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Comparison of Tensile Properties of 3D Printed PETg and ABS materials

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***Abstract* - The industries have adapted Additive Manufacturing as a modern tool to prepare the job or prototypes. 3D printing technique is a material addition process used to construct complex structures of the desired shape. The present study focuses on comparing the tensile strength of 3D Printed PETg and ABS specimens using the Fusion Deposition Method (FDM). The experiments were designed using the Taguchi approach while the machine variables considered are print speed, layer thickness and infill density. The results revealed that ABS possesses better mechanical properties as compared to PETg. Moreover, layer thickness was found to be the crucial factor for tensile strength.**

***Keywords* – 3D Printing, ABS, PETg, Tensile Strength.**

1. Introduction

The process of 3-D printing entails producing tangible items from a geometric representation, layer-by-layer addition of material. This technology has experienced remarkable growth in recent years, Charles Hull unveiled the first 3D printing technology for business applications in 1980. Also known as additive manufacturing (AM), in 3D printing, materials are bonded together, often layer-by-layer, to create elements from 3D model data. Utilizing solid CAD modeling administered by a computer, this approach may rapidly create elements of any challenging shape.

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. This contrasts with conventional production techniques like moulding or milling, which frequently entail utilising fixed tooling or removing material from a solid block.

It uses various materials such as plastics, metal, and even polymer. The techniques used for 3D printing come in multiple forms, such as Stereo-lithography (SLA), Selective Laser Sintering (SLS), and Fused Deposition Modelling (FDM) this categorization is shown in Fig.1. Each of these technologies uses a different process to build objects, but the basic concept of building layer by layer remains the same. It is a world-shattering machinery that is transforming the way products are made and how we think about manufacturing. Numerous sectors, including medical treatment, aviation, defense, and consumer goods, have found numerous uses for 3D printing. In medical treatment, it has been used to create prosthetics, implants, and surgical tools. In the consumer products industry, 3D printing has enabled the creation of customized products, such as jewelry, phone cases, and furniture. Designers can create unique designs that can be produced on demand, reducing waste and the need for inventory.

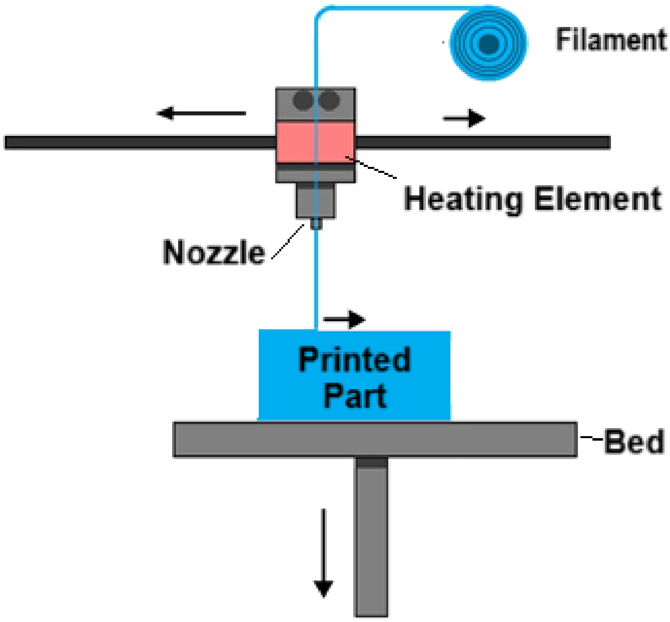

Fig. 1 Illustration of 3D Printing Process

Khan and Neeraj [1] reviewed the influence of process variables on the mechanical characteristics of ABS. Through the study, it was revealed that this could improve the printing procedure, resulting in a perfect additive manufacturing process for various assembly use where quality and dimensional accuracy requirements are high. Hsueh et al [2] in their research investigated the effect of machine variables on thermal as well as mechanical characteristics of 3D Printed PLA and PETg. They found that PLA and PETG exhibit tensile and compression asymmetry. The compressive stress is more as compared to the tensile stress. Furthermore, the nozzle temperature has a direct impact on the mechanical characteristics of both materials. Moreover, the print speed has a direct impact on the mechanical characteristics of PLA and an inverse impact for PETG.

