IMPACT OF PLA AND ABS ON THE MECHANICAL PROPERTIES OF FUSED FILAMENT FABRICATION

Abstract

This study examines the impact of printing parameters on fused filament fabrication (FFF) parts using PLA and ABS filament. It aims to determine the ideal conditions for increasing the strength of these materials. The study uses Taguchi's method to determine the effects of infill percentage, wall line count, and infill pattern on the materials' mechanical characteristics. PLA is found to be more rigid and have higher tensile strength than ABS. The optimal combination of manufacturing parameters can result in higher PLA strength.

Keywords: FFF Printed Parts, ABS filament, PLA filament, Parameters, infill, wall count, pattern.

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I. INTRODUCTION

The cost of 3D printed components varies significantly based on the printer, filament material, and process parameters. Researchers have studied the mechanical characteristics of components printed using ABS filament and found that fracture resistance depends on induced stress, crack propagation, and laminate composite mechanics. Ultrasonic vibration impacts the mechanical properties and microstructure of ABS and PLA samples, with higher compressive strength in Z-axis orientation and smoother surface roughness at 20 kHz. [1]

II. LITERATURE REVIEW

The research aimed to enhance ABS mechanical properties using fused deposition modeling. Results showed contour numbers significantly improve properties, with layer thickness being the most effective. Both RSM and ANN models can control build properties individually, with a slight interaction between infill percentage and contour numbers. ANN modeling has a higher R value, making it more reliable for additive manufacturing ABS. [2] Additive manufacturing gains popularity due to its versatility, and fused deposition modeling (FDM) shifts from rapid prototyping to rapid manufacturing. This article presents a multi-objective optimization approach for selecting optimal 3D printing parameters for PLA and ABS parts, focusing on mechanical behavior and value analysis. It identifies optimal parameters based on desirability function. [3] A multi-objective optimization approach for selecting optimal 3D printing parameters for PLA and ABS parts, focusing on mechanical behavior and value analysis. It identifies optimal parameters based on desirability function. The study investigates the influence of FFF parameters on tensile, bending, and impact mechanical properties in 20% short-carbon-fiber reinforced PEEK. Results show that lower LH and PT reduce volumetric defects, while average values (385 °C) benefit the microstructure. The optimized parameters yielded UTS, UBS, and UIS values of 116.7 ± 5 MPa, 167.2 ± 11 MPa, and 28.2 ± 3 kJ/m^2. [4] Additive manufacturing (AM) is rapidly growing, with 3D printing being used in automotive, aerospace, and medical sectors. Fused deposition modeling (FDM) is popular for fabricating PEEK parts for biomedical implants.

An ANN model with 4-12-2 network architecture improves surface roughness and mechanical strength. [5] A Computational Fluid Dynamics (CFD) model predicts fiber orientation in extruded material during material extrusion. The model simulates fiber/polymer suspension deposition, providing detailed information on material extrusion and fiber orientation evolution. This simulation can improve mechanical properties and adhesion during layup. [6] Impact resistance of PLA 3D-printed components, focusing on infill percentage and layer thickness. Results show annealing increases impact energy, indicating potential for mechanical integrity. [7] This research explores the influence of FDM process parameters on surface roughness parameters in nylon carbon fiber printed parts. It uses a definitive screening design, Pareto chart, optical microscopy, and multi-response optimization to enhance 3D printed parts quality and performance. [8] influence of used filament fabrication (FFF) on part quality aspects and conducts dynamic analysis of FFF parts for various applications. [9] 3D printing critical materials for electrochemical energy storage devices (EESDs), particularly rechargeable batteries. It covers design principles, materials selection, and optimization strategies, as well as challenges and potential applications in the development of these materials. [10] Impact of filament colour on printed PLA parts' quality and properties has been limited. This study analysed dimensional accuracy, tensile strength, and friction properties of samples under different printing temperatures. [11] Impact of process parameters on tribological and frictional behavior of acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) 3D-printed parts. The optimal input parameters for achieving minimum friction and linear wear were found to be 50% infill percentage and 0.1 mm layer thickness. [12] FFF parts made from ABS, revealing that voids can be eliminated entirely, thereby opening new applications for FFF, despite its limitations. The study compares fatigue behavior of polymer weld joints 3D printed using additive manufacturing, revealing superior resistance in PLA/PLA joints compared to non-welded PLA. [13] This study successfully processed tensile samples of a tri-material based 3D-printed polymer composite using fused filament fabrication (FFF). The study found that selected FFF process parameters significantly impacted tensile properties. The results showed that high LT, high PS, and low ID led to defects, while high LT, high PS, and high ID resulted in no defects. [14] The study explores the impact of infill patterns and densities on tensile and impact strength in 3D printed lightweight geometrical designs, revealing that Grid patterns yield higher results. [15]

