

Comparative Analysis of 3D Printed Nylon and PETG Specimens for Mechanical Properties

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Abstract

Fused deposition modeling (FDM) is one of the most used additive manufacturing techniques for polymer components. The polymer materials generally used in FDM process are polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), Nylon, etc. The mechanical properties of parts fabricated by FDM depend on material and process parameters. Several researchers have tried to investigate the influence of process parameters on mechanical properties for some of the materials. So, those parameters can be taken care of for better properties during fabrication of parts. In this paper, effects of layer thickness, raster angle, infill density and printing speed on mechanical properties have been investigated and comparative analysis has been carried out for PETG and nylon specimens. The result showed that nylon and PETG materials are suitable for application related to flexibility and high tensile strength, respectively.

Keywords: Fused deposition modeling (FDM), nylon, polyethylene terephthalate glycol (PETG), tensile strength, percent elongation

INTRODUCTION

Nowadays, additive manufacturing (AM) technologies are being used in various applications like casting, architectural work, automobile parts, jewelry and fashion, on-demand products, medical implants, construction work, complex parts, etc. Fused deposition modeling is one of the most widely used AM techniques. It is necessary to have mechanical properties in fused deposition modeling (FDM) printed parts equivalent to that of conventionally manufactured parts. Hence, several researchers have studied influence of different FDM process parameters on mechanical properties of fabricated parts for various materials. Alafaghani and Qattawi [1] investigated influence of FDM parameters like layer thickness, infill pattern, infill percentage and extrusion temperature on dimensional accuracy and some mechanical properties for polylactic acid (PLA) specimens using Taguchi's L9 array. It was found that higher extrusion temperature improves strength and ductility while decreases dimensional accuracy. Rajurkar and Thesiya [2] explored and compared effect of various parameters on dimensional accuracy and mechanical strength for acrylonitrile butadiene styrene (ABS) and PLA materials. PLA specimens showed lower shrinkage and warping problem with consistent tensile properties as compared to ABS specimens. Based on testing of ABS composite specimens, Christiyan et al. [3] suggested minimum layer thickness and printing speed to achieve better tensile and flexural strength. Calignano et al. [4] carried out experimental analysis of carbon fiber-reinforced nylon specimens for various mechanical properties like young's modulus, tensile strength, hardness, resilience, etc. The building direction affects significantly to these properties. In failure analysis carried out by Rankouhi et al. [5], the specimens printed with 45° and 90° raster orientation showed failure of inter-raster fusion bond while the specimens with 0° showed trans-

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raster failure. Oliveira de Miranda et al. [6] tested 20 polyethylene terephthalate glycol (PETG) specimens and found that Young's modulus increases with increase in nozzle temperature. Letcher and Waytashek [7] conducted tensile and fatigue testing on PLA filament as well as specimens and observed that raster angle 45° gives the highest tensile and fatigue strength. They also showed possibility of recycling of failed parts into new filaments. Hrituc et al. [8] analyzed behavior of hollow spherical parts under axial compression load and concluded that the higher wall thickness of part increases elasticity. A comparative analysis of PLA and PETG specimens was carried out by Hsueh et al [9] to explore influence of printing temperature and printing speed on mechanical and thermal properties. PLA specimens exhibited better mechanical properties and poor thermal resistance as compared to PETG specimens. Moradi et al. [10] examined the effect of different infill pattern on various mechanical properties of PLA. The tensile strength and young's modulus were found highest in triangular pattern while largest ductility, elongation and toughness were found in wiggle pattern. Zolfagharian et al. [11] studied fracture behavior of nylon specimens fabricated by two different 3D printing techniques, FDM and multi-jet fusion (MJF). They observed that integration of equivalent material concept (EMC) and J-integral failure principle can be helpful in prediction of fracture in 3D printed ductile parts. Li and Lou [12] presented an analysis of FDM printed poly-ether-ether-ketone (PEEK) parts and proved that improvement in tensile and bending strength of PEEK parts can be possible by selection of appropriate FDM parameters. There is no literature reported on comparative analysis of strength and elongation for PETG and nylon parts. In this work, effect of certain FDM parameters on mechanical properties have been experimentally investigated and compared.

