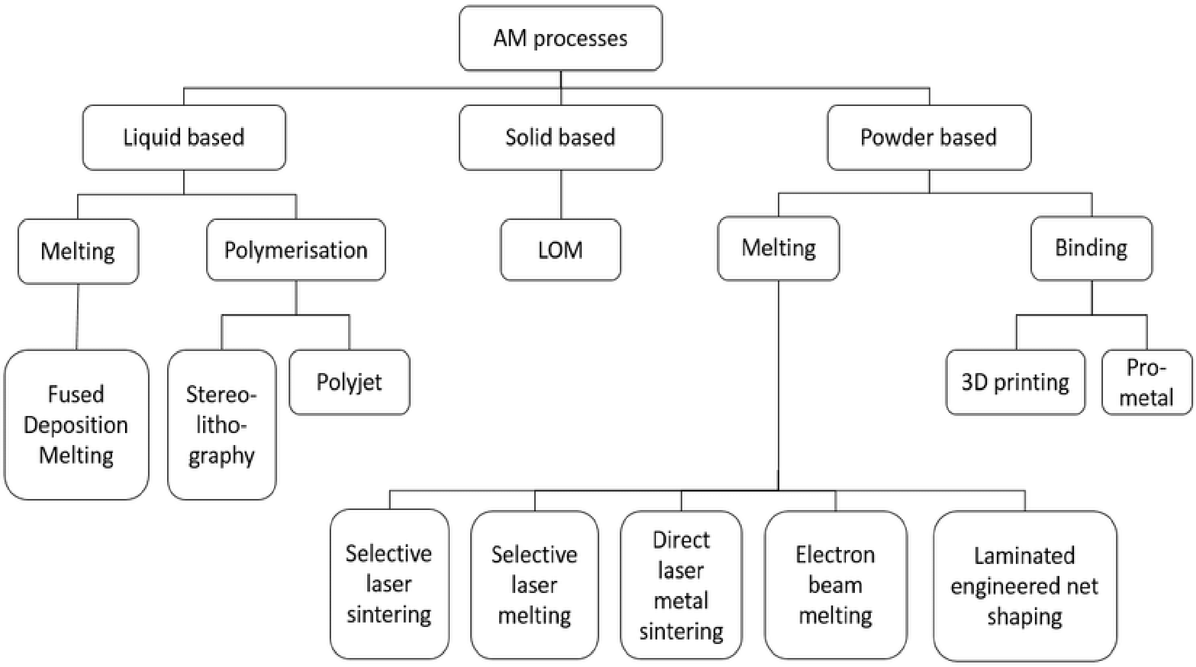


Figure 1 Detailed classification of additive manufacturing

The Technology Used: With 3D CAD data as an aid, by the Fused Deposition Modelling (FDM) technique three-dimensional objects are directly constructed. A temperature-controlled head extrudes layer after layer of thermoplastic material. In the FDM process, this begins with loading a model's STL file into a pre-processing programme. The thickness of this model ranges from +/- 0.127 to 0.254 mm; it is along the plane and mathematically divided into horizontal layers. According to the shape and location of the part, a support structure is arranged when it is needed. After the path data has been reviewed and toolpaths have been generated, the data is then downloaded to the FDM machine.

The system draws the model one layer at a time on the X, Y and Z axes. The method is like the extrusion of molten glue beads from a hot glue gun. The temperature-controlled extrusion head is supplied with the thermoplastic modelling material heated to a semi-liquid state. The head precisely extrudes and guides the material into ultrathin layers onto a fixture. The solidified material laminating to the previous layer is the result of a plastic 3D model constructed one strand at a time. When the component is completed, the surface is finished and the support columns are removed.

Working Process: FDM begins with a software technique devised by Stratasys, which mathematically divides and orders the model according to the build procedure in a few minutes from an STL file (stereolithography file format). If needed, support structures are generated automatically. For the model, one material is dispensed by the machine; another for a temporary support framework.

A CAD file defines a tool path that an extrusion head follows in liquefying and depositing the thermoplastics. One layer at a time, starting from the bottom and working upward, in layers as thin as 0.04 mm (0.0016"). The layering principle applied by FDM is an additive one. From a coil of plastic filament or metal wire that has been unwound, the material is fed into an extrusion nozzle capable of controlling the flow. A computer-aided manufacturing (CAM) software program controls a numerically controlled mechanism that heats the nozzle to melt the material and allows for vertical and horizontal movement. The layers of little beads of thermoplastic material are extruded from the nozzle to form the model or part. After extrusion, the material hardens immediately. As can be seen, the extrusion head is commonly driven by stepper motors.

Different materials provide different compromises between the temperature and strength characteristics. It also incorporates waxes, polycarbonates, polycaprolactone; polyphenylsulfones and acrylonitrile butadiene styrene (ABS) polymer. During construction, a "water-soluble" substance can be used to make temporary supports. This soluble support material is rapidly dissolved using specialised mechanical agitation equipment and a precisely heated sodium hydroxide solution. Stratasys Inc. holds trademarks for both the phrase fused deposition modelling and its abbreviation, FDM. The RepRap project members created the precisely similar term, fused filament fabrication (FFF), in order to provide a term whose use would not be restricted by law. This model is brand-new.

