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Effect of Process Parameters on Different Properties of 3D Printed PETG Parts Prepared Using FDM

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Abstract: *This study has been undertaken to give a review of polyethylene terephthalate glycol (PETG) material used in fused deposition modelling (FDM). It offers a review of the existing literature on PETG material. The objective of the paper is to providing guidance on different process parameters that can be used to improve strength of the part by performing various testing like tensile, compressive, flexural etc. This research targets to find new paths that can be used for further development of use of fiber reinforcement in PETG material.*

Keywords: FDM, PETG, Process Parameters, Mechanical Properties

I. Introduction

Additive manufacturing is one of the manufacturing technologies of industry 4.0 that is used to manufacture 3-dimensional prototypes using CAD models. In additive manufacturing, the printing of a part is done by adding of layers without removing materials as in conventional machining process. There are various additive manufacturing methods such as Stereolithography (SLA), Fused Deposition Modelling (FDM), Selective Laser Melting (SLM), Binder Jetting, Direct Energy Deposition, Kinetic Fusion, Laminate Object Modelling (LOM), etc.

Fused Deposition Modelling is the process based on material extrusion in which the polymer filaments are heated to the melting temperature and the nozzle head is moved to the required direction layer by layer to obtain the designed component. The nozzle moves according to the codes generated by a 3D model of the object to be printed. FDM fabricates the parts having complex shapes and reduces the number of assembly units. Fig. 1 shows the schematic of FDM 3D printer. It is characterized by different materials, easy accessibility, durability, low cost and a broad range of usability. Some of the thermoplastic materials which are used in fused deposition modelling are ABS (Acrylonitrile Butadiene Styrene), PETG (Polyethylene Terephthalate Glycol), PLA (Polylactic Acid), TPU (Thermoplastic Polyurethane) and PC (Polycarbonate). FDM has its applications in medical industries, aerospace industries, automotive industries, tooling applications etc. Fig. 2 shows the steps involved in the printing of any part using fused deposition modelling which are starting from creation of CAD model to the cleaning to part.

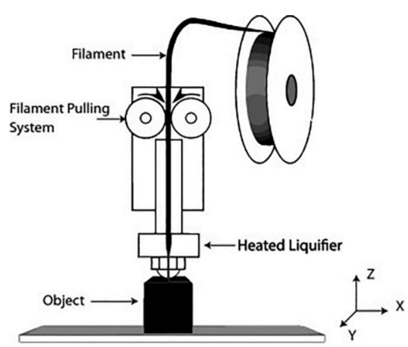

Figure 1: Schematic of FDM 3D printer

Figure 2: Steps involved in FDM

Polyethylene Terephthalate Glycol (PETG), a thermoplastic polyester is widely used for various commercial applications like the manufacturing of bottles, containers, packaging of materials for medical implants, etc. as it has excellent formability, durability, and is resistive to chemical changes. It is produced by the copolymerization of two different monomers which are PET and glycol. Where glycol is colourless in nature or transparent. The chemical formula of PETG is given as (C10H8O4)n. The PETG material have the advantages of ABS and PLA. It produces very strong parts and it has more flexibility than other materials.

For printing of part and for investigating different properties of PETG material, the proper selection of process parameters is necessary as it has impact on strength of the part. Also, it affects the part quality and dimensional stability of the part. The different process parameters are as layer thickness, extrusion temperature, infill density, infill pattern, raster angle, feed rate, air gap, etc. Layer thickness is the measure of the deposited layer on the print bed. Extrusion temperature is the temperature at which the filament of thermoplastic materials heated in the nozzle before extrusion in fused deposition modelling. Infill density indicates the percentage of the material to build a product. The material deposition pattern to form the internal structure of the FDM printed part is the infill pattern. Raster angle is the angle with respect to X-direction of build platform, in which extruded material is deposited.

