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# Tribology of 3D Printed Polyethylene Terephthalate Glycol (PETG) and Acrylonitrile Butadiene Styrene (ABS) Polymer

**Deepak Kumar B N[1], Mahesh Dutt K[2], Abhinav[3*]**

[1]Research Scholar, Department of Mechanical Engineering, VTU – Regional Research Centre, Belagavi-590018, Karnataka, India.

[2]Professor, Department of Mechanical Engineering, Dayananda Sagar Academy of Technology & Management, Bengaluru-560078, Karnataka, India

[3*]Assistant Professor, Department of Mechanical Engineering, Dayananda Sagar Academy of Technology & Management, Bengaluru-560078, Karnataka, India

Corresponding Email: [3*]abhinavtechno5@gmail.com

***Abstract:*** It has been discovered that polymers can play an essential role in tribo-systems due to their remarkable physico-technical attributes. These attributes include their ability to resist deformation,attenuate vibrations and allied energies, as well as their resilience against friction and wear but not limited to. Among thermoplastic polymers, Acrylonitrile butadiene styrene (ABS), belonging to the styrene ter-polymer family, is frequently used in the construction of durable automotive parts, resilient household appliances, and robust electronic enclosures. This research investigates the tribological performance of 3D-printed PETG and ABS materials reinforced with varying concentrations of carbon fibers (CF) and multiwall carbon nanotubes (MWCNT), tested at loads of 30N and 50N. The study also examines the effect of build orientation on the wear rate of the 3D-printed specimens. The findings highlight the superior attributes of reinforcement, particularly with carbon fibers, in achieving enhanced wear resistance properties.

***Keywords:*** *Acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), carbon fibers (CF), 3D Printing, Tribology*.

## 1. INTRODUCTION

Over the past decade, 3D printing technology has seen extensive use across various industries, including the military, fostering innovation and further research into rapidly producing intricate objects with improved material properties [1]. While the user and low-performance commercial sectors have experienced rapid expansion in 3D printing, the greatest benefits in terms of performance enhancements lie in meeting the requirements of high-performance manufacturing, particularly benefiting the composites industry [2].The physical characteristics of polymers and their blends have been enhanced through the incorporation of organic, inorganic, or powder-based metallic reinforcements or fillers using 3D printing fabrication technology. This manufacturing process has led to the development of composite polymers with superior strength-to-weight ratios, increased fracture toughness, and bending strength. Among the various materials containing carbon in nano-sized forms (below 10 nm), graphene sheets and carbon nanotubes (CNTs) have been extensively utilized to create modern nano-composites with improved mechanical, electrical, and thermal properties, as well as superior friction and wear behaviour[3].Carbon fiber is utilized to reinforce 3D printer filaments such as PETG and PLA, resulting in a remarkably tough and lightweight material. These compounds excel in structural applications requiring durability, impact resistance, and higher strength compared to PLA-carbon fiber. Carbon fiber-PETG filaments are available in various colours and diameters, with printing and bed temperatures ranging from 230–250 °C and 80–100 °C, respectively. Applications include component replacement in model automobiles or airplanes, as well as mechanical body components[4].ABS, also known as acrylonitrile butadiene styrene, is a popular thermoplastic polymer commonly used in injection molding applications. This engineering plastic is favoured for its affordability and ease of machining by plastic manufacturers[5]. Wear is a primary cause of failure in many mechanical applications of ABS, such as gears, bearings, and washers. Strengthening ABS with carbon fiber can help mitigate wear, thereby extending its lifespan.