Srinivasan et al [3] analyzed the effect of FDM variables on the performance of PETg specimens. Tensile and surface roughness test were performed while considering thickness of layer, density of infill and patter as machine variables. Grid infill, lower thickness of layer and higher density are suggested to achieve better tensile properties. Cubic infill was found to yield second highest tensile strength. Moreover, the tensile strength was directly dominated by infill density and inversely by the thickness of layer. Durgashyam et al [4] performed investigation on mechanical characteristics of PETg. They perceived the influence of machine variables on flexural and tensile strength printed by FDM technique. The result depicts that for achieving better tensile strength, thickness of layer and feed should be lowered along with higher level of infill density. Furthermore, better flexural properties are experienced with low thickness of layer, medum feed and low density of infill.

Khabia and Jain [5] compared the characteristics of parts printed through ABS filament. They carefully modified the process parameters and the highest tensile strength of 35.7 MPa was achieved at lower level of machine variables. Perez al. [6] investigated the Fracture Surface Analysis of 3D-Printed Tensile Specimens of Novel ABS-Based Materials. They studied the influence of reinforcing elements on mechanical characteristics of ABS . Tensile test revealed that ABS reinforced with 5%

of TiO_2 yields best tensile properties. They also found that when reinforcing chemicals are added to ABS PMC, the mechanical properties and fracture surface features of tensile specimens differ from pure ABS. Veteška et al. [7] investigated the Novel composite filament for printing of difficult ceramic shapes. They successfully synthesized a novel ceramic-polymer composite filament with 50% ceramic powder, having a lower sintering temperature. The novel filament possesses better printability without the need for special adjustments.

Torrado et al. [8] analyzed the influence of additives in ABS for mechanical characteristics. They investigated the influence of physical property altering compounds on mechanical property anisotropy in acrylonitrile butadiene styrene (ABS). SEM was used to perform fracture surface analysis, which revealed the failure of the novel filament when compared with ABS. Durgashyam et al. [9] investigated PETg using Taguchi approach for analyzing the outcome. The results elucidated that layer height influences the tensile and flexural characteristics of PETg. Furthermore, Vishwas and Basavaraj [5] in their study used 3D printed ABS material for analyzing mechanical strength. They concluded that optimal level of 3D printing parameters will enhance the bonding strength and tensile strength.

Ramesh and Panneerselvam [10] conducted investigation on nylon material using FDM process to assess the mechanical performance. They also concluded that optimum parameters are to be selected to achieve better reults of the material. Vishwas et al. [11] conducted a comparison of ABS and Nylon 3D printed samples based on Taguchi Approach. The result showed that a lower level of thickness of layer yield significant impact on tensile strength.

Depending upon the literature survey, the objectives are formulated for the present research work to be carried out by 3D printing of the PETg and ABS filaments is to assess and compare the tensile properties of both the materials using layer thickness, print speed and infill density as the machine variables.

2. Experimental Details

The material used for the present work are ABS and PETg. Acrylonitrile Butadiene Styrene is a strong, durable, and impact-resistant thermoplastic commonly used in engineering applications. It is known for its toughness and ability to withstand physical stress, making it ideal for products such as automotive parts, electronic housings, and toys like LEGO bricks. Polyethylene Terephthalate Glycol is a versatile and durable thermoplastic that has the quality of ABS along with the printability of PLA. It is chemically resistant, impact-resistant, and slightly flexible, making it suitable for applications such as packaging, medical equipment, and protective enclosures. The filaments were purchased in 1.75 mm diameter. The specimens were prepared based on ASTM D638.

Creality K1 3D Printer was used to print the PETg and ABS specimens as per the standards. Instrom Universal Testing Machine available at Narayan Industries and Technical Services Testing Laboratory, Kanpur was used to assess the value of tensile strength of printed specimens.

Fig. 2 3D Printed Tensile Test Specimens of ABS and PETg material based on ASTM D638

ASTM D638 is the majorly used test standard for tensile characteristics of polymers. . The tensile strength is the amount of force that can be applied to a plastic before it yield or breaks. ASTM D638 only applies to rigid plastic samples between 1.00 mm and 14 mm in thickness. The specimens for tensile test were prepared using ASTM D638 standard.

