THE EFFECT OF VARYING INFILL DENSITIES ON TRIBIOLOGICAL PROPERTIES OF 3D PRINTED AND ANNEALED CF-PETG COMPOSITES

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ABSTRACT

Heat-resistant polymers were a class of Polyethylene Terephthalate Glycol (PETG) that had high strength and light weight. Carbon fibre with PETG (CF-PETG) composites are also more resistant to heat and chemicals, making them a popular choice for use in automotive and other industrial components. Using a dry sliding tribometer apparatus, this study aims to investigate the most important process parameter of FDM technique for different infill density of 20%, 40%, and 60% at various load conditions and velocities, on wear characteristics or tribological behavior of CF-PETG under both 3D-built and annealed conditions. The experiments were carried out by applying loads of 10N, 20N, 30N, and 40N, with a sliding distance of 2500m and two different velocities of 1m/s and 5m/s, and analyzing the recorded responses of the wear rate.

The findings demonstrate that the wear properties of CF-PETG specimens improve with a higher percentage for infill density at all test parametric conditions, followed by annealed condition of printed parts, where the load and velocity increase, and the wear rate of all samples increases. Due to the presence of carbon fibre in the matrix combined with the annealing effect, the annealed CF-PETG specimen with a 60% infill density exhibits the best wear resistance under all load and velocity conditions. FED Process components are used in a wide range of applications including automotive, aerospace, medical, construction, and electrical.

Keywords: Polyethylene Terephthalate Glycol, Fused Deposition Modeling, Infill density, Tribological Properties, Annealing

I. INTRODUCTION

Additive manufacturing is one of the latest technologies used in the manufacturing of components in which addition of layer by layer takes place to build a component which is used in production of critical and complex shapes by 3-D printing process. When using additive manufacturing, there are a few key parameters like part-orientation, material selection, infill density, printing temperature and speed. The 3D Printing (3DP) technology due to its greatest strength, resistance to wear and corrosion to oxidizing agents and has good temperature resistance with durable one. The effect of print orientation and infill density of the 3DP route on mechanical and tribological properties of PETG filament is discussed in this paper. The results show that when the orientation is in the X direction and the infill density is 100%, all of the mechanical and tribological properties tested increase by around 30-60% because of the formation of anisotropic nature in the parts built in X direction. It would be a good idea to use 3DP parameters that were influenced by this. The use of PETG filament in various application parts with higher properties results in a useful data base set [1]. Additive manufacturing was used in the manufacturing of components by rapid prototyping techniques. The manufacturing in this process is done by layer by layer addition to form a single component. This advanced manufacturing technique is appropriate for the printing of critical and complex shapes [2].

The results show that the wear rate and coefficient of friction properties of neat PETG and CF-PETG specimen change in improving way with a higher percentage for infill density followed by annealed condition of printed parts at all test parametric conditions. In which load and sliding distance increases wear rate increases for all the
samples and followed by the coefficient of friction. Finally compared annealed samples with as-print samples at the end, the infill percentage and annealing route afford a base work for any parts in conjunction with each other to improve wear and friction behavior. [3]. PA12+CF was better than PA6+CF or PETG+CF. The best load bearing capacity was found for the tribologically optimized thermoplastic composite iglidur J260, consisting of a thermoplastic matrix with no further specified kinds of particulate fillers, commercially advertised by the company igus GmbH [4].

The reuse of PETG foils as a matrix reinforced with inexpensive PET fibres gives a cost advantage and proposes a smart solution for recycling of problematic waste material. In order to be able to reprocess the r-PETG, the molecular weight of matrix material is restored during compounding by means of an efficient epoxy chain extender. [5]. The 3D printing is a way of additive manufacturing that allows the creation of sophisticatedly shaped bodies at relatively low cost and in short time span. The paper outlines strengths and weaknesses of the materials described and compare the properties of PETG with and without the addition of glass fiber. The gathered data helps to quantify the mechanical properties of parts made of PETG and may also be used for modeling the properties of 3D printed elements [6].

Fused deposition modeling (FDM) 3D-printing technology was used for fabricating the specimens. The tribological tests have been carried out under reciprocating sliding and dry condition. The results show that the presence of various orientations during the 3D-printing process makes a difference in the coefficient of friction and the wear depth values. Findings suggest that printing structure in the horizontal orientation (X) assists in reducing friction and wear. To date, there has been very limited research on the tribology of objects produced by 3D printing. [7]. According to the results, the maximum tensile stress force for ABS parts, 1438N, is reached at 100% infill. Moreover, the maximum tensile stress for 100% infill parts is (34,57MPa). From this it can be concluded that the printer type or printer manufacturer, as well as the plastic roll manufacturer, are parameters than can significantly influence the mechanical properties of the printed parts. Moreover, it is recommended to increase the extrusion temperature for ABS from 230ºC to 250ºC in order to obtain the best possible results during experimental studies and investigations. Another recommendation is that for small parts or parts with complex geometries, it is recommended that the travel speed be reduced in order to avoid deformed parts [8].