One of the research demonstrated that the carbon filler and polymer matrix were well mixed however, the physical bonding was determined to be insufficient, and Fibers were torn out reported [6]. Researchers discovered PETG qualifies as a material that may be used to create effective impact resistance gear using a standard 3D printer. According to recent research, 3D printing had a favourable impact on mechanical performance based on the infill density and filling loads. Products made using the method, which uses fused filament fabrication (FFF) or FDM 3D printing, have outstanding mechanical strength among other advantages [7]. As the demand for carbon Fiber reinforced plastics (CFRP) rises, it will soon be necessary to establish a method of recycling CFRP wastes. A lightweight structural material for aerospace vehicles, automobiles, and other industries, CFRP has exceptional mechanical qualities, including a high specific strength and modulus [8]. Carbon Fiber reinforced composites (CFRP) offer several advantages over conventional materials, including high specific strength, high specific modulus, and light weight. Carbon Fiber reinforced resin matrix composites have enticing application prospects due to their abundant raw resources, simple manufacturing process, and low cost. Injection molding is a crucial part of the processing of carbon Fiber reinforced resin matrix composites. The Fibers will be treated to high shear, strain, and distortion during the injection molding process from the entry to the entire cavity, which will induce breakage and movement, revealing a specific length distribution and orientation distribution. The association linking melt temperature and flow behaviour is close [9]. The research the mechanical wear of nano composites made by blending of ABS and PETG is covered in a few academic studies. Researchers examined the tribological nature of ABS is much better in comparison with that of the PETG. Regarding the load and the sliding distance, PETG demonstrated poor wear resistance. Multi-walled carbon nanotubes (MWCNTs) were added to ABS, which lead to negligible enhancement in the polymers load-bearing and thermal stabilities [10]. In abrasive wear the damage in interface is attributed to plastic deformation or fracture is predominant when exterior of the hard material is forced over a smooth material surface. Also, popularly known as abrasive wear. Particles of hard surface cause the softer material to flow plastically in yielding materials with elevated fracture toughness. Even under small stresses, metals that encounter one another will plastically deform [11]. Abrasive wear typically manifests in two distinct forms. Firstly, in a scenario where one surface is harder than the other (known as two-body abrasion), the harder surface is referred to as such. This situation commonly arises in mechanical activities like grinding, cutting, and milling. Secondly, in another scenario, a third body, often a small abrasive particle with a hard surface, is introduced between the two surfaces. This third body is sufficiently hard to remove particles from one or both of the mating surfaces (termed three-body abrasion), as seen in processes like free-abrasive lapping and polishing. Three-body abrasive wear often initiates as an adhesive wear mechanism, generating wear particles that become embedded at the interface [12].

After gaining insights from the literature survey, it has been found that there is still scope for further improvement. In the present work, an effort is made to develop novel 3D printed PETG and ABS composite materials reinforced with varying concentrations of carbon fibers (CF) and multiwall carbon nanotubes (MWCNT). It is believed that this experimental investigation will help researchers to explore in greater detail, using the present data as a reference.

## 2. EXPERIMENTAL WORK

The features of the experimental work, including the selection of base materials, reinforcements, weight percentage, employed processing methods, and testing parameters, are briefly discussed in the next section

**2.1 Base Material Selection**

PETG, also known as polyethylene terephthalate glycol or PET-G, is thermoplastic polyester with notable chemical resistance, durability, and formability for manufacturing. Table 2.1 shows the physical properties of PETG. Acrylonitrile butadiene styrene, also known as ABS, is a popular thermoplastic polymer frequently utilized in injection molding applications. This engineering plastic is popular because it is inexpensive to produce and simple for plastic manufacturers to machine. Table 2.2 shows the physical properties of ABS.

Table 2.1: Physical Properties of PETG

| Parameters | Value |
|---|---|
| Density | 1.23g/cm$^3$ |
| Shore Hardness | 78 |
| Yong's Modulus | 2950MPa |
| Melting Temperature | 260$^0$C |
| Diameter | 1.75 mm |

Table 2.2: Physical Properties of ABS

| Parameters | Value |
|---|---|
| Density | 1.04g/cm$^3$ |
| Shore Hardness | 100 |
| Yong's Modulus | 3200Mpa |
| Melting Temperature | 200$^0$C |
| Diameter | 1.75 mm |

**2.2 Reinforcement Materials**

Carbon Fiber(CF) and Multi Walled Carbon Nano Tubes (MWCNTs) are reinforced polymers. Carbon Fiber is lightweight and robust material. Carbon Fiber is twice as rigid and five times stronger than steel [13]. Table 2.3 shows the physical properties of CF. Figure 2.4 shows the carbon fine in powder form. On the other hand MWCNTs is as a collection of single wall tubes nested inside one another. These concentric walls could number as few as 6 or as many as 25. Therefore, MWNTs may have diameters as large as 30 nm as opposed to 0.7 to 2.0 nm for conventional SWNTs. Table 2.4 shows the physical properties of MCNT. Figure 2.5 (a) and (b) shows the CF and MCNT Fiber respectively in the powder form.

