

# Assessment of Flexural Strength of 3D Printed PETg and ABS filaments

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**Abstract** - The process of 3D printing yields manufacturing complex shapes from a geometric model layer-by-layer addition of material. Additive manufacturing has been utilized as emerging tool for rapid prototyping. It uses fused deposition modelling to deposit layer by layer to construct complex contours of required shape. This assessment focuses on study of flexural strength of 3D Printed PETg and ABS and to provide better results of flexural properties. The variables selected were speed of print, density of infill and thickness of layer. The results revealed that ABS yields better flexural strength than PETg. Moreover, Infill density was found to be the most influential factor followed by thickness of layer. Speed of print was found to be insignificant variable.

**Keywords** – Additive Manufacturing, ABS, PETg, Flexural Strength.

## 1. Introduction

Over the years, 3-D printing technology has evolved, introducing new materials and processes that have expanded the range of applications for this technology. By the early 2000s, it had become an established technology used in various trades, containing motorized and pharmaceutical. The first step in the 3D printing process is to use CAD software, which stands for computer-aided design, to create a 3D model. After that, the model is transferred to a 3D printer, which processes it and starts layer-by-layer fabrication of the object. The printer builds the object by extruding or depositing substantial in a specific replica of the object, based on the instructions in the digital model.

Additive manufacturing, also known as 3D printing, employs layer-by-layer material deposition from a digital design file to create three-dimensional things is the fundamental idea behind additive manufacturing. Doctors can now use 3D printing to create customized implants that fit a patient's bone structure perfectly, reducing the risk of complications and improving recovery time. In the aviation trade, it is employed in the creation of components that are light and components that are strong enough to withstand extreme conditions. In motorized production, designs have been made using jigs and fixtures to produce customized parts for high-performance vehicles.

In the consumer products industry, 3D printing has enabled the creation of customized products, such as jewellery, phone cases, and furniture. Designers can create unique designs that can be produced on demand, reducing waste and the need for inventory. Moreover, 3D printing has been utilized to make fashion accessories, such as shoes and handbags, using materials such as leather, nylon, and rubber. The capacity of 3D printing technology to produce goods on demand has greatly accelerated industrial output as well as scholarly study.



**Fig. 1 3D Printer**

Vikneswaran et al. [1] investigated the tensile strength and stiffness of 3D Printed PETG, PLA and ABS. The research found that PETG possesses higher tensile strength while ABS possesses higher stiffness. Popescu et al. [2] investigated the mechanical properties of 3D printed material. The research revealed that infill density and nozzle temperature have great impact on the mechanical properties of material.

Jha and Narasimhulu [3] in their study investigated the creep and vibration of 3D printed specimens. Yao et al. [4] and Xia et al. [5] study showed that the tensile strength of FDM printed part is mainly influenced by printing angle. Gordelier et al. [6], found that the tensile strength can be improved by optimizing different 3D Printing parameters. They also concluded that investigation on printing temperature is insufficient. In another research carried by Tymrak et al. [7], found that the tensile strength increases as the layer height is reduced. Furthermore, they also found that PLA depicted greater variation among the machine variables.

Lanzotti et al. [8] carried study on PLA material using RSM technique and found that the ultimate tensile strength was achieved at 0.15 mm layer thickness along with 45° orientation. They also concluded that the tensile strength trend was nonlinear and depends on other machine variables. Sood et al. [9] in their study included print angle, layer thickness, raster angle, width and air gas as process variables while 3D Printing ABS for its tensile and flexural strength and impact energy. Lower layer thickness is suggested for better tensile strength while higher layer thickness should be selected in order to achieve better flexural strength and impact energy. Chacón et al. [10] through their study found that on-edge orientation yields optimal mechanical performance. Minimum layer thickness and

elevated rate of feed are suggested for better ductility. They also concluded that high layer thickness and elevated rate of feed should be selected for minimum printing time.

Based on the above reviews of past literatures, the aim of study for this assessment to be performed on 3D printing using ABS and PETg. Flexural strength of both the material will be compared while considering thickness of layer, infill density and speed of print as machine variables. Bending properties of the 3D printed specimens are assessed to determine its flexural strength.

