Tensile and Fatigue Behavior of CF-reinforced PETG manufactured by Fused Filament Fabrication

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Abstract

The development of fiber composites in recent years has been remarkably strong, owing to their high performance and durability. The fatigue behavior of components is an important knowledge block, as cyclic loading is a common feature of most engineering applications. The scope of this poster is to present the fatigue property findings of Carbon Fiber-Reinforcing Polyethylene Terephthalate Glycol (CF-PETG) components manufactured by Fused Filament Fabrication (FFF) with a focus on different printing orientation. Simplify 3D and Stacker S2 are used to slice and manufacture the components respectively. The printing orientation and direction used are XY-0^0, XY 45^0 and XY 90^0. Fatigue testing is carried on 70% of Ultimate Tensile Strength (UTS). Analysis of Variance (ANOVA) is used to analyze the data obtained from the fatigue test.

FFF

- The recent advances in additive manufacturing (AM) have driven this technology as a competing alternative to traditional manufacturing processes.
- One of the most extended AM techniques is FFF and is used in this research due to its popularity and low cost.
- FFF generates a 3D object by extruding a filament of a heated material [1], as shown in fig. 1 [2], which is accurately distributed onto successive layers.
- The main advantages of this technology include: the ability to develop complex shapes practically without geometric limitations and the conversion from the 3D solid model to the manufactured part with configuration of only a few parameters.

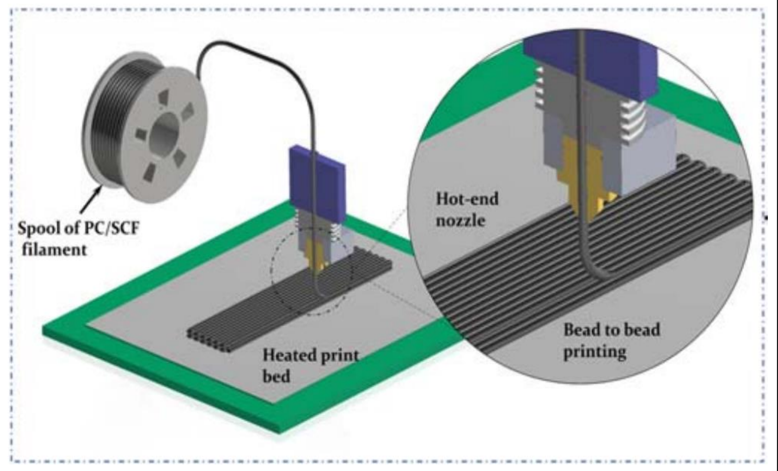

Fig. 1: Layer-by-layer FFF process [2]

Methodology

The steps followed for this research study is highlighted in fig. 2.

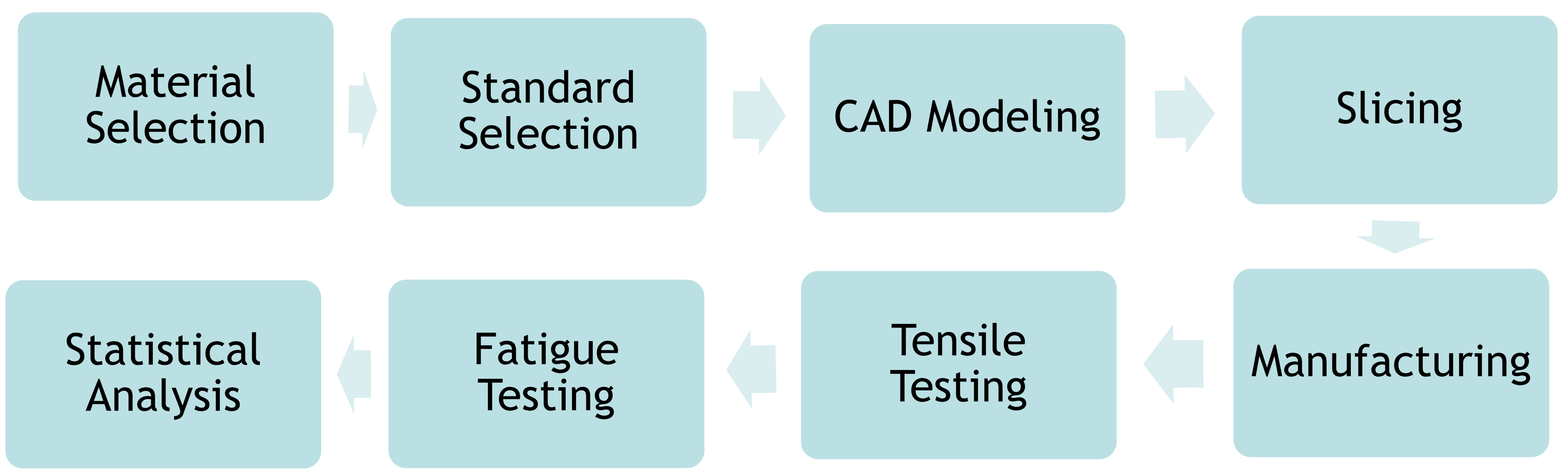

Fig. 2: Methodology for the research

Material and Standards

- For this research, XT CF 20- Eastman Amphora PETG base resin combines with 20% carbon fibers is used.
  - Material Properties
    - Density – 1.35 g/cm3
    - Glass Transition Temperature – 75^0 C
- The geometry considered is based on the ISO-11782-1 and the tensile and fatigue tests are carried as per ISO 13003 [3].