II. Literature Review

R. Srinivasan et al.[1] investigated the effect of infill density on tensile strength and surface roughness of PETG part produced by fused deposition modelling method. Infill density is varying in between 20 to 100 percent while other parameters i.e., layer thickness, infill pattern, raster angle, air gap etc. are taken as constant. A filament of 1.75 mm diameter and 2.7 g/cc density is used at 235 ^{0}C working temperature. ASTM standard D638 was used to prepare tensile specimens in SOLIDWORKS 2016 software. According to this study, parts have a higher tensile strength at high infill density whereas lower surface roughness at higher infill density. Also, layer thickness has more influence on tensile strength. Maximum tensile strength is obtained at 0.1 mm layer thickness and 100% infill density. Lesser surface roughness value of 2.87 µm achieved at 100% infill density and grid pattern.

R. Srinivasan et al.[2] conducted another study to find the impact of the infill pattern on the strength of the part printed of PETG material. Infill patterns considered in this study were triangular, cubic, grid, concentric, honeycomb, rectilinear, rectangular, wiggle, and octet. All other process parameters are kept as constant. The aim of this study is to find the optimum infill pattern for PETG components. It is found that grid pattern followed by honeycomb and rectilinear pattern has more impact on tensile strength of the part as tensile strength was higher for these patterns. It is because grid pattern provides strong bonds in printed parts. Honeycomb infill pattern has more tendency to hold its intermolecular layers. The highest tensile strength was obtained for grid pattern while the lowest tensile strength was obtained at concentric infill pattern.

In another study, R. Srinivasan et al.[3] considered the layer thickness, infill density, and infill pattern as varying process parameters to note down the influence of these parameters on mechanical properties of printed PETG part. Layer thickness were taken as 0.1 mm, 0.15 mm and 0.2 mm while infill density was considered as 60%, 70% and 80% along with triangular, grid and cubic as the infill pattern. Tensile strength and surface roughness was measured to determine mechanical properties. As per the study, infill density and layer thickness are directly and indirectly proportional to the tensile strength respectively. The infill pattern with build orientation produces variations in tensile strength. Higher tensile strength values were recorded for grid pattern, 0.1 mm layer thickness and infill density of 80%. Lower tensile strength was observed for the triangular infill pattern due to the continuous bead formation. Lower surface roughness was noted for the grid pattern. With the increase in infill density, the surface roughness value decreases and for increased layer thickness, the surface roughness value increases.

K. Durgashyam et al.[4] experimentally investigated the tensile and flexural strength of PETG material which is processed by fused deposition modelling. Feed rate, infill density, and layer thickness were considered as variable parameters. A filament of 1.75 mm diameter and 1.7 g/cc density was used to print the specimen at 235 ^{0}C bed temperature. Tensile and

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flexural specimens were prepared according to the ASTM standards D638 and D790 respectively using full factorial case. Tensile and flexural testing was conducted on Universal Testing Machine (UTM). ANOVA (Analysis of Variance) is used to obtain the most influencing parameter on the tensile and flexural strength of PETG material. Layer thickness has more impact on both tensile and flexural strength of the part than feed rate and infill density. Tensile strength increases at lesser layer thickness and feed rate with higher infill density. Good flexural strength was observed at minimum layer thickness, moderate feed rate, and low infill density.

T. Panneerselvam et al.[5] investigated the tensile and flexural strength and hardness of the 3D printed PETG material by FDM. In this study infill percentage (20%, 50%, 80%), layer height (0.2 mm, 0.25 mm, 0.3 mm), and infill pattern (square, triangular, hexagonal) were taken with multiple responses. Taguchi's grey relational analysis was employed to observe the combined responses of the tensile strength, flexural strength, and hardness. It was found that the hexagonal pattern has a greater influence on the tensile strength of the material. High shore-D hardness was measured at higher infill percentage, hexagonal pattern, and higher layer height. Highest mean values were obtained at 80% infill density, 0.3 mm layer height and hexagonal pattern. The infill pattern was found to have greater influence on tensile strength of PETG parts. As per the study, the failure mode was brittle fracture as there are no signs of yielding during the testing. The increased values of process parameters help to increase flexural strength.

Muammel M. Hanon et al.[6] studied an anisotropy evaluation of different raster angles, print orientations, and infill percentages by taking PETG as a build material. An impact of these variable parameters on tensile strength and elongation at break was to observed. A total of 36 specimens were printed using Bq Witbox 2 3D printer according to ISO 527-2: 2012 standard 1B type. As per the study raster direction as well as orientation parameters have a considerable impact on the tensile strength and also on the elongation values of the printed parts. Also, higher tensile strength and elongation values were obtained at 0^0 raster angle and Y orientation. PETG is proved to be better than PLA as it provides improved elongation results.