## 2. Experimental Details

Creality 3D Printer was used for printing the tensile and flexural specimens. FDM technique of Additive manufacturing was used to print the samples. The samples were printed layer by layer. The material used for the present work are ABS and PETg. ABS possesses good impact resistance, moderate tensile strength, rigidity, and resistance to many acids and alkalis. On the other hand, PETg possesses high impact strength, is more flexible, has better dimensional stability, better resistance to acid and alkalis, and better surface finish. Both thermoplastics widely are used in engineering, manufacturing, and 3D printing. ABS finds its application in the Automotive and Electronics industries as well as toys, pipes, fittings and 3D printing, while PETg applies to the packaging industry, medical devices, displays and 3D printing. The filaments used were of 1.75mm diameter. The specimens were printed based on ASTM D790. Figure 2 depicts the slicer image for flexural specimen.



Figure 2: Flexural Specimen Slicing on 3D Printer Software

Creality K1 3D Printer was used to print the PETg and ABS specimens as per the standards. Flexural Strength was assessed using the point loading method on Instron 3382 UTM machine at CIPET, Lucknow. Figure 3 illustrates the testing of specimen for flexural strength.



**Figure 3. Flexural Test Specimens of PETg material based on ASTM D790 on UTM**

Experiments were planned as per Taguchi Approach L9 orthogonal Array. The range of Layer Thickness lied between 0.1-0.3 mm while that of print speed lied between 40-60 mm/s. The range of density of infill was kept between 40 to 80%.

### **3. Results and Discussion**

The ASTM D 790 standard was used to design flexural strength specimens and later sliced using creality software and printed. The flexural tests were performed at CIPET, Lucknow and the values are depicted in the Table 1.

**Table 1. L9 Orthogonal Array for Flexural Strength of ABS and PETg**

Exp. No.	Layer Thickness (mm)	Print Speed (mm/s)	Infill Density (%)	Flexural Strength of ABS (MPa)	Flexural Strength of PETg (MPa)
1	0.1	40	40	41.37	38.84
2	0.1	50	60	57.23	48.12
3	0.1	60	80	69.46	59.58
4	0.2	40	60	64.22	56.63
5	0.2	50	80	72.93	60.38
6	0.2	60	40	58.77	50.77
7	0.3	40	80	73.12	66.54
8	0.3	50	40	52.44	49.65
9	0.3	60	60	65.27	57.98

The range of flexural strength for ABS lies between 41.37 to 73.12 MPa while that of PETg lies between 38.84 to 66.54 MPa. It is noted that the flexural strength of ABS was more as compared to PETg. The Table 2 depicts the S/N Ratio for the present set of experiments performed for flexural strength.

**Table 2. S/N Ratio for Flexural Strength**

Exp. No.	Flexural Strength of ABS (MPa)	S/N Ratio for Flexural Strength of ABS (db)	Flexural Strength of PETg (MPa)	S/N Ratio for Flexural Strength of PETg (db)
1	41.37	32.3337	38.84	31.7856
2	57.23	35.1525	48.12	33.6465
3	69.46	36.8347	59.58	35.5020
4	64.22	36.1534	56.63	35.0609
5	72.93	37.2581	60.38	35.6179
6	58.77	35.3831	50.77	34.1121
7	73.12	37.2807	66.54	36.4617
8	52.44	34.3933	49.65	33.9184
9	65.27	36.2943	57.98	35.2656

The influencing parameters are depicted in the table with their ranks. The rank of the parameter depends upon the delta value. Infill density is the crucial factor for flexural strength trailed by thickness of layer. The influence of speed of printing was least among the selected parameters.

**Table 3. Mean S/N ratio for Tensile Strength of ABS**

Level	Layer Thickness	Print Speed	Infill Density
1	34.77	35.26	34.04
2	36.26	35.60	35.87
3	35.99	36.17	37.12
<b>Delta</b>	1.49	0.91	3.09
<b>Rank</b>	<b>2</b>	<b>3</b>	<b>1</b>

**Table 4. Mean S/N ratio for Tensile Strength of PETg**

Level	Layer Thickness	Print Speed	Infill Density
1	33.64	34.44	33.27
2	34.93	34.39	34.66
3	35.22	34.96	35.86
<b>Delta</b>	1.57	0.57	2.59
<b>Rank</b>	<b>2</b>	<b>3</b>	<b>1</b>

The table 5 and table 6 illustrates ANOVA of Tensile Strength carried out on Minitab software. The result shows that the contribution of Infill density is highest for both ABS (76.63%) and PETg (second highest for PETg (41.09%). Furthermore, Infill density is the major dominating factor (68.26%). Similarly, layer thickness was found to be the second most dominating parameter for flexural strength of ABS and PETg. Print speed, as earlier depicted by S/N ratio table, is the least influencing parameter for flexural strength of both the materials.

