Effect of Fused Deposition Modelling Parameters on the Mechanical Properties of ABS/GP Parts: An Experimental Approach

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***Abstract*— The purpose of this paper is to examine the effect of process parameters on ABS/GP parts made by fused deposition modeling (FDM). Several parameters of the FDM process affect the parts produced, such as part build orientation, layer height, raster width, infill percentage, and infill pattern. To achieve these objectives, it is necessary to gain a better understanding of the process parameters of FDM to reduce the building time, increase mechanical strength, and enhance part quality. The effect of process parameters on the specimen's tensile strength and modulus of elasticity is investigated using Taguchi's design of experiment (DOE) and analysis of variance (ANOVA). Analyzing experimental data led to the identification of optimal parameters.**

Keywords—* *Fused deposition modelling, ABS/GP (Acrylonitrile Butadiene Styrene/General Parts), Print Orientation, Layer Thickness, Infill Pattern, Infill Density, etc.;

I. INTRODUCTION

Three-dimensional virtual models that can be produced using computer-aided design software are used in the 3D printing process to create things. It is appropriate for the creation of specific things with intricate geometries. A thermoplastic material is extruded from a nozzle and utilised in the fused deposition modelling (FDM) process to build the part layer by layer. The material for the feedstock is provided as a solid polymer filament. The polymer material is heated in the nozzle's resistive heater so that it flows easily out of the nozzle and forms the layer. The FDM technique has many benefits, including the elimination of expensive tools, flexibility, and the capacity to create exceedingly complex parts and forms. The quality of the pieces manufactured is where FDM has its drawbacks. Understanding how parts from the FDM process behave when processing conditions vary is crucial to ensuring their dependability for various applications. FDM has many uses in the medical field, including bone and dental implants [1].

II. LITERATURE SURVEY

One of the most popular and flexible modern manufacturing processes is additive manufacturing (AM), sometimes referred to as 3D printing. It is currently widely used in a variety of industries, such as those involving architecture, medicine, dentistry, aerospace, cars, furniture, machining, and jewellery [2, 3]. The seven primary types of additive manufacturing techniques are: vat polymerization, binder jetting, material jetting, material extrusion, powder bed fusion, sheet lamination, and directed energy deposition. These procedures are divided into groups based on the materials and power sources they use [4].

One of the most well-liked and affordable additive manufacturing technologies is fused deposition modelling (FDM). A polymer in the form of a filament is utilised as a feedstock material in FDM. To create a raster, it is extruded through a heated nozzle. Such adjacent rasters combined create a layer. Also, the entire portion is printed by piling each layer on top of the one before it. Together with prototypes, FDM's goods have begun to enter the consumer market as functional parts. Some researchers have recently carried out experimental studies in the area of fused deposition modelling.

Ahn et al. [5] studied the influence of model temperature, air gap, bead width, and Infill Pattern on the compressive and tensile strengths of 3D printed specimens. A number of build rules for designing FDM parts were developed based on experimental findings. Bellini and Güçeri [6] observed utilizing an analytical and experimental approach, they determined the effects of Infill Pattern and construct orientation on tensile and flexural strength. Chin Ang et al. [7] experimentally investigated the impact of the following factors on the porosity and mechanical characteristics (compressive strength and compressive modulus) of ABS scaffold structures: raster width, air gap, build layer, build orientation, and build profile. The most important criteria, according to the researchers, are the air gap and raster width.

Sun et al. [8] studied the impact of liquefier temperature, envelope temperature, and deposition technique (longitudinal or lateral) on the mesostructure, cooling properties, flexural strength, and total bond strength between layers. Bakar et al. [9] experimentally investigated the impact of surface polish and dimensional correctness on internal raster width, layer height, and contour width of the components. Also, they employed a 3D printed component as the mold's master design for silicon rubber. Chang and Huang [10] observed the impact of extruding aperture and specimen profile error on contour depth, contour width, raster angle, and raster width. Sood et al. [11] explained the impact of the specimen's compressive characteristics on the component construction orientation, layer thickness, raster width, raster angle, and air gap. Also, using quantum-behaved particle swarm optimization, they created a prediction equation that has been statistically confirmed (QPSO).

