Optimization and Characterization of Fused Deposition Modeling (FDM) Parameters for Enhanced Mechanical Properties in 3D Printed material for biomedical application

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Abstract. This study and analysis in the in influence of the FDM 3D Printed part parameter including speed layer thickness filament feed rate and biomedical filler content the flexural tensile strength of composite bone plate and using taguchi L27 orthogonal allay an the specimen value ate through mechanical testing .SN ratio and are identify the optimal parameters combinations and determine the affecting mechanical performance.

Keywords: 3D Printing. Universal testing machine ASTMD638 Testing, FDM and composite plastic material PEEK, Nylon, carbon fiber, PEKK, PLA ABS PETG

1 Introduction

Contrary to subtractive manufacturing, additive manufacturing (AM), often known as 3D printing, is a method of fabricating items by connecting data from 3D models, and it is typically carried out layer by layer. The design and manufacturing processes can be improved in terms of speed and flexibility due to this technology. [1]. Additionally, traditional

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manufacturing methods need a lot of time and money to generate complex shapes, therefore 3D printing machines are employed in many industries to create custom parts during the design phase. However, this technology's rapid progress resulted in the production of end-use components. The 3D printing technique can reduce wasteful material use, labor-intensive processes, and production costs. The output component or product shape is set by a computer-aided design (CAD) file in this method. This are easy design and d modified a easy procedure .the import part of procedure is the fourth industrial revolution that reduces physical movement is 3D printing operations Some other manufacturing industries, including those in the, medical aerospace, , automotive, , clothing food, electronic electric and, educational, prototype, civil engineering works architectural, chemical, building, and construction sectors, have most use fully because it make easy trial and error process and so many applications in 3D printing operation technology. technology [1]. laser melting FDM, electron beam melting, and hybrid processes are a few categories of AM fused filament fabrication

(FFF), stereo lithography (SLA), and direct jetting, and photopolymer jetting, and selective laser sintering (SLS), and FDM technology is the most well-known FDM technology is the most well-known [2] of these 3D printer technologies since it is simple, affordable, Orthopedic implants include a range of applications, including trauma implants (such as plates and screws), spinal implants (e.g., artificial vertebral bodies and cages), joint implants (e.g., artificial hip and knee joints), as well as customized prostheses (e.g., scapular, chest, and rib prostheses), and scaffolds for bone tissue engineering.

Polylactic acid (PLA), a promising polymer due to its high biocompatibility and biodegradability, finds application in various biomedical contexts, including the creation of degradable scaffolds, bone plates, and other implants. However, non-degradable bone plates, made from materials like PLA, often require removal post-fracture healing, subjecting patients to additional surgeries. To address this, researchers have explored composite materials, incorporating bio ceramic particles like hydroxyapatite (HA), Polyether ether ketene (PEEK), Polyethylene terephthalate glycol (PETG). These enhance implant biocompatibility, bone integration, and create a slightly alkaline environment during degradation, reducing the risk of aseptic reducing the risk of aseptic [3,4] inflammation.

Headings may be numbered or unnumbered (“1 Introduction” and “1.2 Numbered level 2 head”), with no ending punctuation. As demonstrated in this document, the initial paragraph after a heading is not indented..

1.1. MATERIAL SELECTION AND MODELING PROCESS

A) TAGUCHI METHOD

Using Orthogonal Arrays (OA) to run fewer well-balanced experiments with minimized variance, the Taguchi Method combines the Design of Experiments with the optimization of control settings to get optimal findings. This method keeps the experiment within the permitted ranges of levels and factors, allowing for the determination of the optimal control parameter values. The Taguchi techniques Avery successful experimental strategy for reducing the number of trials needed while yet producing insightful data and ideal results.

TABLE 1. THE PROCESS PARAMETERS USED

S No.	Parameters	Units	Level1	Level2	Level3	Level4
1	Layer Thickness	mm	0.15	0.20	0.25	0.30
2	Printing Speed	mm/s	30	40	50	60
3	Infill Density	%	15	30	45	60
4	Infill Pattern	-	Gyroid	Support Cube	Line	Honeycomb

B) FACTORAS

Nozzle temperature: The temperature at which a 3D printer's extruder nozzle heats up to melt filament material and enable precise deposition of the material to build a 3D object layer by layer is known as the nozzle temperature. The optimal temperature range for extrusion varies depending on the material. Common filament types, nozzle temperatures typically range from 180°C to 260°C. In this work, we employed a nozzle temperature of 225°C.