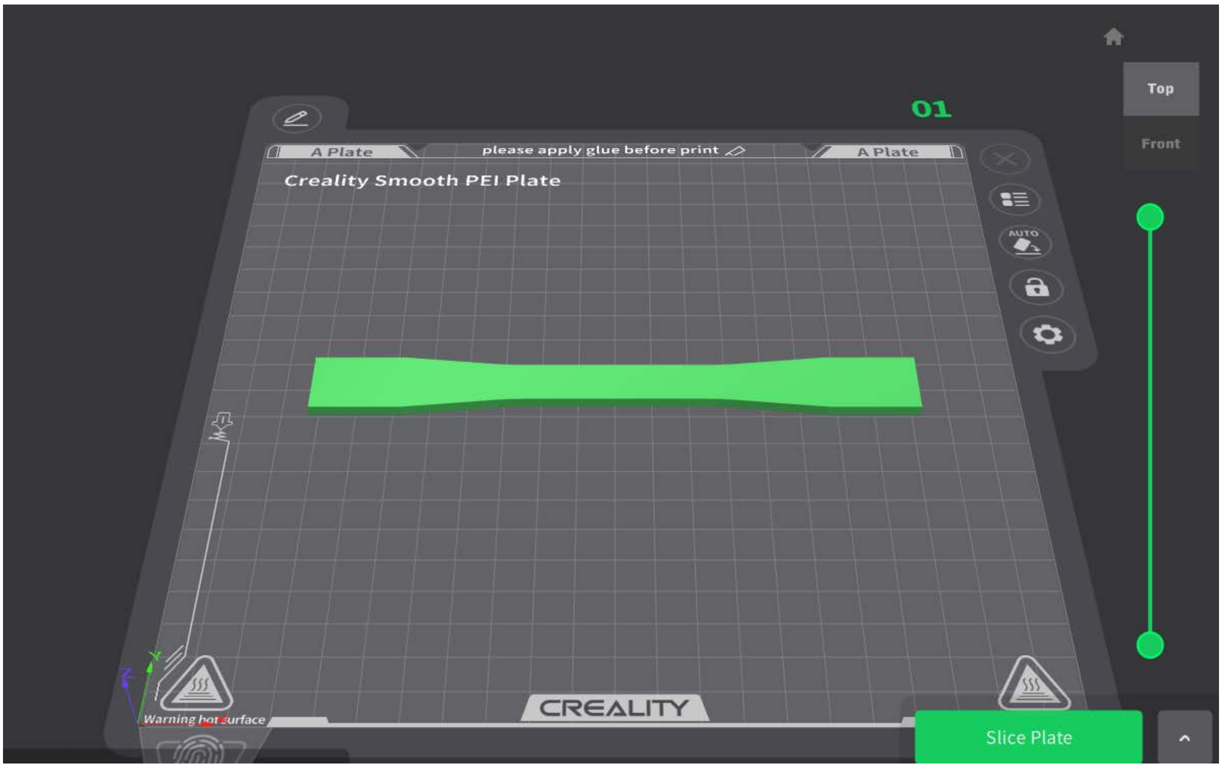

Figure 3: Tensile Specimen Slicing on 3D Printer Software

Figure 4. UTM for Tensile Testing at Narayan Industries & Technical Services Testing Laboratory, Kanpur

Experiments were planned as per Taguchi Approach L9 orthogonal Array. The selection of level of 3D Printing parameters is as per the Table 1 below.

Table 1. Level of 3D Printing Variables

S.No.	Parameters	Units	Level 1	Level 2	Level 3
1	Layer Thickness	mm	0.1	0.2	0.3
2	Print Speed	mm/s	40	50	60
3	Infill Density	%	40	60	80

3.Results and Discussion

The ASTMD 638 standard prepared specimens were tested for tensile strength at Narayan Industries & Technical Services Testing Laboratory, Kanpur and the values are depicted in the Table 2 below.