The tensile strength of ASTM D638 specimens produced by an FDM 3D printer in a zero-degree orientation is tested in this study. For 7F Carbon Fiber PETG specimens, the maximum tensile strength, maximum yield stress, and maximum percentage of elongation were measured. Manufacturers print the CAD 3D model in various orientations and densities and Carbon Fiber PETG components outperform PETG components in terms of overall performance.[9].The effects of infill pattern and density at various part orientations on the tensile properties of the FDM-printed PLA specimen were investigated. To determine the impact of FDM process parameters, a full-factorial experiment was conducted, with statistical analysis using ANOVA. The infill density was found to be the most significant process parameter for tensile strength, followed by the infill pattern and orientation. The interaction effect of part orientation and infill pattern was also found to be significant for tensile strength, according to ANOVA results. [10].

MATLAB, Mini-tab, Excel, and Weka were used for data analysis, optimization and DOE, regression functions. Mechanical properties are influenced more by layer thickness than by infill pattern. The triangle pattern has the strongest mechanical properties, whereas the zigzag pattern has the lowest [11].The results showed that low density had a cost advantage over high density for tensile loading while maintaining similar strength. Low density offered significant cost savings while sacrificing little strength in bending applications. It was also found that solid infill design had higher strength when compared to high-density infill design with similar production cost. When comparing solid infill design to high-density infill design with similar production costs, it was discovered that solid infill design had higher strength [12].

II. MODELING AND SLICING

In additive manufacturing, modeling is the first primary step. The base material used is CF-PETG for fabricating the test samples. The samples are designed in CAD software like solidworks and then they are exported to Luban software by .stl file. The software used for printing is SnapmakerLuban software. 3D printer used is Snapmaker A350 machine. All the input parameters like variation in infill density and so on are given to the printer through luban software. Except infill density all other parameters are kept constant. Fig 2.1 shows the details of the sample drawing. Fig 2.2 shows the details of the specimen in SnapmakerLuban software before slicing. Fig.2.3 shows the specimen in luban software from different angles before slicing. Fig 2.4 shows the sample specimen
having 20% infill density after slicing. Fig 2.4 shows a specimen at 40% infill density after slicing. Fig 2.5 shows a specimen at 60% infill density after slicing.

III. PRINTING AND POST – PROCESSING OF TEST SPECIMEN

Insta 3D printer (FDM) was used for printing the test sample. Once after loading the wire filament and sliced file, pre-heating temperature (extruder temperature) and bed temperature are set and allowed to heat initially. When the wire filament at the nozzle reaches the required temperature FDM printer starts to print the designed model by layer by layer successfully of infill density 20%, 40% and 60 % via X orientation. The Infill Densities - 20%, 40%, 60% having grid pattern, about 60 mm/s of infill speed and X - axis orientation, the print temperature was
about 230°C and heated bed temperature was about 50°C, the thickness of each layer was set to be 0.01mm, the total number of layers was 370, with the above conditions 24 number of samples were fabricated with the diameter of 10mm and length of 37mm. Fig 3.1 shows the printer used for printing the CF-PETG specimens using FDM process - Snapmaker A350 printer.

![Fig 3.1 Snapmaker A350 3D printing machine](image)

After printing of the test samples, those samples were tested under annealed condition for their respective wear rates. Printed specimens with various infill density were taken for post heat treatment annealing process and allowed to heat above 5°C from the glass transition temperature for 60 minutes and then permitted to cool in the room temperature in order to improve the properties of the printed specimens. Based on the standard procedure printed and annealed specimens are tested and responses are noted for further analysis.

![Fig 3.2 3D Printed Specimen](image) ![Fig 3.3 3D Printed Specimen after annealing](image)

IV. RESULTS AND DISCUSSION

4.1 EXAMINATION OF WEAR RATE

The wear prediction test was carried out in a pin-on-disc tribometer (Ducom TR-20LE-PHM256) apparatus at dry sliding condition. Both as-built and annealed specimens are tested for their wear rates. All specimens are tested for two different velocities – 1m/s and 5m/s. All specimens are tested under four different loads – 10N, 20N, 30N, 40N. The sliding distance for all experiments is kept constant at 2500m. Fig 4.1 shows some pictures of the tribometer apparatus used for the wear rate prediction of as-built and annealed CF-PETG composite specimens.
Fig 4.1 Pin-on-disk tribometer

Wear is the progressive damage usually occurs on the outside of two parts surface being contacted together due to relative motion between the rubbing parts of varying hardness leading to material loss. Fig 4.2 shows some pictures of the printed specimens before and after the experiment.