EXPERIMENTAL METHODOLOGY

For experimental analysis of mechanical properties for nylon and PETG specimens, Taguchi's design of experiment is used. According to four factors and four levels as shown in Table 1, L16 orthogonal array is selected to perform experiments. A 2D drawing of test specimen is shown in Figure 1. For slicing and G-code generation, 3D model of specimen prepared in Solidworks software is imported in simplify3D and Ultimaker Cura software, respectively. Total 16 dog-bone shaped specimens are prepared using 1.75mm diameter filaments for both Nylon and PETG materials in FDM based 3D printer having chamber volume of $550 \times 550 \times 550$ mm The extruder temperature and printing bed temperature are kept 250°C and 80°C during preparation of specimens respectively All the printed specimens of nylon and PETG are shown in Figures 2 and 3, respectively.

Table 1. Process parameters and their levels.

Process Parameters	Levels			
	A	B	C	D
Layer thickness (mm)	0.10	0.15	0.20	0.25
Print speed (mm/s)	30	40	50	60
Infill (%)	70	80	90	100
Raster angle ($^\circ$)	0	45	60	90

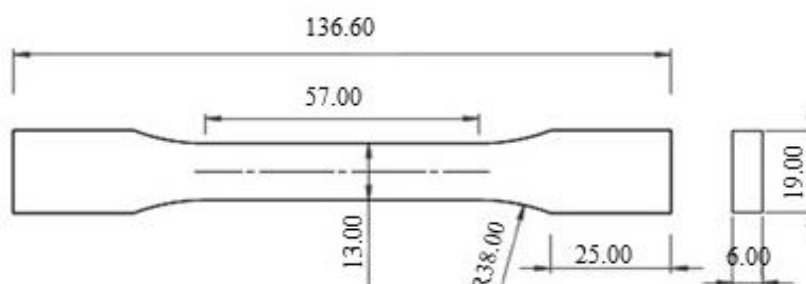


Figure 1. Test specimen dimensions (mm).

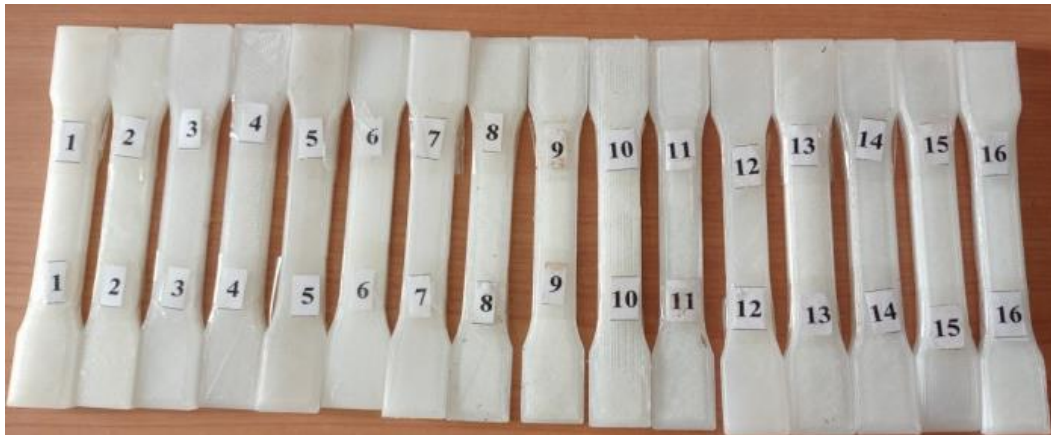


Figure 2. 3D printed specimens of nylon.



Figure 3. 3D printed specimens of polyethylene terephthalate glycol (PETG).

TESTING OF SPECIMENS

For evaluation and comparison of tensile properties, tensile tests have been carried by using Tinius Olsen H50KL universal testing machine. The machine has a load cell of 50 kN and a built-in Horizon software that allows to control, monitor and record measurement data. The specimen is gripped and tightened by the top and bottom jigs. Figures 4 and 5 shows the tensile testing setup of a specimen on the Tinius Olsen machine and the tested specimens, respectively. The crosshead speed has been maintained at 5 mm/min for tensile specimen according to ASTM D638. The crosshead motion continues till the specimen fractures while performing the test. Test data such as force and grip displacement are recorded through the Horizon software.

RESULTS AND DISCUSSION

All the specimens were tested for tensile strength and percent (%) elongation. The result of testing is shown in Table 2. The result shows that the tensile strength of PETG material is more than nylon material and % elongation of nylon material is more than PETG material.