Ankita Jaisingh Sheoran et al.[7] conducted a review on different process parameters and their effect on mechanical properties and quality of printed parts. They concluded that apart from thermoplastics, more research has been done using composite materials. Also, the different parameters have different impact on material being printed. As per the study tensile strength, surface roughness and dimensional accuracy were more impacted by infill pattern, extrusion temperature, print speed and raster width while compressive strength was more impacted by infill density, infill pattern and raster orientation. For print time, raster angle is yet an unexplored parameter. Parts have higher tensile strength and flexural strength at 0^0 raster angle and higher extrusion temperature. For compressive strength, the layer thickness is most influencing parameter. At 0^0 build orientation, higher layer thickness and lesser infill density the print time will be the least. Layer thickness is found as most influencing parameter for dimensional accuracy and surface roughness. Fig. 3 shows cause and effect diagram of different process parameters for different properties.

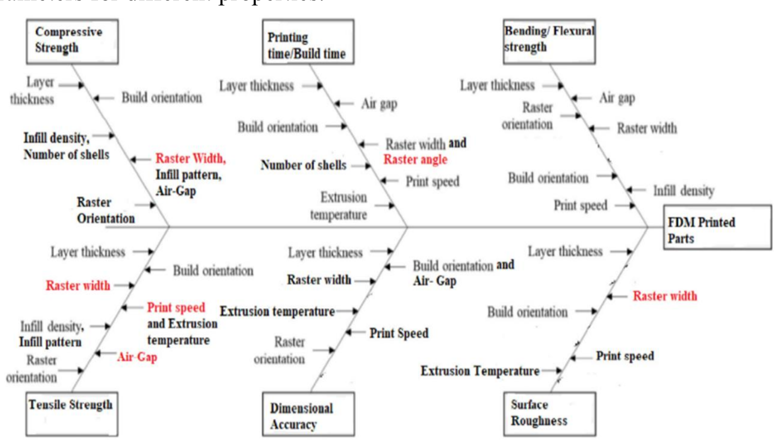

Figure 3: Fish-bone diagram of process parameters and properties

Dinesh Yadav et al.[8] investigated the process parameters of fused deposition modelling using ANFIS (Adaptive Neuro-Fuzzy Inference System) by taking PETG, ABS, and multi-material (60% ABS and 40% PETG). The process parameters selected were extrusion temperature, layer height, and material density. For printing of a multi-material part, half of the part was printed using ABS then another half of the part was printed using PETG by replacing the filament. After performing the tests, it was validated using ANFIS. It was found that tensile strength is more affected by extrusion temperature rather than layer height. Higher tensile strength was noted at the higher extrusion temperature up to a certain limit. PETG filaments show maximum tensile strength at extrusion temperature of 225 ^{0}C and layer height of 0.1 mm. Minimal error percentage was observed by created ANFIS model.

Juan M. Barrios et al.[9] conducted the study to improve the properties PETG 3D printed self-cleaning parts. The aim of this study is to obtain the most affecting values for different process parameters which helps to reduce surface roughness in PETG 3D printed parts. Layer height, print temperature, print speed, print acceleration, and flow rate were taken as variable parameters up to three levels for each. They concluded that the flow rate and the print acceleration were the parameters with greater influence than remaining considered parameters. The section of the deposited filament is somewhat circular due to flow rate. Print acceleration was responsible for keeping the section more or less uniform with respect to printing load.