Croccolo et al. [12] observed the impact of construction orientation and contour count on the tensile characteristics of ABS-M30 parts. They used raster patterns to anticipate the mechanical behaviour of the 3D printed pieces. Magalhães et al. [13] suggested that the final strength or stiffness of pieces of a construction with a sandwich-like form can be significantly increased by carefully choosing the raster angles. Carniero et al. [14] investigated the impact of layer thickness, orientation, and infill level on the mechanical characteristics of polypropylene parts reinforced and unreinforced with glass fibre. They discovered that 3D printed components can be utilised as working goods as well as prototypes.

Chockalingam et al. [15] studied employing a non-dominated sorting evolutionary algorithm, the dependence of raster angle, orientation, air gap, and Orientation on tensile strength and density (NSGA-II). Cantrell et al. [16] performed experiments to ascertain the directional qualities of the materials. Experiments were conducted by altering the Infill Pattern and build orientations. Arif et al. [17] experimentally investigated the impact of the construction orientation and Infill Pattern on the components' flexural, tensile, and fracture toughness. Because of the interfacial voids, specimens that were vertically assembled showed stick-slip fracture and a lower Poisson's ratio.

Gebisa and Lemu [18] examined how the flexural properties of the ULTEM 9085 material affected the air gap, raster width, raster angle, contour number, and raster width. Rajpurohit and Dave [19] examined how the tensile properties of PLA specimens were affected by the raster angle, raster width, and layer thickness. They found that raster angle and layer thickness are the most crucial factors.

Srinivasan et al. [20] used reaction surface techniques to comprehend the impact of layer thickness, infill density, and infill pattern on the tensile strength and hardness of 3D printed ABS specimens. They discovered that the two most important variables are layer thickness and infill density. Chikshe et. al. [22] evaluated PVC material with a 100% meshing density, and the compressive test for PLA material at three various meshing densities (80%, 90%, and 100%) is plotted. With mesh densities of 80%, 90%, and 100% and a material density that is about the same, PLA is used in the comparative analysis of compressive strength.

According to the literature review, much of the study has focused on analyzing how build orientation, raster angle, and layer thickness affect the mechanical characteristics of the most widely used thermoplastics, such as PLA. Very less amount of work has been reported, which investigates the influence of process parameters on tensile properties of Acrylonitrile Butadiene Styrene/General Parts (ABS/GP) (ABS/GP-modified) parts.

Taguchi's orthogonal array L27 has been used for experimentation. The measured value of mechanical properties is further studied by ANOVA. The optimum parameter settings have been suggested for obtaining the maximum tensile strength of ABS/GP parts as per ASTM standard i.e. ASTM D638 Type 1 as shown in Fig. 1. This design is used for testing the tensile properties of rigid plastics like UTM Tensile strength, Yield Point, Strain & elongation at break and elastic modulus.

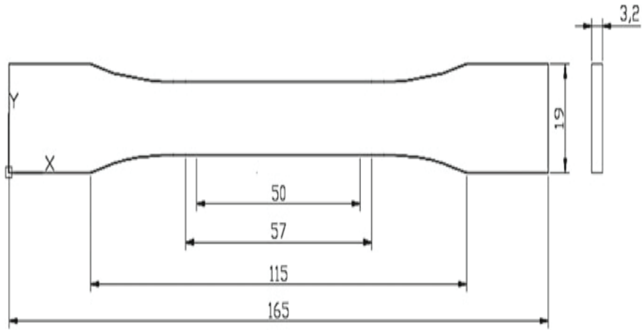

Fig. 1. 2D CAD model of specimen (ASTM D638 Type 1)

III. MATERIALS & METHODOLOGY

In the present work, specimens are produced by a fused deposition modelling process. The Zortrax M200 Plus FDM machine has been used for printing the parts, as shown in Fig. 2. The machine has a build volume of 200X200X250 mm. It can print the parts of various materials such as ABS, PLA, HIPS, and Nylon. The maximum extrusion temperature and maximum bed temperature that can be achieved are 300 °C and 120 °C, respectively. The extruder of the machine is equipped with a nozzle of 0.4 mm diameter.