An analysis of variance (ANOVA) was performed using MINITAB 19 software to investigate the effect of layer thickness, print speed, infill and raster angle on tensile strength. Table 3 shows the ANOVA results for the tensile strength of nylon. It can be seen that infill is the most significant parameter for the tensile strength with contribution of 74.31% and print speed is the least significant parameter with contribution of 1.38%.

To examine the relationship between each parameter and tensile strength of nylon parts, the main effects are plotted using mean data as shown in Figure 6. It can be seen that the tensile strength is in direct relation with the infill. When the layer thickness and raster angle rise, it climbs from level one to level two and subsequently lowers from level two to level three and level three to level four. When the print speed rises, it lowers from level one to level two and then it climbs and lowers again consequently.

Table 4 shows the ANOVA results for the tensile strength of PETG. Like in the case of nylon, here also, infill is the most significant parameter for the tensile strength with contribution of 74.05% and print speed is the least significant parameter with contribution of 0.14%.



Figure 4. Tensile testing of specimens: (a) nylon and (b) polyethylene terephthalate glycol (PETG).



(a)



Figure 5. Tested specimens: (a) nylon and (b) polyethylene terephthalate glycol (PETG).

Table 2. Results of testing.

Exp. No.	Layer Thickness (mm)	Print Speed (mm/s)	Infill (%)	Raster Angle (°)	Nylon		PETG	
					Tensile Strength (MPa)	Elongation (%)	Tensile Strength (MPa)	Elongation (%)
1	0.1	30	70	0	25.86	17.91	35.68	3.70
2	0.1	40	80	45	29.40	219.92	43.38	4.50
3	0.1	50	90	60	23.02	37.50	45.98	5.56
4	0.1	60	100	90	23.90	33.12	52.57	7.09
5	0.15	30	80	60	33.96	221.00	31.72	3.34
6	0.15	40	70	90	18.09	72.49	29.52	3.08
7	0.15	50	100	0	18.52	49.15	51.56	13.70
8	0.15	60	90	45	19.93	26.83	36.16	15.00
9	0.2	30	90	90	21.52	24.00	29.64	2.72
10	0.2	40	100	60	26.71	35.81	46.13	5.53
11	0.2	50	70	45	22.64	25.00	39.10	6.00
12	0.2	60	80	0	36.04	268.13	35.59	4.37
13	0.25	30	100	45	26.66	21.25	59.36	12.50
14	0.25	40	90	0	20.63	34.37	33.96	3.12
15	0.25	50	80	90	31.19	202.50	29.18	3.12
16	0.25	60	70	60	9.14	63.13	41.25	5.50

Table 3. Analysis of variance results (nylon).

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Layer thickness	3	155.14	51.714	4.03	0.141	17.36
Print speed	3	12.33	4.110	0.32	0.813	1.38
Infill	3	663.92	221.307	17.26	0.021	74.31
Raster angle	3	23.62	7.872	0.61	0.651	2.64
Error	3	38.48	12.825			4.31
Total	15	893.48				100

The main effects are plotted for tensile strength of PETG using mean data as shown in Figure 7. Similar relation can be seen for all the parameters except layer thickness. When the layer thickness rises, it lowers from level one to level two and level two to level three then it climbs from level three to level four.

To compare tensile strength and % elongation of nylon and PETG, bar charts are prepared as shown in Figures 8 and 9, respectively. From Figure 8, it can be observed that the tensile strength of PETG

specimens is higher than nylon specimens for almost all parameter settings. The highest tensile strength of nylon specimen was found 36.04 MPa by setting layer thickness 0.20 mm, print speed 60 mm/s, infill density 80%, and raster angle 0°. The highest tensile strength of PETG specimen was found 59.36 MPa by setting layer thickness 0.25 mm, print speed 30 mm/s, infill density 100%, and raster angle 45°. The result also showed that in achieving higher tensile strength, the parameter setting can be different for different materials.

Table 4. Analysis of variance results (polyethylene terephthalate glycol; PETG).