Nozzle diameter: In 3D printing, "nozzle diameter" refers to the size of the aperture at the extruder nozzle tip of the printer, which controls the diameter of the filament that is extruded. The nozzle diameter is commonly expressed in millimeters (mm), and, contingent upon the printer model and intended application can vary from 0.1mm to1.0mm or greater. The nozzle utilized for printing in this investigation has a diameter of 0.4 mm.

Infill density: The quantity of material utilized to fill a printed object's internal structure is referred to as infill density in 3D printing. The layer of material printed inside an object's wall so router shell is called an infill, and it gives the structure solid it and support. In our analysis, we employed an infill density ranging from 15 – 60%.

Infill layer height: The thickness of each layer of material deposited by the printer's extruder nozzle during the printing process is referred to as layer height in 3D printing .Given that it directly impacts the final printed object's quality and resolution; it is one of the most crucial 3D printing settings. In our work, we use an infill height of 0.1–0.3 mm

Printing speed: The rate at which the printer's extruder nozzle moves along the X, Y, and Z axes to deposit the melted filament and build each layer of the printed item is referred toes printing speed in 3Dprinting.We have taken into consideration the range of30–60millimetresper second (mm/s), which is the standard unit of measurement for printing speed. printing speed. [2]

Printing orientation: In 3D printing, printing orientation describes how the object is positioned on the printer's build platform. The final printed object's strength, quality, and beauty can all be impacted by orientation

2. MODELING

2D MODELLING IN CAD.

A 2D CAD model is a digital representation of a design or object created using computer-aided design (CAD) software. It consists of two-dimensional shapes and lines that accurately depict the object's dimensions, proportions, and details. Here is some additional information about 2D CAD models. It's important to note that while 2D CAD models provide detailed information about the object's shape and dimensions, they lack the additional depth and spatial information offered by 3D CAD models. However, 2D models are still valuable for many design and documentation purposes, especially when working with 2D represent.

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Subsequent paragraphs, however, are indented.

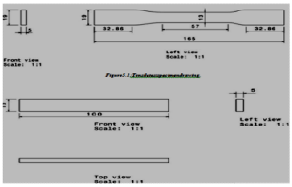

Figure 1 CAD modeling 2D drawing

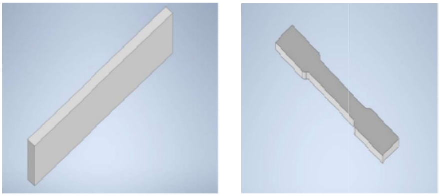

Fig A Fig B

Figure 2 .A Tensile test specimen B.**Flexural test specimen model**

TABLE 2 EXPERIMENTAL PRINTING FILAMENT.

Chemical Structure	• PETG belongs to the family of polyester. • Chemical formula:$(C_{10}H_8O_4)_n$
Physical Properties	• Density:1.28g/cm³ • Melting Point:220°C-260°C • Glass Transition Temperature(Tg):80°C
Mechanical Properties	• Tensile Strength: 50Mpa. • Flexural Strength: 74Mpa. • Hardness(Rockwell):71HRM
Thermal Properties	• Thermal Conductivity:0.162–0.225W/m-K

3D Printing Process for Polyethylene tere phthalate glycol (PETG):

1. Preparation of 3D Printer: Make sure your 3D printer is properly calibrated and clean. PETG prints best on a heated print bed, typically set between 70°C to 85°C. Additionally, some printers may benefit from an enclosure to maintain stable printing conditions.
2. Filament Loading: Load the PETG filamentintothe3Dprinter'sfilamentholder and feed it into the extruder according to the manufacturer's instructions.
3. Slicer Settings: Use a slicer software (e.g., Cura, Simplify3D) to generate the G-code for your 3D model. PETG prints best with a nozzle temperature between 230°C to 250°C. Adjust the printing speed, layer height, and cooling setting according to yours pacific printer and filament.
4. Bed Adhesion: PETG tends to stick well to heated glass print beds coated with materials like Build Take or PEI. Ensure proper bed leveling and use adhesion aids like a thin layer of glue stick or specialized bed adhesion sprays if needed.
5. Printing: Start the printing process. PETG tendstoooze more than other filaments, so consider using or brim to prime the nozzle before printing the actual model. Monitor the first layer closely to ensure proper adhesion to the print bed.
6. Cooling: PETG benefits from minimal cooling during printing. Unlike PLA, which requires active cooling to prevent warping PETG should be printed with minim altonocooling fan.