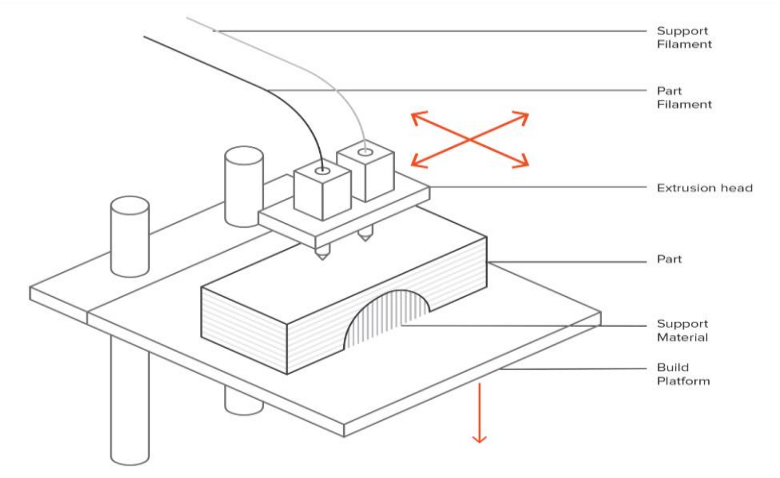


Figure 2 Schematic of a typical FDM printer

Materials Used In FDM: The most prevalent materials (and compounds) in this format are ABS Acrylonitrile Butadiene Styrene, Polylactic Acid (PLA) and Polyvinyl Alcohol (PVA): These materials are soluble and are typically used to make supports since they are simple to remove from the part after fabrication. Polyurethane, or TPU, is used to make flexible parts.

The following are a few sources of technical materials: ULTEM: Material resistant to heat, ABS - PC: Acrylonitrile styrene acrylate, nylon, polycarbonate compound, and polyphenyl sulfone (PPSF)

PLA: PLA is the easiest polymer to print and provides good visual quality. It is very rigid and quite strong but is very brittle.

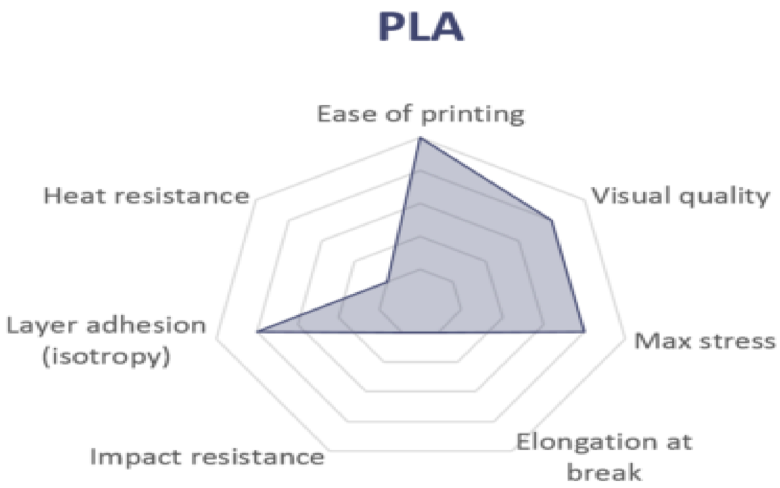


Figure 3 The material profile of PLA

Unlike other commercial materials made mostly of petroleum, PLA, also known as polylactic acid or polylactide, is a thermoplastic created from renewable resources such as sugar cane, tapioca roots, and maize starch. Owing to its more environmentally friendly beginnings, this material has gained popularity in the 3D printing sector and is starting to appear in culinary and medical items.

PLA filament Used in 3D printing: PLA filament is super popular in 3D printing because it's easy to handle and made from eco-friendly stuff. It melts at a lower temperature than other materials like ABS, so you don't need fancy equipment to print with it. However, it can get thick and cause problems with your printer if you're not careful.

ABS is tougher than PLA, but PLA can handle heat better, making it great for food-related stuff. It's perfect for simple projects because you don't need extra steps like tricky finishing touches. If needed, you can sand it or use acetone on it, and taking off supports is usually a breeze. To avoid issues when starting a print, it's a good idea to use tape on the printing surface.

2. LITERATURE REVIEW

The analysis of the background data important to this evaluation is the focus of this section. In this investigation of landscape architecture, sculpture, and photography. Development of much of the technology did not begin until the mid-1980s. "RAPID PROTOTYPING" was the term used during this time to describe 3D printing. Chuck Hull, from 3D Systems Corporation, created the first 3D printer that could be used. Dr. Deckard developed Selective Laser Sintering (SLS) technology at the University of Texas later in the 1980s, at the outset of a Defence Advanced Research Projects Agency project. In the 1990s, a technique for solidifying photopolymer, a highly viscous liquid material, using UV light was developed, significantly improving the technology. Throughout the 20th century, a variety of objects were printed using incredibly costly 3D printers. Scientists and electronics groups controlled the majority of the printers, which they used for display and study. But because to developments in 3D printing, intricate shapes and colours are no longer a constraint on product design.