III. METHODOLOGY

1. **FDM 3D Printer:** Make 3d Company has provided the Pratham 5.0 3D printer with a maximum printing size of 500mm*500mm*500mm. shown in Figure 3.1, as per ASTM technical standards, which is widely used to determine the mechanical properties of reinforced and non-reinforced plastics of 2d image of compression and flexural as shown in Figure 3.2 a & b

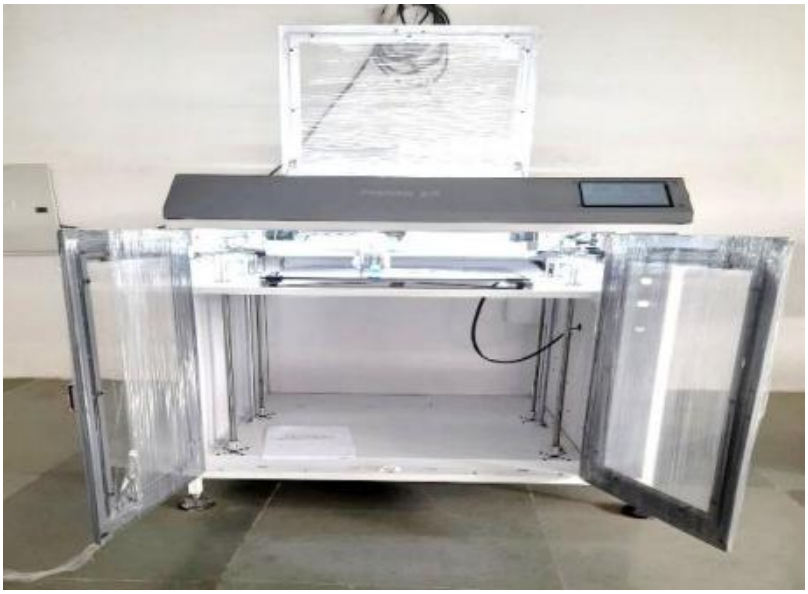

Figure 3.1: 3D Printer

Table 1: PLA & ABS Filament Properties

Properties	PLA	ABS
Extrusion Temperature (°C)	190–210	220–260
Density (g/cm3)	1.25	1.04
Compressive strength (MPa)	48.2-65	43-70
Flexural strength (MPa)	97	66
Biodegradability	Yes	No
Fume toxicity	Very low	Medium

2. **Material:** The filament material used was PLA & ABS of 1.75 mm diameter, purchased from WOL3D. Table 1 provides its properties.

3. **DOE:** The Taguchi method is used to improve the quality of products and processes. Improved quality results when a higher level of performance is consistently obtained. The highest possible performance is obtained by determining the optimum combination of design factors.

In this project, there is a total of 4 parameters. They are Infill %, Wall Count, Infill Pattern and Nozzle diameter. And for every parameter, there is a total of 3 values. They are one low value, intermediate value and high value. So, there are 4 factors and 3 levels. By using the Minitab software, we minimize the optimization of the design. L9 array is chosen with 3-levels and 4-factors. Optimization of the design by L9 array in Minitab shown in table 2.