Table 2. L9 Orthogonal Array for Tensile Strength of ABS and PETg

Exp. No.	Layer Thickness (mm)	Print Speed (mm/s)	Infill Density (%)	Tensile Strength of ABS (MPa)	Tensile Strength of PETg (MPa)
1	0.1	40	40	35.7	30.1
2	0.1	50	60	37.4	34.5
3	0.1	60	80	39.2	36.2
4	0.2	40	60	32.0	28.7
5	0.2	50	80	35.2	30.3
6	0.2	60	40	30.8	26.4
7	0.3	40	80	33.7	34.3
8	0.3	50	40	28.9	26.8
9	0.3	60	60	30.7	31.8

The range of tensile strength for ABS lies between 28.9 to 39.2 MPa while that of PETg lies between 26.4 to 36.2 MPa. It is noted that the tensile strength of ABS was more as compared to PETg.

The Table 3 depicts the S/N Ratio for the present set of experiments performed for tensile strength.

Table 3. S/N Ratio for Tensile Strength

Exp. No.	Tensile Strength of ABS (MPa)	S/N Ratio for Tensile Strength of ABS (db)	Tensile Strength of PETg (MPa)	S/N Ratio for Tensile Strength of PETg (db)
1	35.7	31.0534	30.1	29.5713
2	37.4	31.4574	34.5	30.7564
3	39.2	31.8657	36.2	31.1742
4	32.0	30.1030	28.7	29.1576
5	35.2	30.9309	30.3	29.6289
6	30.8	29.7710	26.4	28.4321
7	33.7	30.5526	34.3	30.7059
8	28.9	29.2180	26.8	28.5627
9	30.7	29.7428	31.8	30.0485

The variables that influence the printing parameters are shown in the table with their ranks. The rank of the variable relies upon the delta value. Rank one is allotted to that parameter for which the delta value is higher than the other. Layer Thickness shows the major influence for tensile strength of ABS while Infill density was crucial factor for tensile strength of PETg samples. Print speed is the uninfluential factor for tensile property of both the materials. Table 4 and Table 5 depicts the mean S/N Ratio for ABS and PETg.

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

Level	Layer Thickness	Print Speed	Infill Density
1	31.46	30.57	30.01
2	30.27	30.54	30.43
3	29.84	30.46	31.12
Delta	1.62	0.11	1.10
Rank	**1**	**3**	**2**

Table 5. Mean S/N ratio for Tensile Strength of PETg

Level	Layer Thickness	Print Speed	Infill Density
1	30.50	29.81	28.86
2	29.07	29.65	29.99
3	29.77	29.88	30.50
Delta	1.43	0.24	1.65
Rank	**2**	**3**	**1**

The table 6 and table 7 illustrates ANOVA of Tensile Strength carried out on Minitab software. The result depicted in the contribution column reveals that the layer thickness is most crucial for ABS (69.81%) and second most influencing variable for PETg (41.09%). Furthermore, Infill density is the crucial parameter for PETg with a contribution of 55.06% and second most influential factor for ABS (29.39%). Print speed, as earlier depicted by S/N ratio table, is the uninfluencing variable for tensile property of both the materials.

Table 6. ANOVA of Tensile Strength of ABS

Source	DOF	SS	Adj MS	F Value	Contribution
Layer Thickness	2	65.287	32.643	105.30	69.81%
Print Speed	2	0.127	0.063	0.20	0.13%
Infill Density	2	27.487	13.743	44.33	29.39%
Error	2	0.620	0.310		0.67%
Total	8	93.520			100 %

At least 95% confidence

Table 7. ANOVA of Tensile Strength of PETg

Source	DOF	SS	Adj MS	F Value	Contribution
Layer Thickness	2	39.536	19.768	16.55	41.09%
Print Speed	2	1.309	0.654	0.55	1.36%
Infill Density	2	52.976	26.488	22.18	55.06%
Error	2	2.389	1.194		2.49%
Total	8	96.209			100 %