ABS/GP feedstock material is used for printing the specimen. The CAD model is created in AutoCAD 2020 software. The dimensions of the specimen are decided according to ASTM D638 Type 1. The 2D CAD model of the specimen is shown in Fig. 1. The 3D CAD model is converted into stl file. The Z-Suite software slices the STL file into a number of layers.

Fig. 2. FDM Machine Setup

The software exports a G-code file, which is fed to the FDM machine using SD card. ABS/GP is used as a feedstock material. The following table 1 gives an idea about the constant process parameters used during printing.

Their values are stated in Table 1. In order to get more accurate results, the maximum number of experiments to get the mean value of the outcome, Taguchi's orthogonal array L27 is used for experimental design.

TABLE I. CONSTANT PROCESS PARAMETERS OF FDM

Parameters	Value
Extrusion Temperature	235^{0}C
Platform Temperature	80^{0}C
Nozzle Diameter	0.4 mm
Raster Angle	0^0
First Layer Gap	0.44 mm
Support Angle	45^0

In the present study, four process parameters are selected for experimentation such as Layer Thickness, Orientation, Infill Pattern, and Infill Density. The process parameters and their corresponding levels are listed in Table 2. The literature review and machine setup range are used to determine the level and range of these parameters.

TABLE II. PROCESS PARAMETERS AND THEIR LEVEL

Parameters	Level 1	Level 2	Level 3
Layer Thickness (LT) mm	0.19	0.29	0.39
Orientation (O)	Flat	On Long Edge	On Short Edge
Infill Pattern (IP)	Linear	Grid	Honeycomb
Infill Density (ID) %	50	70	90

Tensile testing of ABS/GP material parts printed using Fused Deposition Modeling (FDM) was conducted in accordance with ASTM D638 Type 1 standards at Dutech Lab, a renowned testing facility located at Nanded City MIDC Road, Pune. The lab is equipped with state-of-the-art testing equipment, ensuring accurate and reliable results. The test evaluated the tensile properties of the ABS material, including tensile strength, yield point, strain, and elongation at break.

In a tensometer, the specimens are clamped, and they are permitted to elongate until they break. The non-stationary mandible moved at a 5 mm/min speed. The apparatus could bear a load of 20 kN. At the conclusion of each tensile test, the load-displacement graph is obtained. It is then further processed with Microsoft Excel to obtain the mean Ultimate tensile strength numbers. Thus, 27 samples were fabricated with varying process parameters, as outlined in Table 3. For each combination, three samples were printed, and the mean Ultimate Tensile Strength (UTS) in MPa was calculated, resulting in a set of tensile mean values.