**Table 5. ANOVA of Flexural Strength of ABS**

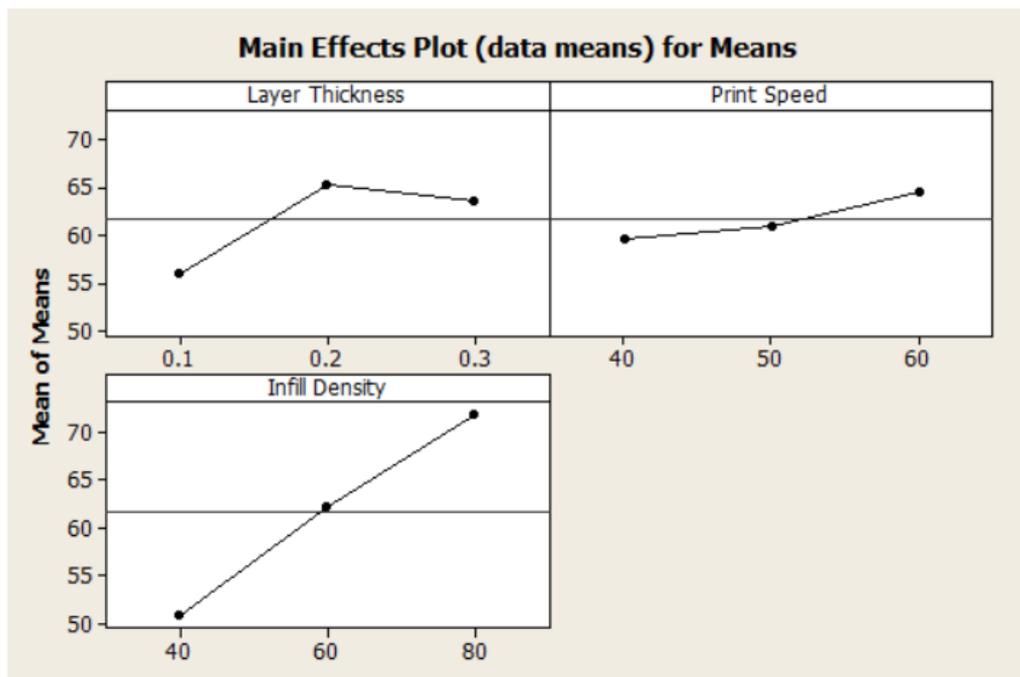
Source	DOF	SS	Adj MS	F Value	Contribution
Layer Thickness	2	146.73	73.36	9.23	16.99%
Print Speed	2	39.19	19.59	2.46	4.54%
Infill Density	2	661.62	330.81	41.61	76.63%
Error	2	15.90	7.95		1.84%
Total	8	863.44			100 %

At least 95% confidence

**Table 6. ANOVA of Flexural Strength of PETg**

Source	DOF	SS	Adj MS	F Value	Contribution
Layer Thickness	2	139.487	69.744	8.78	25.60%
Print Speed	2	17.608	8.804	1.11	3.23%
Infill Density	2	371.941	185.971	23.42	68.26%
Error	2	15.879	7.940		2.91%
Total	8	544.916			100 %

At least 95% confidence



**Figure 4. Main effect plot for Flexural Strength of ABS**

Figure 4 and Figure 5 represents the main effect plot for Flexural Strength of ABS and PETg respectively. It depicts that the flexural property increases with increase in 3D Printing parameters for both the materials. Strength is imparted in the sample having extra amount of material. With high layerthickness (0.2-0.3 mm), the intra-layer adhesion is more in the present case and hence the flexural strength is more. Infill density had direct and significant influence on flexural strength. At 80% infill density, the printed part is almost solid and provide maximum resistance to bending.