Mohamed et al., (2017) looked at how a specific kind of material called PC-ABS behaves when it's made into parts using a 3D printing method called fused deposition modeling (FDM). He used a computer-based method called I-optimal response surface methodology to understand how different manufacturing settings affect the strength and flexibility of these parts. To do this, he studied the tiny structures of several samples using a special microscope called a scanning electron microscope (SEM).

For various combinations of procedure settings, a total of sixty specimens were created for this experiment. Every specimen was created via a Fortus 400 FDM device. PTC Creo was used to design each specimen, and then STL (Stereolithography) format was converted. The findings demonstrate that processing circumstances have a significant impact on the manufactured parts' dynamic mechanical performance. The outcomes also demonstrate the superiority of computer-generated optimal design based on I-optimal design over traditional experimental designs since the latter require a greater number of tests to address several parameters at different levels.

Gupta et al., (2018) The study focused on making 3D prints smoother using a method called fused deposition modeling (FDM) with a material called polylactic acid (PLA). Usually, people haven't paid much attention to how smooth these prints turn out. So, this research aimed to figure out what factors affect the surface quality of these prints. They looked at five different things that can be changed when you're making these prints. They used a BQ WITBOX printer from Madrid, Spain, for their experiments. This printer has a glass base about the size of a sheet of paper and a nozzle that's 0.4 mm wide. They found that it's best to print at a speed of around 50 mm per second, but you can go up to 80 mm per second. They even have a fan on the printer to cool things down as they print. They used some special software called Ultimaker Cura Software 3.2.1 to make the instructions for the printer. Then they looked at all the data using different kinds of tests like Analysis of Variance and some math stuff called Kendall's _ and Spearman's r correlation coefficients. Their big discovery was that the most important things for making smooth prints were the height of each layer they printed and how thick the walls of the object were. The way they moved the printer head, how fast they printed, and even the temperature didn't really make much of a difference.

M. Dilberoglu el at., (2019) showed a way to fix shrinkage issues with ABS material in 3D printing. This study reveals how the shape inside objects made on regular 3D printers can help stop things from shrinking too much. They found that adding extra lines around holes or slots can keep their size right. They used computer tools to predict how much things might shrink and then measured them with a special machine to check if their fix worked.

The FEA on the ABS pieces filled with the suggested line segments indicates that shrinkage is significantly more noticeable at the outside frame. As height grows, the holes' dimensional precision appears to have declined. In the event of a single hole, the commercial programme accurately predicts the actual amount of shrinkage, but in the latter scenario, the prognosis is not as good. Numerous manufacturing aspects in the process lead to an unsystematic/random tendency on dimensional variations. In comparison to the default interior structure produced by the 3D printer's CAM software, the suggested interior structure (auxiliary line segments) is confirmed to be significantly more satisfactory in terms of dimensional correctness.

Wen Feng Lu el at., (2019) tried out a new way to keep an eye on nozzle problems in a type of 3D printing called fused deposition modelling (FDM). FDM is used a lot for making prototypes and custom parts on the cheap. Sometimes, the nozzle in these printers can get blocked, causing issues with how things are made. So, this research focused on finding a way to watch out for these blockages by looking at the electrical stuff happening in the printer. They made equations to understand how different forces inside the printer affect the printing process. They even figured out how a blocked nozzle changes the electrical stuff inside the printer. They made a method based on these findings to check if the nozzle was blocked or not while printing using a material called polylactic acid (PLA) on an FDM machine. They wanted to see if this method could help predict when the nozzle might get blocked. This is crucial because it affects how accurate and strong the things printed turn out. They used a MakerBot Replicator 1 printer to figure all this out. Their tests showed that by keeping an eye on the electrical currents in the printer, they could tell if the nozzle might be getting blocked. This method they suggested, based on the basics of how the printer works, could be used to spot nozzle problems in these types of 3D printers.

Rajpurohit el at., (2020) presented the Impact strength of 3D printed PLA using an open-source FFF-based 3D printer.

Customisable items have been made using fused filament fabrication (FFF), which has several benefits because it can produce end products with any complex geometry in a shorter amount of time. Unfortunately, because the FFF technique forms the object layer by layer, its use for functioning parts is limited because of the low mechanical performance. The choice of construction settings has a significant impact on the mechanical qualities of the object that is FFF printed. As a result, the impact strength of the PLA that was created using FFF has been assessed in this study about three build variables: angle, layer height, and width. In this investigation, the impact specimen was printed using PLA material utilising an open-source FFF-based OMEGA twin extruder 3D printer. The test specimen's CAD model was transformed into an STL file and then imported into Slice3r to create a tool pathway with all of the construction settings changed. Once the component is constructed, it is removed from the print bed so that the supports may be taken out. The test specimens' impact strength is assessed after they are printed under various build settings. Measurements were taken to assess and examine the impact of the various build characteristics.