At least 95% confidence

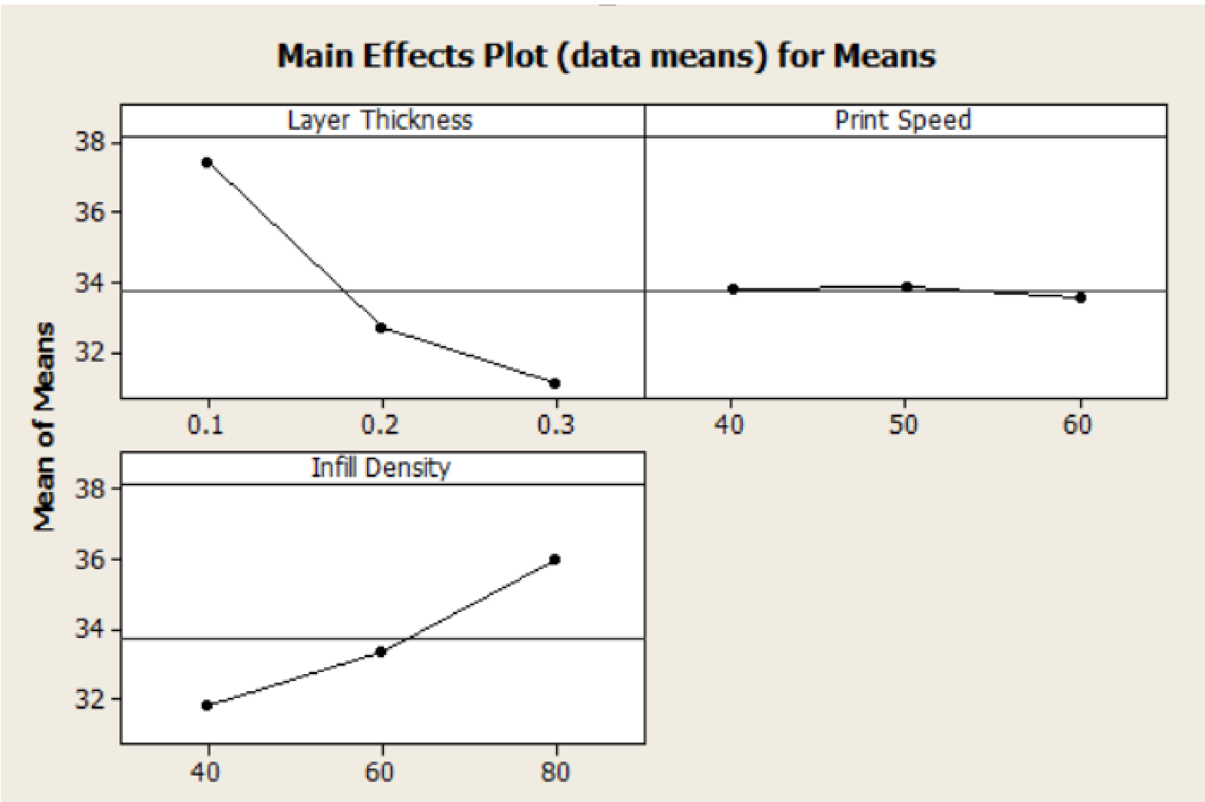

Figure 5. Main effect plot for Tensile Strength of ABS

Figure 5 and Figure 6 represents the main effect plot for Tensile Strength of ABS and PETg respectively. It depicts that the tensile property declines with an increase in thickness of layer for both the materials. Moreover, the tensile strength of both the material follows an increasing trend with infill density. Strength is imparted in the sample having extra amount of material. With low layer thickness, the intra-layer bonding is strong which yields better tensile characteristics of the material. As we increase the layer thickness, intra-layer bonding reduces resulting in a weaker material.