Table 2: Selected process parameters

Run	Infill %	Wall Count	Infill Pattern
1	30	3	Rectilinear
2	30	6	Grid
3	30	9	Line
4	60	3	Grid
5	60	6	Line
6	60	9	Rectilinear
7	90	3	Line
8	90	6	Rectilinear
9	90	9	Grid

In this Fixed Parameters are Speed-50mm/s, Orientation 0, Layer Thickness-0.1mm, Bed Temperature-67C. The Taguchi method adjusts average and reduces variance by arranging factors and their levels. Infill Density is adjusted to 30, 60, and 90 for nozzle diameter 0.4mm. This method requires fewer experiments, reducing production costs. The parameters and range were chosen based on previous studies, with a recommended printing temperature of 200-220°C. [12,13,14] High temperature yields higher tensile strength for PLA & ABS filament. In this present research Wall line count levels are 2,4, and 8, and infill patterns were Rectilinear, Grid, and Line and, Layer height 0.2mm, Print Speed 65mm/s and Print temperature is 220^0C were set to print the specimens. The experiments were set up using Minitab software and Taguchi's [16] orthogonal array of fractional factorial design. [17].

4. **Preparation of Specimens:** Flexural and Compression specimens were prepared using Creo software shown in figure 3.3 and exported in Stereolithography (STL) file format for readable by slicer software cura 5.5.0 shown in figure 3.4 . The sliced model was saved as G-code and read by a 3D printer to create a 3D shape. Figure 3.4 shows the samples Printed by using selected parmeters of Infill dinsilty and pattern, wall line count.

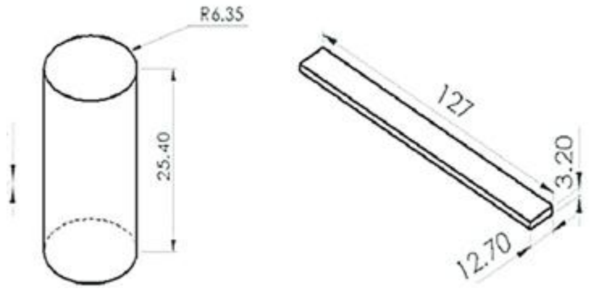

Figure 3.2: a) Compression b) Flexural specimen

Figure 3.3: Design in Cre-o

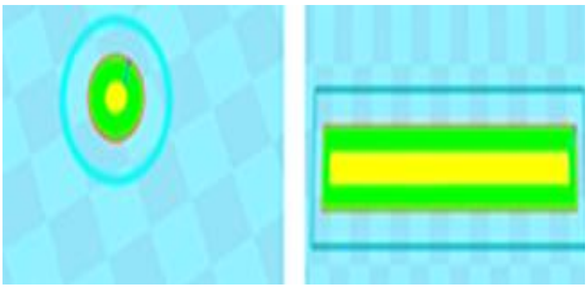

Figure 3.4: slicing using CURA 5.5.0

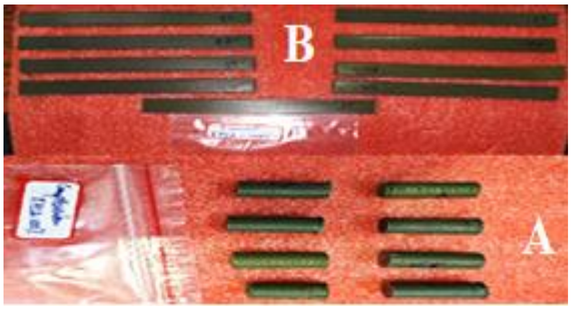

Figure 3.5: Printed samples a) Compression b) Flexural

The samples were tested using the universal testing machine FUEL INSTRUMENTS & ENGINEERS PVT LTD, with a 400 Kn load as shown inf Figure 3.6 a & b. and figure 3.7 a & b shows the specimen after tested on UTM.