3. OBJECTIVE OF THE STUDY

This research wants to see how the way a 3D-printed object is filled inside, the pattern it's made in, and which way it's positioned affect how strong it is when you pull it. They're testing different ways to fill the inside of these objects and how the strands inside are lined up compared to the way the object might be pulled. To do this, they're using a method called the Taguchi method. It's a popular way to set up experiments and make designs better. It helps simplify the plan for the experiment and lets them see how different parts of the process affect each other. This method is really helpful when making prototypes because it can be expensive.

The Taguchi method suggests a plan for experiments that includes lots of different combinations of things they're testing for each try. In this study, they're looking at three important things—how thick each layer is, the angle the object is positioned at, and the angle of the filling inside. They're seeing how these things affect how strong the object is, how accurate its measurements are, how rough its surface is, and how long it takes to make.

Understanding all of this helps make better designs and decisions when making things with 3D printers. It's important because it helps save time and money when creating prototypes.

Parameter	Symbol	Level 1	Level 2	Level 3
Orientation	A	On-edge	Top Flat	Side View Flat
Pattern	B	Cubic	Gyroid	Cubic Subdivision
Infill %	C	30	40	50

Table 1 Parameters and their levels

Run	Parameters/Levels		
	A	B	C
1	1	1	1
2	1	2	1
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 2 L9OA(L9 Orthogonal array)

Using Solid Works modelling software, parts that were to be fabricated were modelled and then exported as STL files. The FDM Insight programme imports the STL file. The parts were created using a Creality Wol3d Ender Pro-3 3D printer, which has a 0.4-micron nozzle diameter. Polylactic Acid (PLA) was the substance employed in the part manufacture process. As per the ASTM D638 Standard, the tensile test was carried out via the Universal Testing System (UTS). The dimensional accuracy test was carried out using a digital calliper by measuring specimen dimensions in the directions of the X, Y and Z axes. Rectangular bar specimens of the stylus movement device were subjected to a surface roughness test in both vertical and horizontal directions. The mean of the two directions was taken into consideration for optimisation. The amount of time the 3D printer needs to use FDM technology to generate the pieces is known as the manufacturing time. The test specimens follow their FDM manufacturing procedure. The arrangement of input factors influencing response attributes.

4. RESEARCH METHODOLOGY

To establish a foundational understanding of the historical evolution and widespread applications of FDM, both experimental and secondary research is conducted. The data collected for the experimental research came from reliable sources, academic journals, and industry reports. The experimental research involved material selection, input process parameters, experiment design, analysis, conclusion, and recommendations.

5. EXPERIMENTATION

5.1 Material Selection

A nozzle, or nozzles, used in FDM printers melt and extrude filament material to deposit objects layer by layer in accordance with a code. Even at home, FDM printers are simple and safe to use, prints don't always require sophisticated post-processing methods, and the selection of materials and upgrades keeps expanding in tandem with demand.

The materials that each technology uses help to identify it, and the processing techniques regulate the output quality. There are many industrial-grade thermoplastics with high-performance tailored solutions available for fused deposition modelling (FDM). Each has distinct qualities to take into account, thus in order to choose the ideal material, look for the best blend of material attributes while allocating priority appropriately.

The FDM materials PC, NYLON, ASA, PET, PETG, PLA, ABS, and ULTEM are utilised in 3D printing. In accordance with the results of our experiment, we have chosen PLA material for the experiment and research since it is odourless, biodegradable, and has strong UV resistance in addition to being easy to print on and having acceptable visual quality and layer adhesion.

Advantages

Manufacturing

i. Renewable raw materials are used to make PLA.
ii. It emits less carbon dioxide than plastic made from fossil fuels: - Compared to fossil-based plastic, PLA is produced with less energy and hence emits fewer environmental gases during growth because crops absorb CO2.
iii. Nature Work Ingeo produces PLA in the United States.

Material

i. Compared to many plastics derived from fossil fuels, PLA has a lower melting point, which makes it melt more readily. PLA is simple to deal with and transforms with little energy.
ii. With a 45% market share, one of the two plastics most frequently used in 3D printing. It produces no odours, is cheap, easy to print, and has a low melting point. When it comes to 3D printing, it's the greatest choice.

End-of-life

i. Plastics can be composted
ii. Compared to oil-based plastics, PLA produces fewer harmful fumes when burned.
iii. Unlike plastic recycling, food contamination of food packaging is not an issue.
iv. When used in biomedicine, PLA breaks down into a non-toxic acid.