   However, some printers may benefit from a fan runningata low speed for small, intricate details.

7. Post processing after the print is complete; allow it to cool on the

print bed before removing it. PETG prints tend to be more flexible than PLA or ABS, so take care when removing supports or rafts to avoid damaging the print.

8. Finishing: PETG prints can be sanded and painted if desired .Sanding can help smooth out layer lines and imperfections, while painting can add color and texture to the finished print.
9. Storage: Store PETG filament in a dry, cool place away from direct sunlight to prevent moisture absorption, which can affect print quality.

By following these steps and adjusting settings as needed for your specific printer and filament, you should be able to achieve successful 3D prints with PETG successful 3D prints with PETG [2,4]

EXPERIMENTATION

TENSILETEST

A tensile test, also known as tension test or pull test, is a fundamental mechanical test performed on materials .I ps in determining key properties such as strength, elasticity, ductility, and toughness.

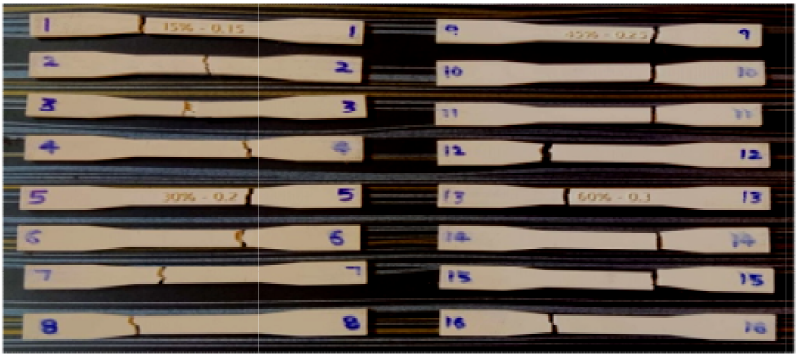

FIG 3 .BREAKING OF TENSILE SPECIMEN

TABLE 3 EXPERIMENTAL RESULTS OF TENSILE TEST

Sl. No.	Layer Thickness (mm)	Printing Speed (mm/s)	Infill Density (%)	Infill Pattern	Tensile Strength (N/mm^2)
1	0.15	30	30	Gyroid	16.691
2	0.15	40	40	Support Cube	18.843

3	0.15	50	50	Line	20.613
4	0.15	60	60	Honeycomb	20.983
5	0.20	30	30	Line	18.122
6	0.20	40	15	Honeycomb	22.997
7	0.20	50	60	Gyroid	22.838
8	0.20	60	45	SupportCube	22.944
9	0.25	30	45	Honeycomb	25.170
10	0.25	40	60	Line	23.792
11	0.25	50	15	Support cube	22.149
12	0.25	60	30	Gyroid	20.930
13	0.30	30	60	Support cube	22.202
14	0.30	40	45	Gyroid	23.474
15	0.30	50	30	Honey comb	24.481
16	0.30	60	15	Line	24.534

FLEXURALTEST

A flexural test ,also know nasa bending test is another important mechanical test used to evaluate the strength and stiffness of materials, especially those used in structural applications such as beams, columns, and bridges. Unlike a tensile test, which applies a force along the longitudinal axis of a specimen, a flexural test applies force perpendicular to the longitudinal axis, causing the specimen to bend.

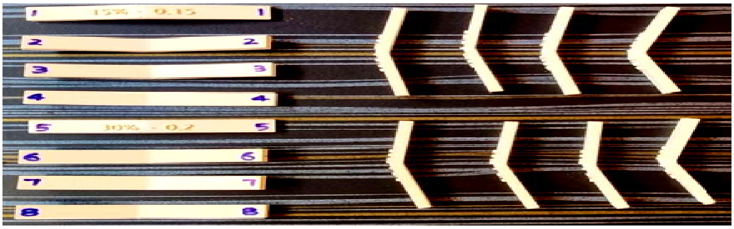

FIG 4 .BREAKING OF FLEXURAL SPECIMEN

TABLE 4 EXPERIMENTAL RESULTS OF TENSILE TEST

Sl. No.	Layer Thickness (mm)	Printing Speed (mm/s)	Infill Density (%)	Infill Pattern	Tensile Strength (N/mm^2)
1	0.15	30	30	Gyroid	2.891
2	0.15	40	40	Support Cube	3.765
3	0.15	50	50	Line	3.967
4	0.15	60	60	Honeycomb	3.833
5	0.20	30	30	Gyroid	3.967
6	0.20	40	15	Support Cube	3.967
7	0.20	50	60	Line	3.900
8	0.20	60	45	Honeycomb	3.026
9	0.25	30	45	Gyroid	3.967
10	0.25	40	60	Support Cube	3.698
11	0.25	50	16	Line	4.102
12	0.25	60	30	Honeycomb	3.967
13	0.30	30	60	Gyroid	4.030
14	0.30	40	45	Support Cube	3.967
15	0.30	50	30	Line	3.967
16	0.30	60	15	Honeycomb	4.371