TABLE III. EXPERIMENTAL DESIGN AND RESULTS

Sr. No.	Layer Thickness	Orientation	Infill Pattern	Infill Density	Tensile Mean UTS (MPa)
1	0.19	Flat	Linear	50	**28.48**
2	0.19	Flat	Linear	50	**28.48**
3	0.19	Flat	Linear	50	**28.48**
4	0.19	On Long Edge	Grid	70	**36.76**
5	0.19	On Long Edge	Grid	70	**36.76**
6	0.19	On Long Edge	Grid	70	**36.76**
7	0.19	On Short Edge	Honeycomb	90	**11.97**
8	0.19	On Short Edge	Honeycomb	90	**11.97**
9	0.19	On Short Edge	Honeycomb	90	**11.97**
10	0.29	Flat	Grid	90	**30.02**
11	0.29	Flat	Grid	90	**30.02**
12	0.29	Flat	Grid	90	**30.02**
13	0.29	On Long Edge	Honeycomb	50	**34.14**
14	0.29	On Long Edge	Honeycomb	50	**34.14**
15	0.29	On Long Edge	Honeycomb	50	**34.14**
16	0.29	On Short Edge	Linear	70	**11.01**
17	0.29	On Short Edge	Linear	70	**11.01**
18	0.29	On Short Edge	Linear	70	**11.01**
19	0.39	Flat	Honeycomb	70	**18.35**
20	0.39	Flat	Honeycomb	70	**18.35**
21	0.39	Flat	Honeycomb	70	**18.35**
22	0.39	On Long Edge	Linear	90	**35.98**
23	0.39	On Long Edge	Linear	90	**35.98**
24	0.39	On Long Edge	Linear	90	**35.98**
25	0.39	On Short Edge	Grid	50	**13.16**
26	0.39	On Short Edge	Grid	50	**13.16**
27	0.39	On Short Edge	Grid	50	**13.16**

IV. RESULTS & DISCUSSIONS

The tensile strength values for each experiment are presented in Table 3. The tested specimens under tensile loading are visually represented in Figure 3. Notably, some samples exhibited brittle behavior and fractured outside the gauge length.

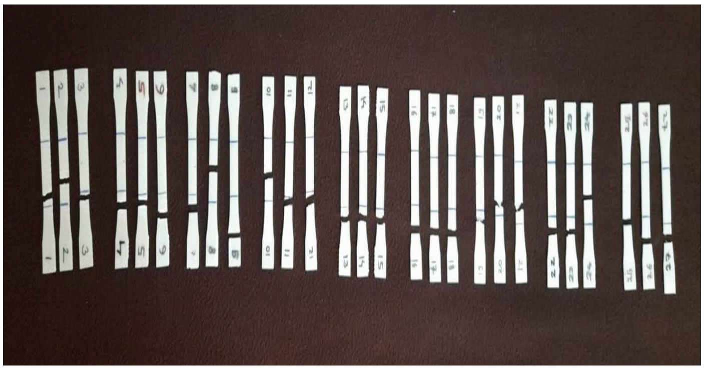

Fig. 3. Tested 27 specimens (L27)

A. ANOVA Analysis

This could occur as a result of stress concentration and voids in the printed specimen's layers. To determine the statistical significance of process parameters on the part's mechanical properties, analysis of variance (ANOVA) is used. Tables 4 show ANOVA with *F*-ratio and *p*-values for the tensile properties of printed samples. The results of the tested specimens showed that almost all ABS/GP specimens exhibit identical brittle behaviour under tensile loading. Maximum tensile strength and modulus are 36.76 MPa. The mechanical characteristics are lower than those of injection-molded items due to anisotropy and tiny voids.

TABLE IV. ANOVA FOR TENSILE STRENGTH

Source	DF	Adj MS	F-value	P-value	Comment
Layer Thickness (LT)	1	60.61	24.56	0.001	Significance
Orientation (O)	1	47.23	17.72	0.014	Significance
Infill Pattern (IP)	1	2.39	0.63	0.567	
Infill Density (ID)	1	128.65	49.90	0.000	Significance
Error	8	3.69			
Total	12				

Further, the influence of each parameter on response characteristics is briefly discussed below. In which p-values below 0.05 show a 95% confidence level and significance of that parameter over the response factor or outcome factor.

B. *Effect of Process Parameters on Tensile Strength*

1) *Effect of Layer Thickness (LT)*

According to the ANOVA table, it is observed that the influence of layer thickness on tensile strength is significant (Table 4). The layer thickness is the height of each layer that is extruded from the nozzle and deposited in FDM. An increase in the layer thickness causes a decrease in the tensile strength, as shown in Fig. 04. Maximum tensile strength is attained at the minimum layer thickness.