Dis Material

Prc

i. Low melting point makes PLA unsuitable for high temperature applications. PLA may even show signs of getting soft or deforming on a hot summer day.
ii. PLA has a higher permeability than other plastics. Moisture and oxygen will go through it more easily than other plastics. This will result in faster food spoilage. PLA is not recommended for long-term food storage applications.
iii. PLA is not the hardest or toughest plastic. PLA is not suitable for applications

Properties	**Range**
Melting Point	150 to 160 °C (302 to 320 °F)
Glass Transition	60-65 °C
Injection Mould Temperature	178 to 240 °C (353 to 464 °F)
Density	1.210–1.430 g·cm–3
Chemical Formula	(C3H4O2)n
Crystallinity	37%
Tensile Modulus	2.7–16 GPa
Solubility	Chlorinated solvents, hot benzene, tetrahydrofuran, and dioxane (not water soluble). where toughness and impact resistance are critical.

Table 3 Important properties of PLA

5.2 Selection of Input Process Parameter

To make the test simpler in this study, the interactions between the four parameters were disregarded. Table 2 displays the orthogonal factor level table. Printing orientation, pattern, and filling density were the three criteria and three levels that were tested orthogonally to determine the best FDM process parameters for PLA tensile specimens. As indicated in Table No. 02, the L9 orthogonal array design was chosen to increase experimental efficiency. The universal testing equipment was used to measure the PLA specimens' tensile characteristics in accordance with ASTM D638 Standards. Table and L9 Orthogonal arrays list the orthogonal factor levels and orthogonal arrays, respectively.

Levels	Print orientation (A)	Infill patten(B)	Infilling Density (C)
1	On-edge	Cubic	30
2	Top flat	Gyroid	40
3	Side view flat	Cubic Subdivision	50