VARIATION OF EXPERIMENTAL DATA

TENSILE TEST RESULTS

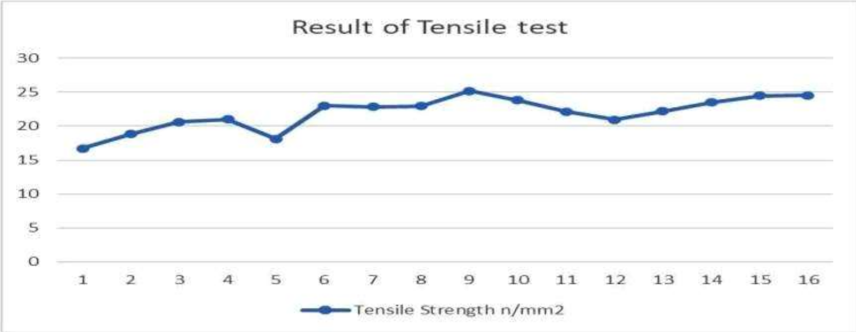

FIG 5 VARIATION OF TENSILE STRENGTH

The data shows a gradual increase in tensile strength from lower values (16.691, 18.843) to higher values (24.534, 25.170).This indicates a general trend of increasing strength .However, there are some fluctuations within this increasing trend. For example, there are instances where the tensile strength decreases slightly (e.g., 18.122 to 22.997) or increases significantly (e.g., 23.792 to 23.474). These variations suggest some level of measurement uncertainty or natural variation in thematerial's strength. Notably, there are a few instances where the tensile strength experiences significant jumps, such as from 22.944 to 23.792 or from 22.202 to 24.534.These larger variations could be attributed to factors like differences in testing conditions, or other external influences .

FLEXURAL TEST RESULTS.

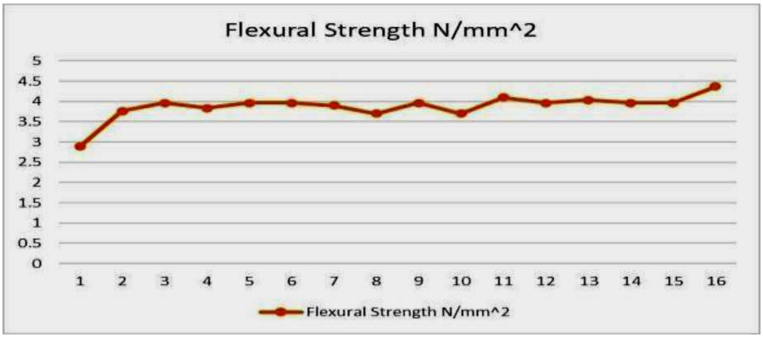

FIG 6 VARIATION OF FLEXURAL STRENGTH

The data shows a range of flexural strength values, ranging from lower values (2.891, 3.765) to higher values (3.967, 4.371). This indicates a general range of flexural strength within the dataset. There are some fluctuations within the range. For example, there are instances where the flexural strength decreases slight (e.g., 3.026 to 3.698) or increases gradually (e.g., 4.102 to 4.371). These variations suggest some level of measurement uncertainty or natural variation in the flexural strength values. Notably, there is a cluster of higher flexural strength values towards the upper end of the dataset (e.g., 4.371). These values indicate a higher level of strength compared to the rest of the dataset.