Print Speed is the least influencing parameter for flexural strength and has only 4.54% and 3.23% contribution for ABS and PETg respectively. It is observed from the graph that print speed has negligible influence on the flexural property of the material. A higher set of levels of 3D printing parameters is suggested from the present set of experiments.

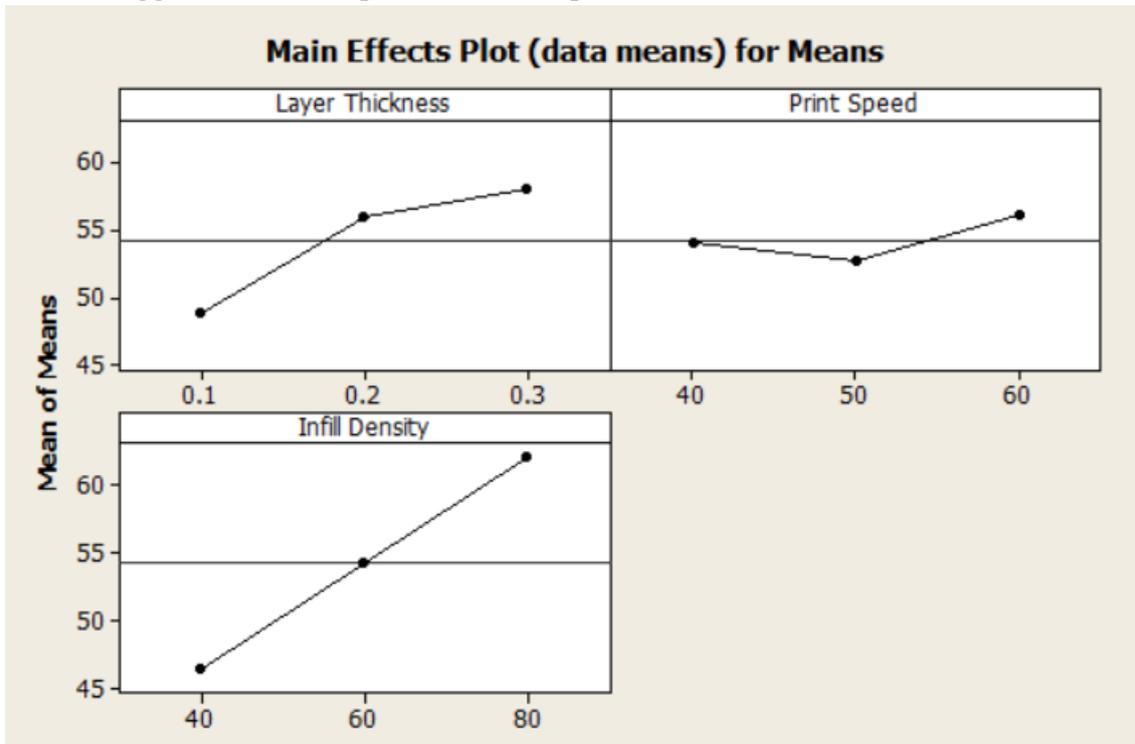


Figure 5. Main effect plot for Flexural Strength of PETg

#### 4. Conclusion

This assessment was conducted for analyzing the flexural strength of 3D Printed ABS and PETg filament. The flexural tests were performed and planned on the basis of TaguchiL9 orthogonalarray. The following conclusions were assessed:

- For both ABS and PETg, Infill density is the crucial factor for flexural strength trailed by thickness of layer. The influence of speed of printing was least among the selected parameters.
- The contribution of Infill density is highest for both ABS (76.63%) and PETg (second highest for PETg (41.09%). Furthermore, Infill density is the major dominating factor (68.26%). Similarly, layer thickness was found to be the second most dominating parameter for flexural strength of ABS and PETg.

- The flexural property increases with increase in 3D Printing parameters for both the materials. Strength is imparted in the sample having extra amount of material. With high layer thickness (0.2-0.3 mm), the intra-layer adhesion is more in the present case and hence the flexural strength is more.
- The infill density has direct and significant influence on flexural strength. At 80% infill density, the printed part is almost solid and provide maximum resistance to bending.
- This investigation suggest the use of ABS instead of PETg while considering the application where high flexural strength is desired.

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