Table 4 Input Process Parameters

Figure 4 demonstration of on-edge orientation

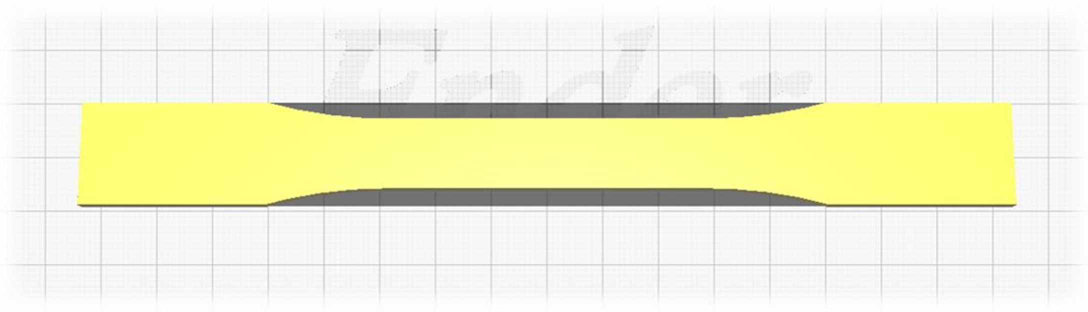


Figure 5 represents top flat orientation

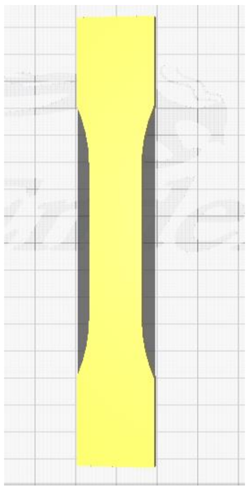


Figure 6 shows side view flat orientation

Figure 7 shows Cubic Infill Pattern

Figure 8 shows Gyroid Infill Pattern

Figure 9 shows the Cubic-Subdivision Infill Pattern

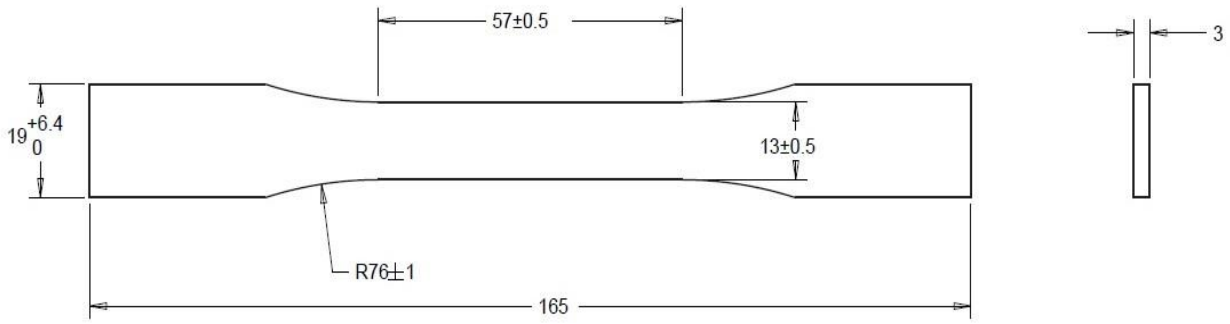
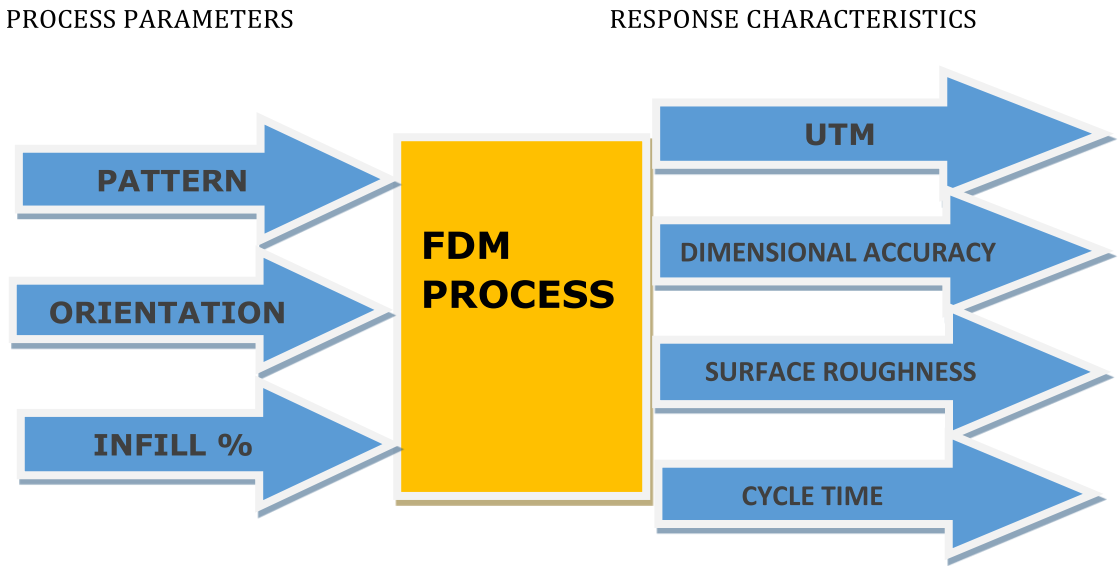


Figure 10 Specification of the specimen



5.3 DESIGN OF EXPERIMENT

As was previously mentioned, the experiment was designed using Taguchi's technique-based L9 orthogonal array design. Table 5 displays the combination of input parameters used in the specimen creation process.

S. No	Print orientation	Infill patten	Infilling Density	Material Req. (gram/m)	Cycle Time (min)
1	On edge	Cubic	30	7g/2.39m	51
2	Top flat	Gyroid	30	7g/2.31m	55
3	90* Flat	Cubic Subdivision	30	7g/2.41m	51
4	On edge	Gyroid	40	7.3g/2.39m	60
5	Top flat	Cubic Subdivision	40	7.31g/2.31m	61
6	90* Flat	Cubic	40	7.32g/2.41m	63
7	On edge	Cubic Subdivision	50	7.80g/2.39m	69
8	Top flat	Cubic	50	7.78g/2.31m	68
9	90* Flat	Gyroid	50	7.9g/2.41m	71

Table 5 Specimens Parameters

5.4 Fabrication of specimens

The act of creating something new or making something is called fabrication. The most crucial aspect of the experiment is fabrication. Solid Works modelling software is used to model the manufactured parts, which are then exported as STL files. The FDM Insight programme imports the STL file. An Ender Pro-3 3D printer from Creality Wol3d, with a 0.4 micron nozzle diameter, is used to produce the parts. Polylactic Acid (PLA) was the substance employed in the part manufacture process. The amount of time the 3D printer needs to use FDM technology to generate the pieces is known as the manufacturing time.

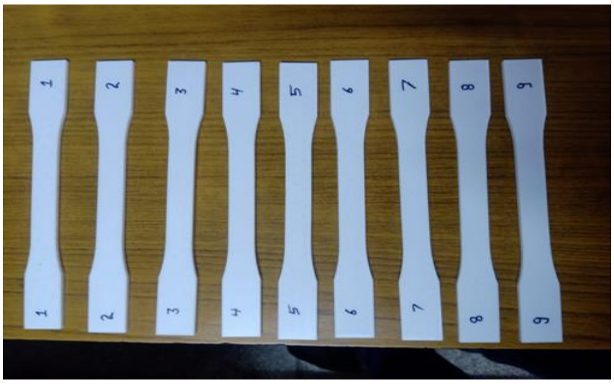


Figure 11 FDM fabricated specimens

5.5 ANALYSIS OF SPECIMEN

Tensile Testing: The behaviour of materials under tensile load is ascertained by tensile tests. To find the material's ultimate tensile strength, a sample is usually tugged to its breaking point in a basic tensile test. Throughout the test, measurements are made of the force (F) applied to the sample and its elongation (ΔL). Stress (measured as force per unit area, σ) and strain (measured as percent change in length, ε) are commonly used to describe material properties. The cross-sectional area of the sample (σ = F/A) is divided by the force values to produce stress. Measurements of strain are derived by dividing the length change by the sample's original length (ε = ΔL/L). The stress-strain curve, an XY plot derived from these parameters, is subsequently displayed.