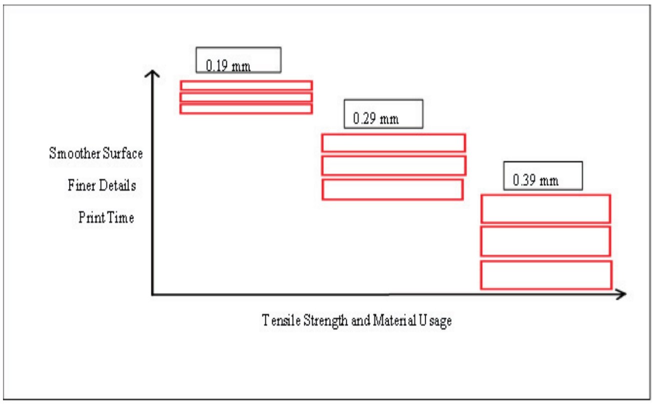

Fig. 4. Layer thickness w.r.t. Smoother Surface, finer Details & Print Time v/s Tensile Strength & Material Usage

The total number of layers required to print the entire part rises as layer thickness decreases. Durgashyam et al. [21] noted that better layer diffusion is encouraged by the increased warming of earlier layers. Similar outcomes were noted.

A greater SN ratio denotes better performance (because "larger is better"), and the Main Effects Plot (Fig. 5) for SN ratios illustrates the impact of each factor (LT, O, IP, and ID) on the signal-to-noise ratio. Given that orientation (O) exhibits the steepest slope and the greatest variance, it is clear from the figure that it has the greatest impact on the SN ratio. While Layer thickness (LT) has a negligible impact, infill pattern (IP) and infill density (ID) also have discernible effects, albeit less so. Overall, this analysis indicates that layer thickness has less of an impact on tensile strength performance and consistency than orientation, with careful infill pattern and density selection allowing for further improvements.

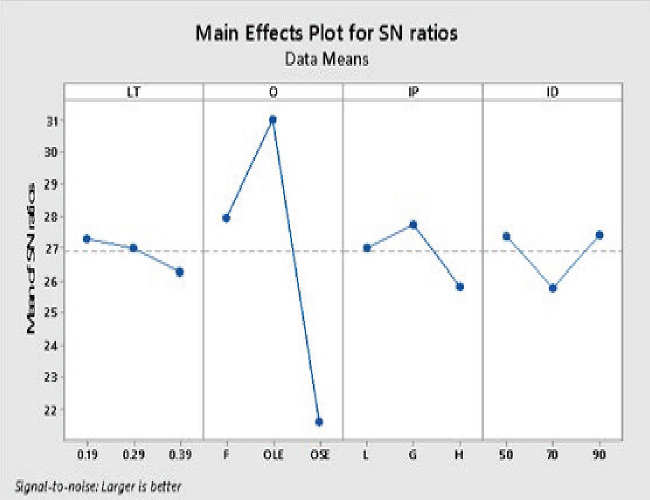

Fig. 5. Main effect plot of S/N ratio for Tensile Strength

2) *Effect of Orientation (O)*

From the ANOVA table, it is found that the influence of the Orientation of tensile strength is significant (Table 4). The orientation refers to how the specimen is printed along any axis on the bead. In this study, we have taken three different orientations, viz., flat, on long edge, and on short edge, from the Z suit software arrangement for placing objects on a machine bed as shown in the Figure. 6.

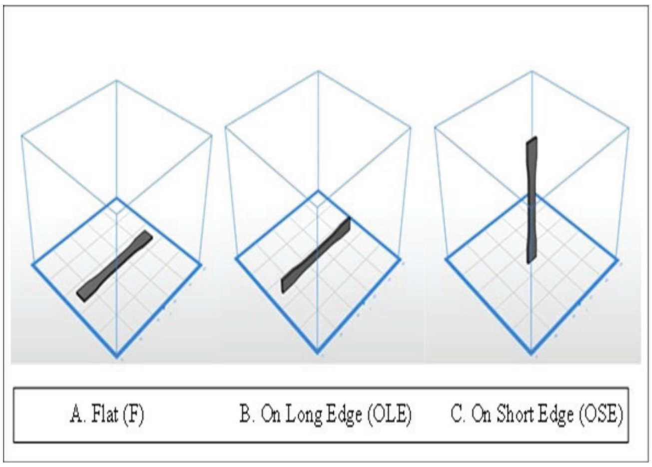

Fig. 6. Part Orientation A. Flat (F), B. On Long Edge (OLE), C. On Short Edge (OSE)