CAD Modeling and Slicing

- SolidWorks is used to create the CAD model as shown in the fig. 3.
- The files are saved in the STL format which is requirement of the slicing software.
- Simplify 3D is used to slice (apply printing parameters) the imported model.
- The important printing parameters are as shown in table 1.
- The printing orientation and filament direction is shown in fig 4 and 5 respectively.

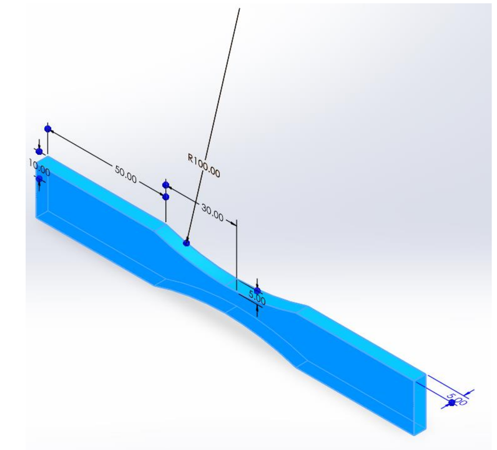

Fig. 3: CAD model of the specimen

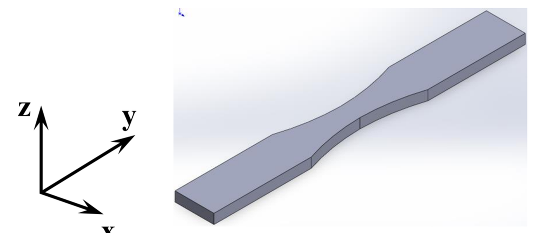

Fig. 4: Printing orientation

Table 1: Printing Parameters	
Nozzle Diameter	0.4
Layer Height	0.2
Number of Shells	2
Infill pattern	Rectilinear
Extruder Temp.	250^0 C
Bed Temp.	70^0 C
Printing speed	50 mm/sec

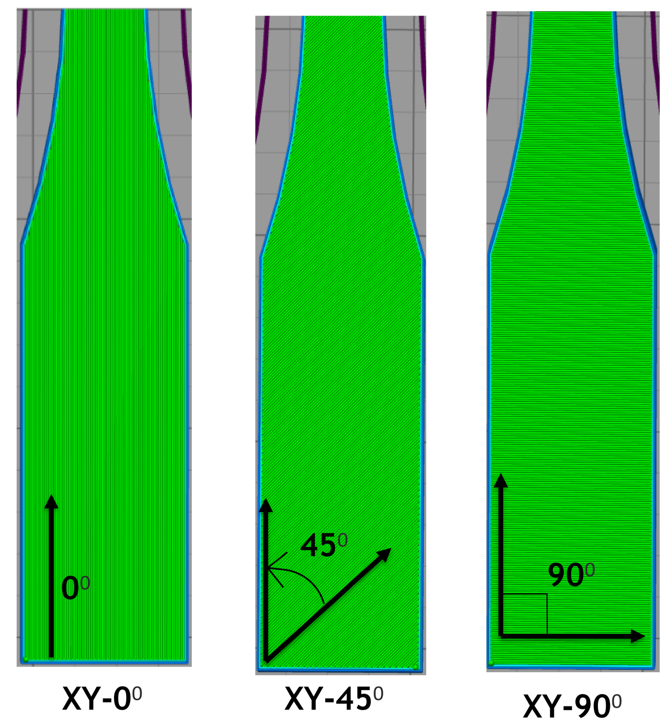

Fig. 5: Filament direction

Equipments

- Stacker S2 Industrial Grade 3D Printer is used for the manufacturing of the specimens as shown in fig. 6.
- 810E4-15 Dynamic Test System as shown in fig. 7 is used for the Tensile and Fatigue tests. It has 15KN axial load capacity for static and fatigue testing applications.

Fig. 6: Stacker S2

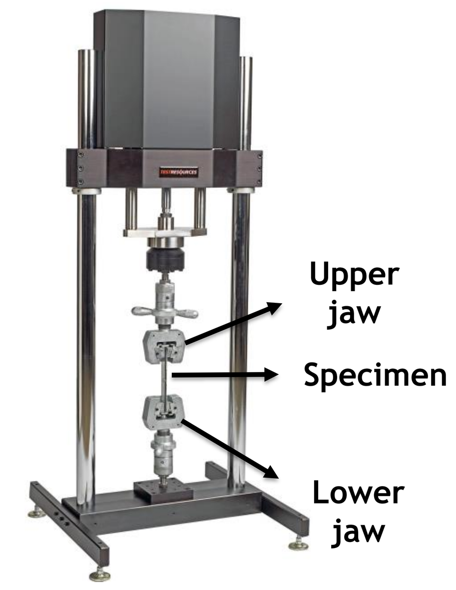

Fig. 7: 810E4-15 Dynamic Test System

Experimental Results

Results of tensile tests and the specimens after tests are presented in table 2 and fig. 8 respectively.