The substance being evaluated and its intended use determine the testing and measuring protocols. The universal testing machines (UTM) precisely compute mechanical parameters like tensile strength, peak load, elongation, and tensile modulus as they pull apart materials. The remaining results are reported in Table 6. The common parameters for all the specimens are width 13 mm, thickness 03 mm, gauge length 57 mm, and area 41.6 sq. mm.

S. No	Peak Load (N)	Peak Elongation (mm)	Break Load (N)	Break Elongation (mm)	Stress at Peak (MPa)	Strength at Break (MPa)	% Elongation at Peak	% Elongation at Break	Strain (MPa)	Young Modulus (MPa)	poison ratio (μ)
1	786	3.8	707.4	3.99	18.89	17	7	7	1.066667	17.70938	0.32
2	434.9	2.85	391.41	3.23	10.45	9.41	5	6	1.05	9.952381	0.33
3	908.1	4.18	817.29	4.37	21.83	19.65	7	8	1.073333	20.33851	0.32
4	1078.2	3.99	**970.38**	4.18	25.92	23.33	7	7	1.07	24.2243	0.36
5	668.8	3.8	601.92	3.8	16.08	14.47	7	7	1.066667	15.075	0.37
6	537.9	3.04	484.11	3.99	12.93	11.64	5	7	1.053333	12.27532	0.34
7	1080.2	3.61	**972.18**	3.8	25.97	23.37	6	7	1.063333	24.4232	0.38
8	824.7	3.99	742.23	4.56	19.82	17.84	7	8	1.07	18.52336	0.35
9	1127.8	4.75	**1015.02**	5.13	27.11	24.4	8	9	1.083333	25.02462	0.34

Table 6 Tensile Testing Parameters

The formula for calculating strain and young modulus

- Strain $\varepsilon = dl / l_o$

  $= \sigma / E$

  Where,

  dl = change of length (mm)

l_o = initial length (mm)