According to the main effect plot of S/N ratio, it is observed that on the long edge in the Orientation shows maximum tensile strength among flat & on short edge orientation, as shown in Fig. 6b. As Orientation changes, the heat transfer rate of the layer increases. It gives more time to the layer for diffusion with previous layers. With further change of orientation on the short edge, the tensile strength is minimum where whereas in flat orientation, tensile strength is considerably higher, with the value nearby to the maximum tensile strength. It may happen due to less time for diffusion with the previous layers.

The tensile strength is substantially impacted by the combined impacts of layer thickness (LT), orientation (O), infill pattern (IP), and infill density (ID), rather than by any one of these factors alone, as the interaction plot for tensile mean UTS (MPa) makes evident in fig. 7. Significant interactions, especially between LT and O, which seem to be the most important elements influencing UTS, are indicated by the non-parallel and crossing lines. Although they also have an impact, IP and ID are heavily reliant on LT and O levels. This implies that since no one factor alone can ensure the maximum UTS, improving tensile strength necessitates carefully choosing the ideal mix of all four criteria.

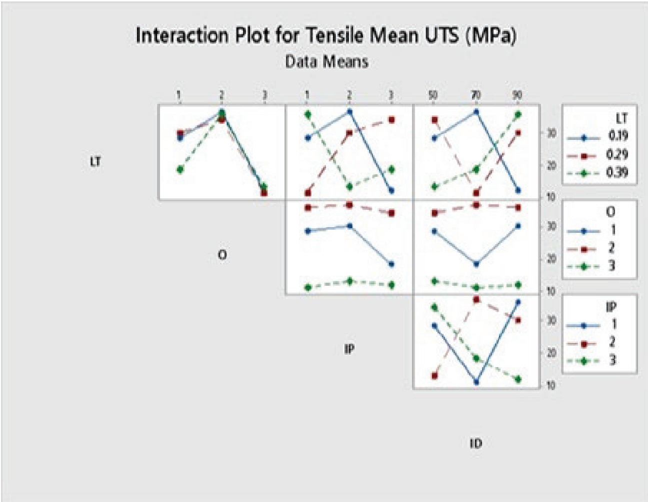

Fig. 7. Interaction plots for Tensile Strength

3) *Effect of Infill Pattern (IP)*

As ANOVA table suggests, the influence of Infill Pattern (IP) on tensile strength is not significant, as the value of p is more than 0.05 (Table 4). The method used to define the boundaries between the inner layers is known as the infill pattern. All that is being printed in the interior structure are geometrical patterns.