Figure 3.6: a) Flexural b) Compression

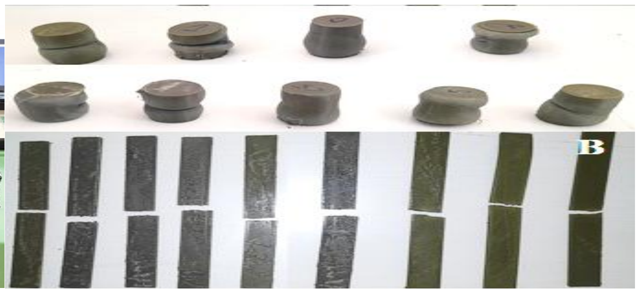

Figure 3.7: After testing a) Compression b) Flexural

IV. RESULTS & DISCUSSION

After testing the experimental results are entered in the minitab to find out the S/N ratio, table 3 shows the s/n ration of the specimens. From table 3 it is observed that the greater (L9 Specimen) flexural and compression strength got high S/N ration whereas the lesser (L1 Specimen) strength of both flexural and compression specimen got less S/N ration.

Table 3: Results of Flexural and Compression test for both PLA & ABS

Run	ABS				PLA			
	Flexural (MPa)	S/N Ratio	Compression (MPa)	S/N Ratio	Flexural (MPa)	S/N Ratio	Compression (MPa)	S/N Ratio
1	34.05	30.90	12.63	22.76	13.86	22.84	54.57	34.74
2	36.34	31.42	18.92	24.61	16.56	24.38	56.27	35.01
3	38.73	32.04	23.63	27.79	18.47	25.33	57.81	35.24
4	44.36	32.72	29.96	28.88	34.45	30.74	60.01	35.56
5	55.36	34.65	33.71	30.32	38.86	31.79	65.6	36.34
6	53.92	34.81	41.68	32.56	55.48	34.88	73.78	37.36
7	61.44	35.69	45.63	32.98	78.97	37.95	85.9	38.68
8	72.47	37.09	56.86	34.92	85.4	38.63	86.13	38.7
9	81.11	38.31	57.13	35.03	87.63	38.85	100.94	40.08

The optimal parameters for tensile strength were determined by selecting the maximum S/N ratio for each factor. The optimal parameters include infill 90%, wall count 9, infill pattern Grid.

Table 5: Anova of Flexural and Compression for both PLA & ABS Material

		Compression				Flexural			
Source	DF	Adj SS	Adj MS	F-Value	P-Value	Adj SS	Adj MS	F-Value	P-Value
Model	6	6408.22	1068.04	1469.20	0.001	5264.08	877.35	47.52	0.021
Linear	3	4263.67	1421.22	1955.05	0.001	3104.33	1034.78	56.04	0.018
Infill %	1	4248.43	4248.43	5844.19	0.000	2748.38	2748.38	148.86	0.007
Wall Count	1	1.46	1.46	2.01	0.292	3.74	3.74	0.20	0.697
Infill Pattern	1	3.57	3.57	4.91	0.157	29.67	29.67	1.61	0.333
Square	1	22.58	22.58	31.06	0.031	266.88	266.88	14.45	0.063
Infill %*Infill %	1	22.58	22.58	31.06	0.031	266.88	266.88	14.45	0.063
2-Way Interaction	2	1.67	0.83	1.15	0.466	64.61	32.31	1.75	0.364
Infill % * Wall Count	1	0.00	0.00	0.00	0.971	23.72	23.72	1.28	0.375
Infill %* Infill Pattern	1	0.04	0.04	0.06	0.829	35.89	35.89	1.94	0.298
Error	2	1.45	0.73			36.93	18.46		
Total	8	6409.67				5301.01			

From table 3 Run 9 maximum strength of 81.11 MPa and minimum of 34.05 MPa, whereas for Compression strength is high for 9th run and low for 1st run is 57.13 MPa and 12.63 MPa, the FDM creates the specimen with high strength in runs 5-9 due to high infill percentage. From Table 5 Infill % got P-Value <0.05 for both the materials, hence the parameter is significant.