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Layer thickness	3	212.64	70.879	2.11	0.278	14.02
Print speed	3	2.09	0.696	0.02	0.995	0.14
Infill	3	1122.83	374.276	11.14	0.039	74.05
Raster angle	3	78.01	26.004	0.77	0.581	5.14
Error	3	100.80	33.600			6.65
Total	15	1516.36				100

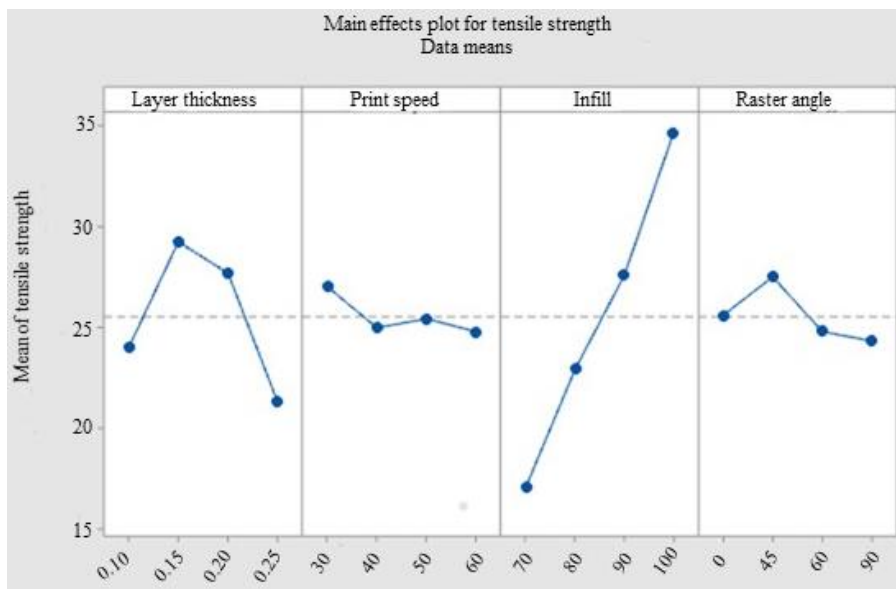


Figure 6. Main effects plot for tensile strength (nylon).

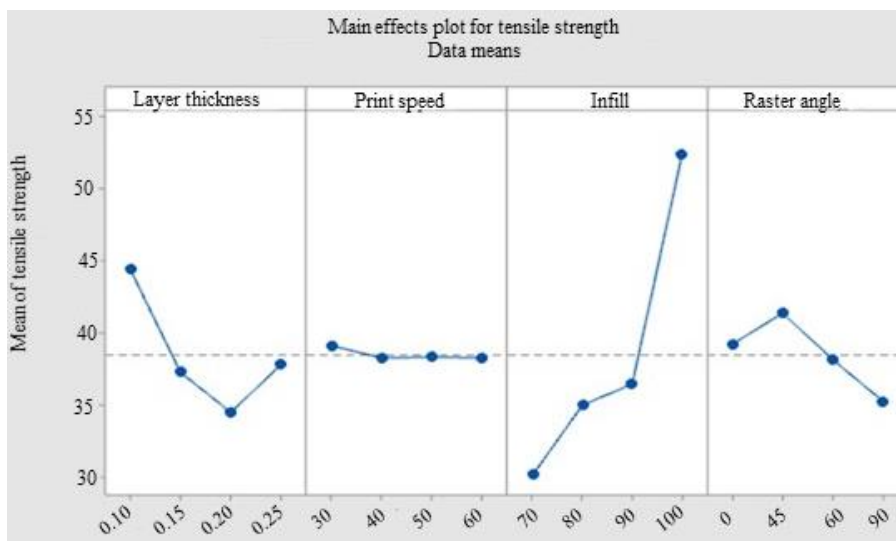


Figure 7. Main effects plot for tensile strength (polyethylene terephthalate glycol; PETG).