Table 2: Results of Tensile Tests

Orientation	Ultimate Tensile Load(UTL) (N)	Mean of Two (N)	70% of UTL (N)
XY-0^0	2708.64 2440.07	2574.35	1802.04
XY-90^0	1907.53 1911.44	1909.48	1336
XY-45^0	2146.35 2169.76	2158.05	1510

Fig. 8: Tensile Specimens

Results of fatigue tests and the specimens after tests are presented in table 3 and fig. 9 respectively.

After tensile tests, fatigue tests were carried out considering-

- Maximum load = 70% of UTL
- R=0.1
- Frequency =3Hz.

Fig. 9: Fatigue Specimens

Table 3: Fatigue Testing

Orientation	Max. Load	Min. Load	No. of cycles
XY-0^0	1800	180	1033
	1800	180	621
	1800	180	1409
XY-90^0	1300	130	2273
	1300	130	2163
	1300	130	2202
XY-45^0	1500	150	1466
	1500	150	2196
	1500	150	1533

Statistical Analysis

The distribution of the number of cycles is presented in fig. 10.
DF-Degrees of Freedom
SS-Sum of Squares
MS-Mean Square

Table 4: ANOVA Table

Source	DF	SS	MS	F Value	P-Value
Model	2	2156477.556	1078238.778	10.07	0.0121
Error	6	642561.333	107093.556		
Corrected Total	8	2799038.889			

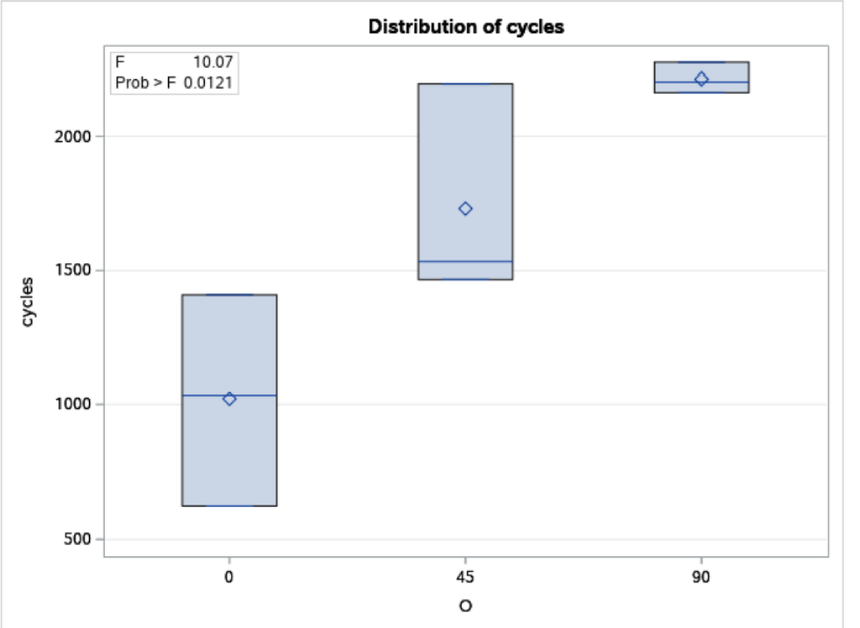

Fig. 10: Distribution of number of cycles

Analysis of Variance (ANOVA) is used for the statistical analysis as presented in table 4

- P-value < 0.05, which concludes that there is enough evidence to suggest printing orientation affects the fatigue behavior.

Conclusions

This work presents the fatigue behavior of XT CF-20 for different printing orientations. The study concludes

- Printing orientation affects fatigue cycles.
- Highest Tensile strength is found in XY-0^0
- The opposite trend is observed for fatigue tests.
- The highest number of cycles are observed for XY-90^0 with minimum standard deviation.
- In future, different printing parameters such as infill pattern, printing orientations such as XZ-90^0 etc. can be considered.

References

[1] Travieso-Rodriguez, J. Antonio, et al. "Fatigue behavior of PLA-wood composite manufactured by fused filament fabrication." *Journal of Materials Research and Technology* 9.4 (2020): 8507-8516.
[2] Gupta, Ankit, et al. "Processing, mechanical characterization, and micrography of 3D-printed short carbon fiber reinforced polycarbonate polymer matrix composite material." *The International Journal of Advanced Manufacturing Technology* 107.7 (2020): 3185-3205.
[3] ISO, 13003:2003 Fibre-reinforced Plastics – Determination of Fatigue Properties Under Cyclic Loading Conditions, ISO, Switzerland, (2003).

Acknowledgements

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