ε = strain -

- Young's modulus = stress/strain

$E = \sigma/\epsilon$

Where, E is Young's modulus

σ is the uniaxial stress

ε is the strain or proportional deformation

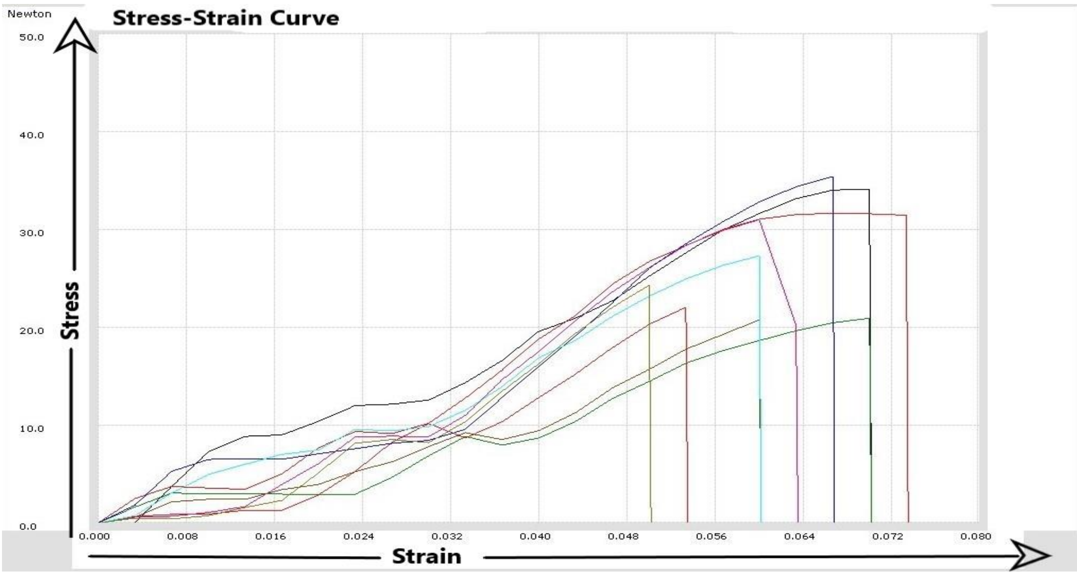


Figure 12 Stress- Strain Curve

Before After

Figure 13 Specimen Tensile Test on UTM

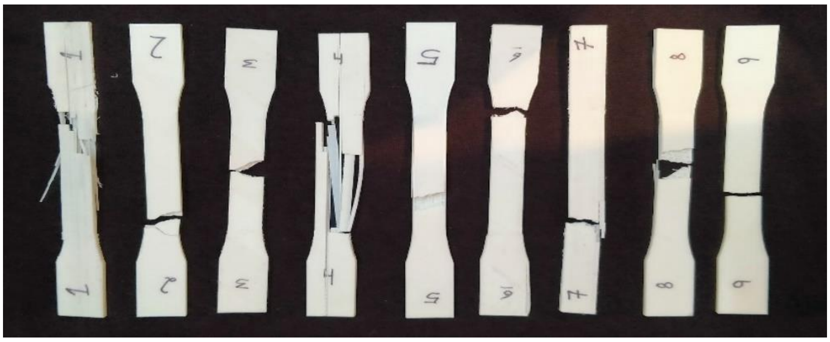


Figure 14 Tensile Tested FDM Specimens

5.7Surface Roughness

The roughness profile's arithmetic average (Ra) was used to measure surface roughness. Superior surface finish quality is essential for reduced total prototyping time and cost, in addition to enhanced functionality and aesthetics. One of the main drawbacks of FDM is that, especially in comparison to other methods, the printed part's surface roughness is extremely high due to the layered manufacturing methodology used in Additive Manufacturing. The building process's layer-by-layer deposition and the tessellation of the source CAD model are the primary causes of the subpar surface finish quality seen in FDM method final products. A precise characterization of surface roughness is of prime importance in many engineering industries. For this reason, the surface roughness, Ra, is a key issue in AM.

Experiment No	Surface Roughness (Ra) along X-axis	Surface Roughness (Ra) along Y-axis
1	12.743	2.607
2	11.262	13.548
3	**8.949**	11.692
4	14.913	1.058
5	15.621	16.649
6	16.705	18.811
7	14.275	**0.973**
8	24.702	22.829
9	13.856	12.975

Table 7 Average surface roughness of FDM Specimens

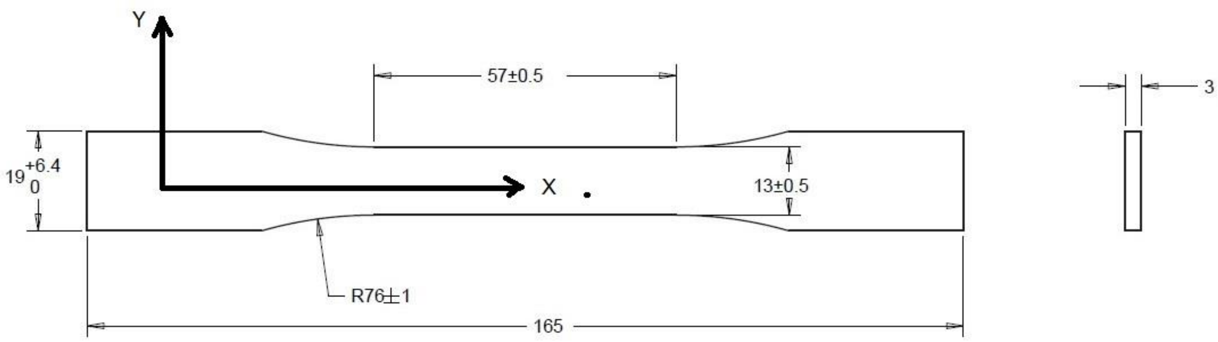


Figure 15 Demonstration of X and Y axis of FDM Specimens for Surface Roughness

Figure 16 Surface Roughness Tester

6. CONCLUSION

Optimal FDM Parameters for PLA Tensile Strength: Conducted an orthogonal test considering printing orientation, infill pattern, and density to identify ideal FDM parameters for enhancing PLA tensile strength, crucial for industrial-grade applications.

Tensile Strength Analysis: Utilized ASTM D638 Standards and Taguchi's L9 orthogonal arrays to evaluate PLA specimen tensile properties, identifying specimens 4, 7, and 9 as exhibiting superior tensile strength, crucial for reliable industrial components.

Surface Roughness Assessment: Employed Mitutoyo Surface Roughness Tester to measure surface roughness. Specimens 3 and 7, characterized by specific orientations and infill densities, demonstrated superior smoothness along both X and Y axes, vital for precise industrial components.

Cycle Period Optimization: Observed varying cycle durations among specimens, with specimens 1 and 3 displaying shorter cycles at 51 minutes, offering the potential for enhanced production efficiency and cost-effectiveness in an industrial setting.

Implications for Industrial Production: Findings offer crucial insights for industrial applications by pinpointing optimal parameters for increased tensile strength, enhanced surface quality, and potential production time improvements, contributing to more reliable and efficient manufacturing processes.

Industrial Relevance of Optimized Parameters: The identified specimen configurations with superior mechanical properties and surface finish have direct implications for industrial-grade prototypes and component manufacturing, addressing the critical cost and performance factors in the production process.

Quality Enhancement and Efficiency Gains: Implementation of the identified optimized parameters promises higher-quality products, reduced surface imperfections, and potential time-saving measures, aligning with industrial goals of precision, reliability, and cost-efficiency in manufacturing.

Software and Equipment Utilization for Precision: Employed SolidWorks for meticulous specimen modeling and the Ender Pro-3 3D printer for actual printing, ensuring precision and adherence to specifications in the manufacturing process.

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