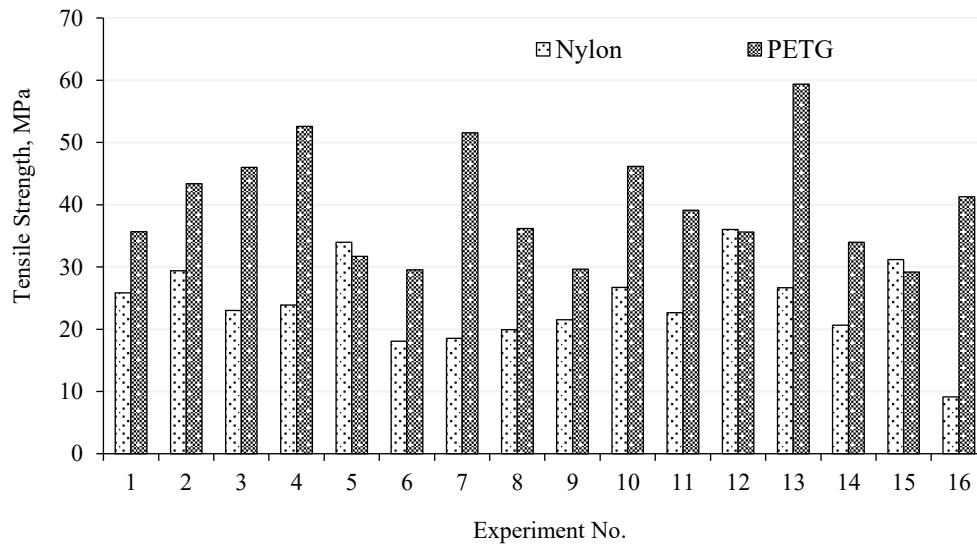


Figure 8. Comparison of tensile strength for nylon and polyethylene terephthalate glycol (PETG).

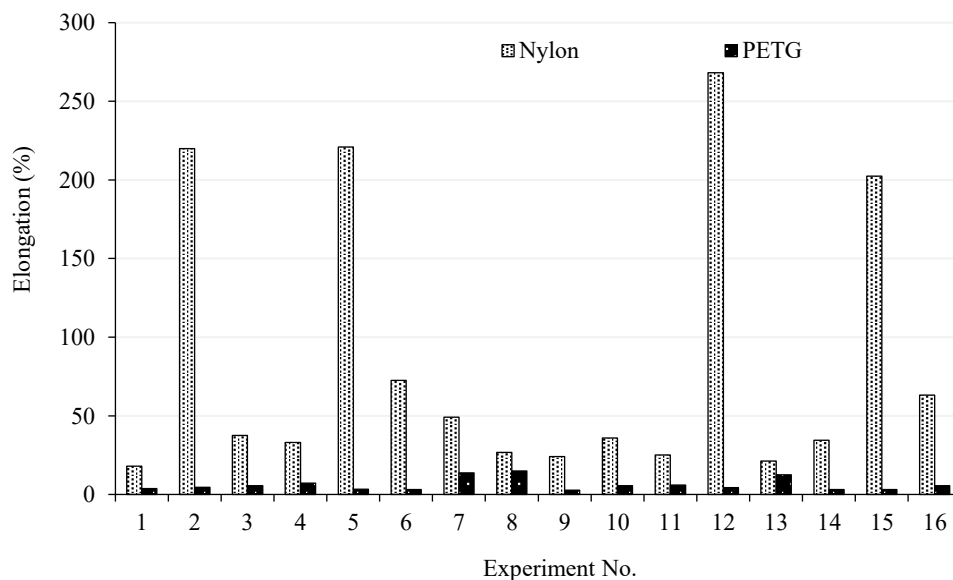


Figure 9. Comparison of % elongation for nylon and polyethylene terephthalate glycol (PETG).

From Figure 9, it can be observed that the % elongation of nylon specimens is higher than PETG specimens for all parameter settings. This depicts that nylon material is more flexible than PETG material. The highest elongation of nylon specimen was found 268.13% at the setting of layer thickness 0.20 mm, print speed 60 mm/s, infill density 80%, and raster angle 0°. The highest elongation of PETG specimen was found 15% at the setting of layer thickness 0.15 mm, print speed 60 mm/s, infill density 90%, and raster angle 45°.

CONCLUSION

A comparative analysis was carried out for nylon and PETG parts based on Taguchi's L16 orthogonal array. Four different process parameters namely layer thickness, print speed, infill density, and raster angle were considered for the design of experiment and tensile strength as well as % elongation as a performance characteristic. According to the ANOVA tables, the infill has contributed the highest in tensile strength of both materials. The highest tensile strength was observed 36.04 MPa at parameter settings of 0.20 mm layer thickness, 60 mm/s print speed, 80% infill, and 0° raster angle in nylon

material while the highest tensile strength was observed 59.36 MPa at parameter settings of 0.25 mm layer thickness, 30 mm/s print speed, 100% infill, and 45° raster angle in PETG material. The highest elongation in nylon and PTEG was found to be 268.13% and 15%, respectively. This analysis concludes that nylon material can be used where more flexibility is needed and PETG material can be used where tensile strength is the prime requirement. This work can be further expanded by investigating the effect of more parameters like extrusion nozzle temperature, build plate temperature, number of shell boundaries, etc. on tensile strength and % elongation.

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