Ming-Hsien Hsueh et al.[10] investigated the effect of process parameters on the thermal as well as mechanical properties by taking print temperature and print speed as variable parameters. PLA and PETG were selected as a build material as the study was focusing on comparing the properties of both the materials. Nozzle diameter was selected as 0.4 mm to reduce the complexity. Infill density of 20%, 450 raster angle, 0.2 mm layer thickness, 25 ^{0}C platform temperature were taken as fixed parameters for printing. It was found that the PLA material shows elastic-plastic like material properties while PETG shows material properties like brittle material. PETG material completely melts at above 225 ^{0}C temperature. The viscosity of both the material PLA and PETG increases with increased printing temperatures which results in increased fusion with decrease in porosity. As per the study both the materials were observed to have asymmetry. The compression stress was more than the tensile stress. With the increase in printing speed, the mechanical properties of PLA material increases while PETG material decreases. At higher printing temperature and printing speed the properties of PETG material observed to be increased.

Arda Özen et al.[11] optimized manufacturing parameters of PETG parts 3D printed by fused deposition modelling. Comparisons of the specimen of four different geometries were studied with the help of the Finite Element Method (FEM). The different geometries were ASTM D3039, ASTM D3039 angle, ISO 527-2, ISO modified. A digital twin of laboratory test has been introduced using FEM analysis for easy understanding of premature failure. It was found that a more homogeneous structure has been achieved at the macroscale. At room temperature, the PETG material was linear elastic and performed a brittle fracture. Stress concentration leads to premature failures if there is a transition in shape. An easy way to comply with the Journal paper formatting requirements is to use this document as a template and simply type your text into it.

Prajwal P. Agarwal et al.[12] conducted the experimental analysis on ultimate tensile strength, dimensional accuracy, and print time of PETG material parts printed on FDM 3D printer. The varying process parameters were infill percentage, layer thickness, and orientation of the specimen. Honeycomb infill pattern was used for printing as it gives maximum strength. Taguchi's L9 orthogonal array was used to reduce the number of specimens. According to the study, elongation percentage increases with an increase in the layer of the specimen. Also, the increased thickness of the layer of material can withstand more load which indicates that it should have higher tensile strength.

Jorge Manuel Mercado-Colmenero et al.[13] conducted experimental and numerical analysis for the characterization of PETG material under pure uniaxial compression stress states. Numerical study of structural element has been done in Ansys Mechanical and then verification of the results by numerical simulations was done by comparing it with experimental results. It was found that the mechanical behavior is completely linear until reaching the elastic limit. For specimens manufactured along the Z direction, the fracture observed was brittle while for the X and Y directions it was permanent plastic deformations. The structural element shows maximum uniaxial compression forces in X-Y manufacturing directions.

S. Swetha et al.[14] aimed to design, validate and 3D print the tensile specimen by varying the infill percentage (50% and 100%) and layer height (0.1 mm and 0.3 mm). Static structural analysis in Ansys 16.2 workbench has been carried out by taking one end fixed. It was observed a clear decrease with the increase in layer height and decrease in infill percentage. Experimentally performed tensile and compressive tests has been validated by static structural in Ansys which shows the error of 5% between the experimental and simulated results.

From literature review, some important factors are tabulated in table 1 such as materials used, variable process parameters, properties and 3D printed used for printing the part using fused deposition modelling.

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Table 1: Critical remarks from literature review