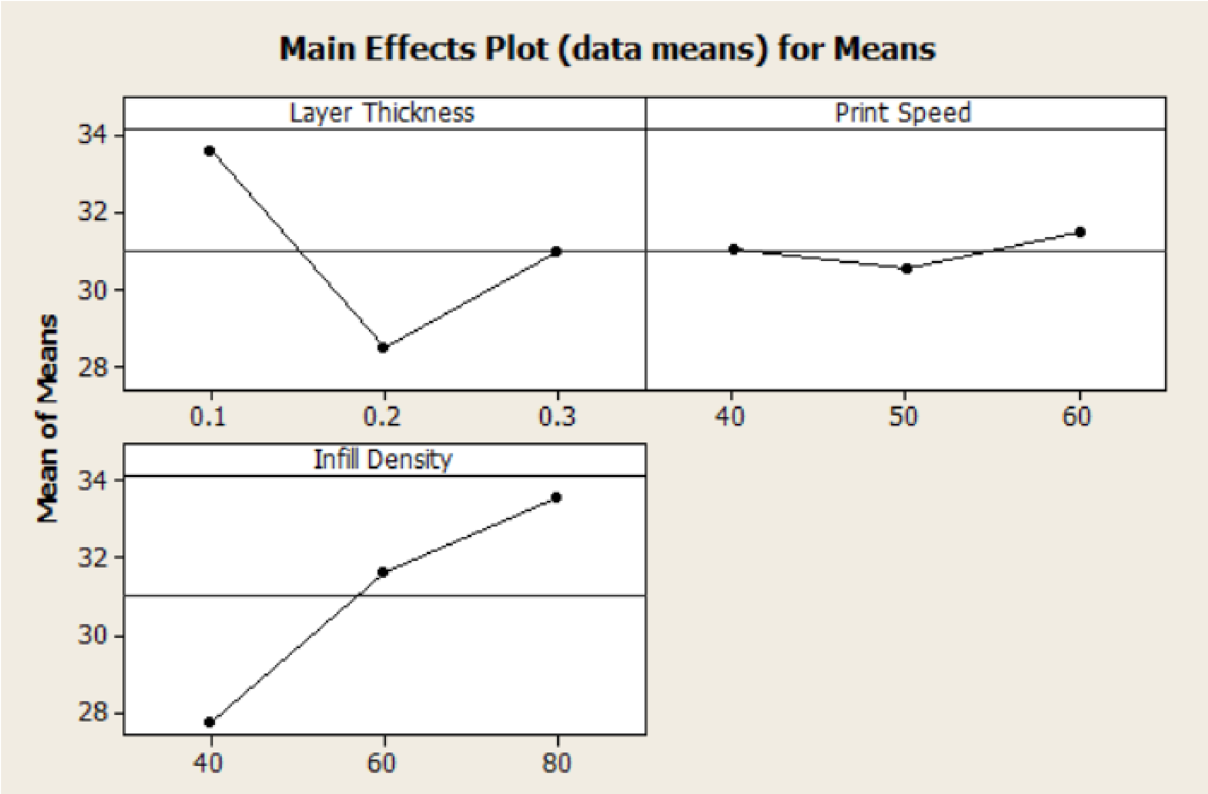

Figure 6.: Main effect plot for Tensile Strength of PETg

Print Speed is the uninfluential variable for tensile strength and has only 0.13% and 1.36% contribution for ABS and PETg respectively. It is observed from the graph that Tensile strength is unaffected with increase in print speed.

4. Conclusion

This experimental comparative study was conducted so as to analyze the mechanical characteristics of 3D Printed ABS and PETg material. The tensile tests were performed to assess the mechanical properties and the trails were designed based on L9 orthogonal array of Taguchi approach. With thickness of layer, speed of printing and infill density as the chosen machine variables, the tensile properties of both the materials were compared. The findings depict the outcome of 3D Printing variables at various levels to optimize the mechanical characteristics and the following conclusions were drawn from the investigation:

- Layer Thickness shows the major influence for tensile strength of ABS while Infill density was crucial factor for tensile strength of PETg samples. Print speed is the uninfluential variable for tensile property of both the materials.

- The outcome depicts that the role of layer thickness is highest for ABS (69.81%) and second highest for PETg (41.09%). Furthermore, Infill density is the most influencing variable for PETg with 55.06% contribution and second most dominating variable for ABS (29.39%).

- The tensile property decreases with increase in layer thickness for both the materials. On the other hand, the tensile strength of both the material follows an increasing trend with infill density.

- Strength is imparted in the sample having extra amount of material. With low layer thickness, the intra-layer bonding is strong which results in better tensile strength of the material. As we increase the layer thickness, intra-layer bonding reduces resulting in a weaker material.

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