TABLE 5 RESPONSE SURFACE METHODOLOGY RESULTS

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	9.74	2.40	4.06	0.002	
Layer Thickness	28.91	6.51	4.44	0.001	1.00
Printing Speed	0.0565	0.0326	1.73	0.111	1.00
Infill Density	0.0336	0.0217	1.55	0.150	1.00
Infill Pattern	0.750	0.326	2.30	0.042	1.00

Tensile Strength N/mm2 = 9.74 + 28.91 Layer Thickness + 0.0565 Printing Speed +

TABLE 6 TENSILE COEFFICINTS OF REGRESSION MODEL

Source	DF	AdjSS	AdjMS	F-Value	P-Value
Regression	4	64.516	16.129	7.60	0.003
Layer Thickness	1	41.794	41.794	19.70	0.001
Printing Speed	1	6.381	6.381	3.01	0.111
Infill Density	1	5.079	5.079	2.39	0.150
Infill Pattern	1	11.263	11.263	5.31	0.042
Error	11	23.342	2.122		
Total	15	87.858			

ANOVA PLOTS.

S/N PLOTS FOR TENSILE TEST

TABLE 7 RESPONSE TABLE FOR SIGNAL TONOISE RATIOS (TENSILETEST)

Level	Layer thickness	Printing speed	Infill density	Infill pattern
1	25.67	26.14	26.60	26.36
2	26.70	26.92	26.12	26.64
3	27.22	27.03	27.23	26.69
4	27.48	26.97	27.02	27.37
Delta	1.81	0.90	1.02	1.00
Rank	1	4	2	3

Using the response table that is supplied for the signal-to-noise ratios from the response surface methodology:

This Response and Table sheds light on how difference various predictor variable levels and affect the Signal to Noise Ratios. And It suggests at while the impacts of orientation ,layer height ,and printing speed are and very modest, increased infill density generally results the in better SNR the help of these results, the predictor variables in the response of surface methodology can be optimized to produce and a greater signal quality and less noise and interference.

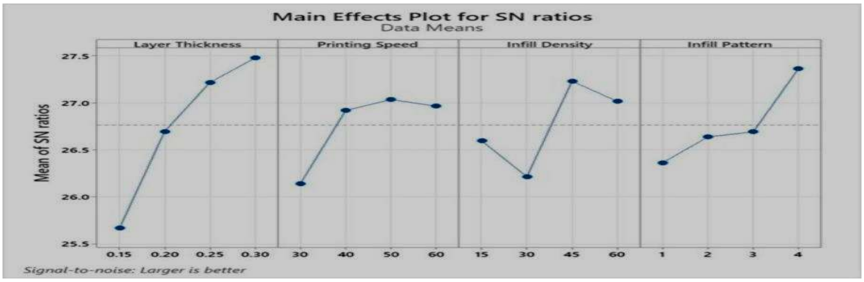

FIG 7 TAGUCHI ANALYSI ULTIMATE TENSILE STRENGTH

S/NPLOTSFORFLEXURALTEST

TABLE 8 RESPONSFOR SIGNAL TO NOISE RATIOS (FLEXURALTEST)

Level	Layer thickness	Printing speed	Infill Density	Infill Pattern
1	11.09	11.32	11.57	11.25
2	11.34	11.70	11.86	11.38
3	11.89	12.00	11.38	12.03
4	12.22	11.52	11.74	11.89
Delta	1.12	0.69	0.47	0.78
Rank	1	3	4	2

FUTURE SCOPE

Although there is no denying that artificial neural networks artificial neural networks [5] have revolutionized engineering, a number of issues still exist. These consist of the requirement for substantial quantities of annotated data, the interpretability of neural networks, and the moral issues related to the application of AI systems. However, continued research and development sin hardware technology, data availability, and machine learning algorithms continue to overcome these issues and open the door for future breakthroughs.

With their emergence as potent engineering tools, artificial neural net works have usheredina new era of intelligent systems. Their capacity to analyze enormous volumes of data, spot intricate patterns, andcometowell informedconclusionshastransformedanumberofengineering specialties. ANNs have revolutionized industries and created new avenues or innovation in a variety of fields, including image recognition, predictive modeling, robotics, structural analysis, fault identification, and condition monitoring. may anticipate so much developments as student and scientist engineers try to fully utilize neural networks, paving the way for the day when intelligent technologies and area regular part of our life. Because of the irexcellent and strength to weight ratio, composite materials are perfect for designing prosthetic devices prosthetic devices [6] that are both less weight lightweight and strong. Developments in composite materials the valve or can result in prosthetic limbs that are lighter, and more comfortable for the wearer, and more resilient to impact. It is simpleton mold and shape composite materialist of it specific an atomically needs. Future advancements could make it possible to manufacture highly tailored prosthetics that precisely match each patient's unique demands and preferences by using composite materials and sophisticated 3D printing techniques. This is possible to develop composite materials with certain qualities to improve and the functionality of prosthetic devices prosthetic devices [6]

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