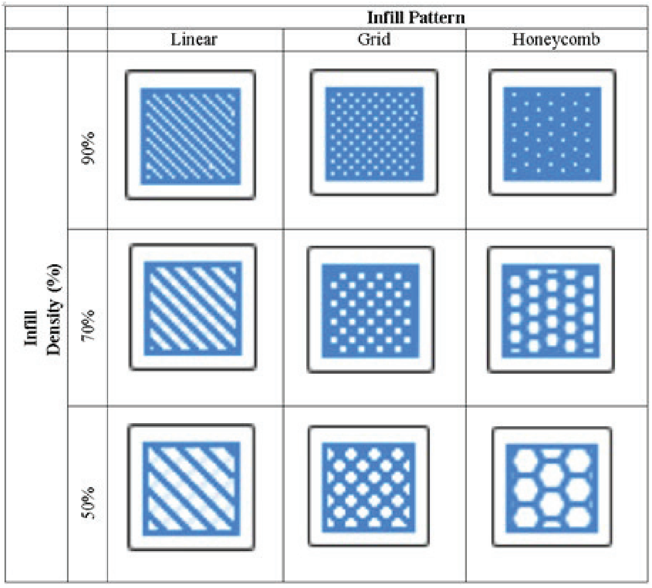

Fig. 8. Different infill patterns with varying infill density

From Fig. 5, it is found that the specimen printed as a grid pattern has the maximum tensile strength. As the Infill Pattern changes, the tensile strength varies as per the pattern. Because an infill pattern pertains to a 3D printed part's internal structure, it implies that the specimen's structural strength varies. the tensile load is applied along the infill pattern for each layer. It results in better tensile strength as compared to the load applied in the direction of normal to the pattern structure. Further, it is observed that higher strength is achieved in the grid pattern as compared to linear and honeycomb patterns.

The results of earlier studies are in conflict with this one. Additionally, the interaction effect of parameters may help to better explain this behavior. A limitation of Taguchi's experimental design is that it does not explain the interaction effect of process parameters on response characteristics.

4) *Effect of Infill Density (ID)*

From the ANOVA table, it is seen that the p-value for the Infill density is less than 0.05, which shows that its effect is significant for tensile strength (Table 4). From Fig.8, it has been discovered that examples with an infill density of 90% have the highest tensile strength. The mechanical strength of the part is increased as infill density rises because of inter-layer bonding between succeeding layers. Reduced infill density speeds up construction and reduces the quantity of material needed. However, it is discovered in the current study that an infill density of 50% & 70% provides roughly the same tensile strength when combined with other parameters, which contradicts the fundamental rule that a higher infill corresponds to a higher strength.

V. CONCLUSIONS

In the present study, efforts are applied to optimize the tensile strength of printed specimens. A set of optimum parameters is defined based on the average S/N ratio for each parameter. It provides a methodical way to enhance these composites' mechanical properties, which can be desirable for a range of industrial uses, like to test prototypes of bigger parts in a sugar factory, an automobile child part or assembly, sanitary product testing, etc. For tensile strength, the optimum combination of parameters is 0.19mm layer thickness, print orientation on the long edge with a grid pattern, and 90% infill density.

An experimental investigation has been carried out to study the influence of process parameters on the mechanical properties of ABS/GP parts printed by FDM. From the analysis of experimental results, the following observations are made:

1. Infill Pattern, Print Orientation and layer thickness are the most significant process parameters that influence the tensile strength of the specimen.
2. Tensile strength increases with a decrease in layer thickness, on long edge orientation, with a grid pattern, and an increase in infill density.
3. The highest UTS values were obtained by combining 0.19mm layer thickness, Grid Pattern (G), On long edge orientation (OLE), and 70% infill with a remarkable mean UTS of 36.76 MPa. This configuration is the best option for situations when a high tensile strength is critical.
4. According to the study, a 0.19mm layer height in conjunction with a long edge orientation is ideal for

increasing resistance to cyclic loading and tensile failure.

5. It was discovered that the best S/N ratio for the highest is better mean UTM tensile strength was 0.19mm layer thickness, on long edge orientation (OLE), and Grid Pattern fused with 50% infill.
6. The intended ultimate mean tensile strength is provided for applications that call for resistance to tensile deformation and tensile strength.

The findings of the experiments have been used to determine a set of ideal parameters. The results of the current paper can be applied to further research to comprehend how the interaction of process parameters affects the mechanical characteristics of 3D printed ABS/GP specimens.

Significantly, the study's confirmation tests confirmed that the experimental results were reliable. The outcomes continuously outperformed the expected values, demonstrating the efficiency and resilience of the Taguchi method-derived optimum settings. This validation demonstrates the accuracy and usefulness of the Taguchi technique in fine-tuning 3D printing parameters for improved material performance and attributes.

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