Fig 4.2 Printed Specimens (a) before wear (b) after wear

Fig 4.3 and Fig 4.4 shows the variation of the wear rates of the as-built and annealed CF-PETG composite with velocity as 1m/s and with different infill densities of 20%, 40%, 60%, and also with different loading conditions of 10N, 20N, 30N, 40N. Fig 4.5 and Fig 4.6 shows the variation of the wear rates of the as-built and annealed CF-PETG composite with velocity as 5m/s and with different infill densities of 20%, 40%, 60%, and also with different loading conditions of 10N, 20N, 30N, 40N.

Fig 4.3 (a) Wear rate at velocity 1m/s and at sliding distance of 2500m for (a) 3D printed specimen.

Fig 4.4(b)
Wear rate at velocity 5m/s and at sliding distance of 2500m for (c) 3D printed specimen (d) 3D annealed printed specimen.

Fig. 4.3-4.6 shows the variation of wear rate of As-built PETG-CF and annealed PETG-CF specimen printed with 20%, 40% and 60 % infill density in X-Orientation at varying load condition of 10, 20, 30 and 40 N at velocity of 1m/s and 5 m/s and at a constant sliding distance of 2500m. At the low load, the material removal rate from the printed specimen was low and hence the wear rate is found to be low at high load condition the removal rate was high and hence the wear rate was high. In similar way at 1m/s, the wear rate is low and for 5m/s the wear rate is high. This phenomenon is due to increase of contact time between the specimen and the disk. When compared to wear rate at 40N for 1 m/s and constant sliding distance of 2500m to the annealed specimen with the same condition, the wear rate is considerably low because of the relieving of the internal stresses on the printed specimen by annealing process. The wear rate at velocity 1m/s and constant sliding distance of 2500m for infill density 60% decreases compared to infill density of 20% because there is an increase in the bond strength between the printed layer increasing the mechanical property there by reducing the wear rate.

When compared to wear rate at 40N for 5 m/s and constant sliding distance of 2500m to the annealed specimen with the same condition, the wear rate is considerably low because when printing the 3D specimen, rapid heating and cooling take place on the printed specimen thus develop an internal stresses on the printed specimen. Post processing technique like annealing relieves the internal stresses induced in the 3D printed specimen, thus it enhances the mechanical property and reduces the wear rate. Annealing has helped carbon fiber to bond well with polymer composites. Low wear rate was attributed due to the presence of carbon fiber in the filament and annealing effect. The presence of carbon fiber improves the tribological properties of the printed specimens and in most of the cases it acts as a lubricant which additionally involves in the rate of reduction of wear of the polymer composites. The wear rate at velocity 5 m/s and constant sliding distance of 2500m for infill density 60% decreases compared to infill density of 20% because there is an increase in the bond strength between the printed layer increasing the mechanical property there by reducing the wear rate.

V. CONCLUSION
The following conclusion were drawn from the experimentation carried out over the printed and post processed CF-PETG at various infill density of 20%, 40%, 60%, through FDM technique.

1. The specimens of CF-PETG composite were printed by varying infill densities as 20%, 40%, 60% successfully.
2. The printed CF-PETG samples of varying infill densities were taken for post treatment annealing process and allowed to heat above 50°C from the glass transition temperature for 60 minutes and then permitted to cool in the room temperature in order to improve the properties.
3. To validate the result of tribological property, the wear rate was calculated and the responses were discussed for each infill density percentage of both as-built and annealed test sample under 10, 20, 30, 40N load condition and 2500m sliding distance and at velocities of 1m/s and 5m/s respectively.
4. Increasing in the infill density percentage from 20% to 60% of both as-built and annealed samples of CF-PETG led to decrement in the wear rate. This was attributed due to increase in strength and load distribution between the printed layers. Using a lower percentage of infill density usually results in a weak bonding strength of the printed sample and lead to higher wear rate.

5. At high loaded condition of 40N and 2500m sliding distance at velocity at 1m/s the post annealed CF-PETG sample printed with 60% infill density reflected 18% decrement in wear rate when compared with as-built CF-PETG sample printed at 60% infill density.

6. At high loaded condition of 40N and 2500m sliding distance at velocity at 5m/s the post annealed CF-PETG sample printed with 60% infill density reflected 12% decrement in wear rate when compared with as-built CF-PETG sample printed at 60% infill density.

The best choice of annealed CF-PETG with 60% or higher infill density printed samples will be a viable one in automotive and aerospace sliding parts for replacing critical parts.

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