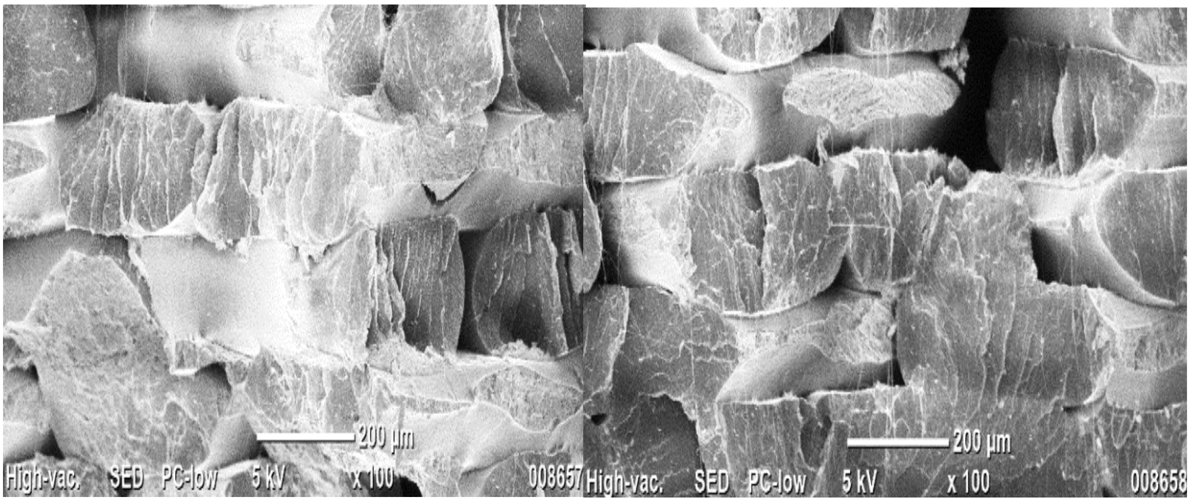

Figure 4.3: SEM images of fractured interface of (a) PLA (b) ABS

In the below SEM image, L9 we can see that Porosity has been developed between the layers. The mechanical properties of the specimen, including flexural and compression strength are reduced when porosity occurs. The failure of the specimen could be caused by porosity. Long reinforcements can be seen in the corresponding figure 4.3 (a), which were generated by scanning electron microscopy of specimen L-6. This provide the specimen more strength. Compare with ABS air gaps, wall lines and void areas of PLA specimens are very good as shown in figure 4.3 b.

Relevant studies were documented in ref. [19], Effect of PEG content on the mechanical properties of PCL/PLA/PEG composites, finding that increasing PEG content improved tensile and impact strength, but not compared with ABS material. In research [20] the influence of geometry and printing temperature on 3D printed PLA specimens, revealing that fillet radius and printer parameters influence material quantity and damage area. In Ref [21 & 22] use of PLA biodegradable material in additive manufacturing (AM) for fast prototyping, focusing on parameters like fill percentage, raster angle, and layer thickness and also found good mechanical and flexural properties, reducing printing time. From ref [4] shows that lower layer height and printing temperature reduce volumetric defects. Ref [12] Impact of process parameters of infill 50% and 100 microns achieved minimum friction during linear wear.

It can be observed from the results Compared to ABS, PLA printed samples exhibit a higher degree of variance in the mechanical property values. The mechanical properties varies by infill %, wall count and pattern

V. CONCLUSION

From Experimental and ANNOVA the suitable process parameter to print specimens fast, flexible and filling with less material than full infilling of material in the specimen i.e., 100%. From the results it is clear that by using infill 90%, wall count 9 and Grid infill pattern for both ABS & PLA material got high strength.

The ANOVA table reveals that infill% is the only statistically significant parameter from Table 6 for both ABS and PLA materials, specimen 9 got high and specimen resulting in flexural strengths of 81.11 MPa for ABS and 87.63 MPa for PLA whereas for compression strength 57.13 MPa for ABS and 100.94 MPa for PLA.

The study reveals that PLA material exhibits high flexural and compression strength, while ABS material has a lower strength. From SEM compare to PLA, ABS got microstructural defects, such as air gaps and voids, are directly linked to the strength outcomes.
By Compared to ABS material, PLA material exhibits an earlier onset of dependence between wall count, infill percentage, and pattern.

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