Author	Research objective	Materials / Standard	Variable parameters	Properties	3D Printer
R. Srinivasan et al.	Effect of infill density on mechanical properties	PETG / ASTM D638	Infill density	Tensile strength, surface roughness	WOL 3D ENDER 3
R. Srinivasan et al.	Impact of infill pattern	PETG / ASTM D638	Infill pattern	Tensile strength	WOL 3D ENDER 3
R. Srinivasan et al.	Influence of process parameters	PETG / ASTM D638	Layer thickness, infill density, infill pattern	Tensile strength, surface roughness	WOL 3D ENDER 3
K. Durgashyam et al.	Investigation of mechanical properties	PETG / ASTM D638, ASTM D790	Feed rate, infill density, layer thickness	Tensile and flexural strength	DRONA CS300
T. Panneerselvam et al.	Investigation of the mechanical properties	PETG / ASTM D638, ASTM D790, ASTM D2240	Infill percentage, layer height, infill pattern	Tensile and flexural strength, hardness	Hydra 200 Pro
Muammel M. Hanon et al.	Anisotropy evaluation	PETG / ISO 527-2	Raster direction angles, print orientations, infill percentage	Tensile strength, elongation at break	Bq Witbox 2
Dinesh Yadav et al.	Modeling and analysis	PETG, ABS, Multi-material (60% ABS + 40% PETG) / ASTM D638	Extrusion temperature, layer height, material density	Tensile strength	GEEETECH A30
Juan M. Barrios et al.	Improvement of mechanical properties	PETG / ISO 4288	Layer height, print temperature, print speed, print acceleration, flow rate	Surface roughness, hydrophobicity	Tevo Black Widow Tevo Technologies
Ming-Hsein Hsueh et al.	Effect of printing parameters	PLA and PETG / ASTM D638, ASTM D3410, ASTM D790, ASTM D648	Printing temperature, printing speed	Thermal and Mechanical Properties - tension, compression, bending, and thermal deformation	X1E
Arda Özen et al.	Optimization of manufacturing parameters	PETG / ASTM D3039, ISO 527-2	-	Tensile strength	Ultimaker 3 Extended
Prajwal P. Agarwal et al.	Experimental analysis of mechanical properties	PETG / ASTM D638	Percentage infill material, layer thickness, the orientation of the specimen	Ultimate tensile strength, dimensional accuracy, production time	-
Jorge Manuel Mercado-Colmenero et al.	Analysis for mechanical characterization	PETG / ISO-604	Printing direction	Mechanical and elastic properties – compressive strength	Ultimaker 2+

S. Swetha et al.	Evaluation of tensile properties	PETG / ASTM D638	Infill percentage, layer height	Tensile strength	GARUDA 3D Printer

III. Critical Remarks From Literature Review

After reviewing research articles from some authentic publications, critical remarks are drawn-out and it is found that,

- PETG material was linear elastic and performed a brittle fracture at room temperature.
- For specimens manufactured along the Z direction, the fracture was brittle while the X and Y directions showed permanent plastic deformations.
- Clear decrease in the tensile strength of the components when there is a decrease in the infill percentage and the increase in layer thickness.
- For high infill density parts have high tensile strength and lesser surface roughness value.
- The highest value of tensile strength was recorded for grid pattern.
- The hexagonal infill pattern also has more influence on the tensile strength of material.
- At lesser layer thickness, the PETG material exhibits good mechanical properties.
- The increasing levels of parameters increases the flexural strength.
- Raster direction and orientation parameters have offered a significant effect on the tensile strength and elongation values of the printed bodies.
- The highest values of tensile strength and elongation were measured at 0° raster direction and Y orientation.
- The PETG filaments show maximum tensile strength at 225 ^{0}C extrusion temperature and 0.1 mm layer height.
- The transition in shape causes a stress concentration leading to premature failures.

The mechanical properties of PETG are increased at higher printing temperatures and the printing speed.

IV. Research Gap

More studies can be carried out by adding fiber reinforcement to PETG material. It has higher strength, thermal and other mechanical properties with respect to PETG material without fiber reinforcement. As infill pattern, infill density, extrusion temperature has more impact on mechanical properties and raster angle, raster width, print speed are still an unexplored parameter to improve print time and other properties. So, more research is required in this area. As the different parameters have the disparity in the result of optimum parameter it should be required to further analysis by varying the process parameters at different levels.

V. Conclusion And Discussion

It is observed from the literature review that PETG material exhibits the greater strength and part quality at varying process parameters. Pure PETG has greater strength than PETG material combined with ABS (Acrylonitrile Butadiene Styrene). More research can be carried out by taking different process parameters with multiple responses to improve the mechanical and thermal properties. Also, fiber reinforcement with PETG material can improve the material properties more than the PETG material without fiber reinforcement.

References

[1]. R. Srinivasan, W. Ruban, A. Deepanraj, R. Bhuvanesh, and T. Bhuvanesh, “Effect on infill density on mechanical properties of PETG part fabricated by fused deposition modelling,” in Materials Today: Proceedings, Jan. 2020, vol. 27, pp. 1838–1842. doi: 10.1016/j.matpr.2020.03.797.

[2]. R. Srinivasan, K. Nirmal Kumar, A. Jenish Ibrahim, K. v. Anandu, and R. Gurudhevan, “Impact of fused deposition process parameter (infill pattern) on the strength of PETG part,” in Materials Today: Proceedings, Jan. 2020, vol. 27, pp. 1801–1805. doi: 10.1016/j.matpr.2020.03.777.

[3]. R. Srinivasan, P. Prathap, A. Raj, S. A. Kannan, and V. Deepak, “Influence of fused deposition modeling process parameters on the mechanical properties of PETG parts,” in Materials Today: Proceedings, Jan. 2020, vol. 27, pp. 1877–1883. doi: 10.1016/j.matpr.2020.03.809.

[4]. K. Durgashyam, M. Indra Reddy, A. Balakrishna, and K. Satyanarayana, "Experimental investigation on mechanical properties of PETG material processed by fused deposition modeling method," in Materials Today: Proceedings, 2019, vol. 18, pp. 2052–2059. doi: 10.1016/j.matpr.2019.06.082.

[5]. T. Panneerselvam, S. Raghuraman, and N. Vamsi Krishnan, "Investigating Mechanical Properties of 3D-Printed Polyethylene Terephthalate Glycol Material Under Fused Deposition Modeling," Journal of The Institution of Engineers (India): Series C, vol. 102, no. 2, pp. 375–387, Apr. 2021, doi: 10.1007/s40032-020-00646-8.

[6]. M. M. Hanon, R. Marczis, and L. Zsidai, "Anisotropy evaluation of different raster directions, spatial orientations, and fill percentage of 3d printed petg tensile test specimens," in Key Engineering Materials, 2019, vol. 821 KEM, pp. 167–173. doi: 10.4028/www.scientific.net/KEM.821.167.

[7]. A. Jaisingh Sheoran and H. Kumar, "Fused Deposition modeling process parameters optimization and effect on mechanical properties and part quality: Review and reflection on present research," in Materials Today: Proceedings, 2020, vol. 21, pp. 1659–1672. doi: 10.1016/j.matpr.2019.11.296.

[8]. D. Yadav, D. Chhabra, R. K. Gupta, A. Phogat, and A. Ahlawat, "Modeling and analysis of significant process parameters of FDM 3D printer using ANFIS," in Materials Today: Proceedings, 2020, vol. 21, pp. 1592–1604. doi: 10.1016/j.matpr.2019.11.227.

[9]. J. M. Barrios and P. E. Romero, "Improvement of surface roughness and hydrophobicity in PETG parts manufactured via fused deposition modeling (FDM): An application in 3D printed self-cleaning parts," Materials, vol. 12, no. 15, Aug. 2019, doi: 10.3390/ma12152499.

[10]. M. H. Hsueh et al., "Effect of printing parameters on the thermal and mechanical properties of 3d-printed pla and petg, using fused deposition modeling," Polymers (Basel), vol. 13, no. 11, Jun. 2021, doi: 10.3390/polym13111758.

[11]. A. Özen, D. Auhl, C. Völlmecke, J. Kiendl, and B. E. Abali, "Optimization of manufacturing parameters and tensile specimen geometry for fused deposition modeling (Fdm) 3d-printed petg," Materials, vol. 14, no. 10, May 2021, doi: 10.3390/ma14102556.

[12]. P. P. Agarwal, T. S. Dadmode, M. R. Kadav, A. P. Ogale, and P. P. Mangave, "Experimental Analysis of Mechanical properties of PETG Material 3D Printed Material by Using Fused Deposition Modelling Technique," 2020, doi: 10.5281/zenodo.3739793.

[13]. J. M. Mercado-Colmenero, M. Dolores La Rubia, E. Mata-Garcia, M. Rodriguez-Santiago, and C. Martin-Doñate, "Experimental and numerical analysis for the mechanical characterization of petg polymers manufactured with fdm technology under pure uniaxial compression stress states for architectural applications," Polymers (Basel), vol. 12, no. 10, pp. 1–25, Oct. 2020, doi: 10.3390/polym12102202.

[14]. S. Swetha, P. Morampudi, K. Aruna, P. & Putha, and P. Kumar, "Evaluation of Tensile Properties of 3D Printed Petg Specimen as per ASTM Standards." [Online]. Available: www.tjprc.org