Table 2.3**:** Physical Properties of Carbon Fiber

| Parameters | Value |
|---|---|
| Density | 1.75g/cm$^3$ |
| Hardness | 50.5 HRC |
| Yong's Modulus | 183Gpa |
| Melting Temperature | 1500$^0$C |


Figure 2.4.(a) Carbon Fiber (b) Multi Walled Carbon Nano Tubes

Table 2.4: Physical Properties of MWCNT

| Parameters | Value |
|---|---|
| Density | 1.72g/cm$^3$ |
| Shore Hardness | 70 HRC |
| Yong's Modulus | 270Gpa |
| Melting Temperature | 3550$^0$C |

## 2.3 Processing Technique

The 3D printing technique is utilized for processing the polymer material. Figure 2.5 (a) & (b) shows the apparatus for fabrication employed in the current work and build orientation in x, y and z directions respectively. Table 2.5 indicates the percentage of matrix material and supplementing material used during the processing of polymer composites. PETG and ABS composites are processed directly as they are in the form of fibers. For processing the composite materials, especially the carbon fiber and MWCNT fibers, the reinforcements will be in the form of powder, which will be blended in a mixing chamber with adhesive agent. Furthermore, the materials will be compacted in the die, and the materials will be extruded to obtain them in the form of fibers. These fibers will be built in the required direction to make changes in weight percentages.

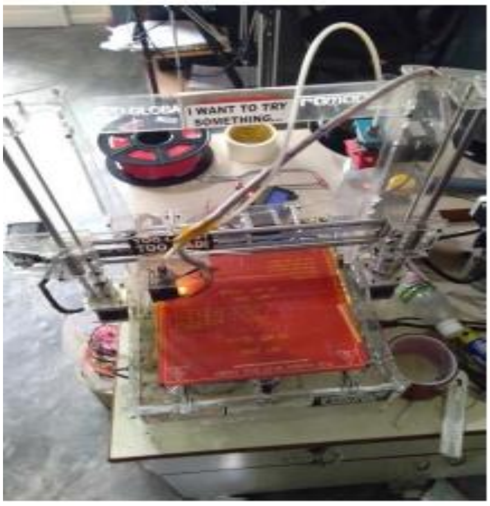
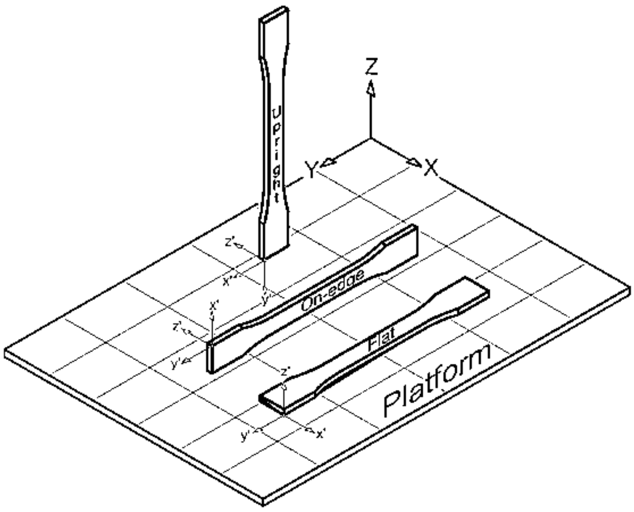


Figure 2.5. (a) FDM apparatus used (b) Build Orientation

Table 2.5: Matrix and Reinforcement Details

| Sl.No. | Matrix Material | Weight Percentage | Reinforcement Material | Weight Percentage |
|---|---|---|---|---|
| 1 | PETG | 100 | - | - |
| 2 | ABS | 100 | - | - |
| 3 | PETG | 98 | Carbon Fiber | 2 |
| 4 | ABS | 98 | Carbon Fiber | 2 |
| 5 | PETG | 96 | Carbon Fiber | 2 |
| | | | MWCNT | 2 |
| 6 | ABS | 96 | Carbon Fiber | 2 |
| | | | MWCNT | 2 |

### 2.4 Tribological Study

Wear test parameters are show in the Table 2.6. Figure 2.7 displays the tribomachine, while Figure 2.8 illustrates the test specimen utilized. The specimen was prepared according to ASTM G99 standard [14], with dimensions of 8 mm diameter and 28 mm length.

Table 2.6: Wear test parameters

| Parameters | Value |
|---|---|
| Velocity | 2 m/sec |
| Sliding Distance | 1400 m |
| Time | 700 sec |
| Speed | 320 RPM |
| Loads | 30N, 50N |

Figure 2.7.Wear test apparatus

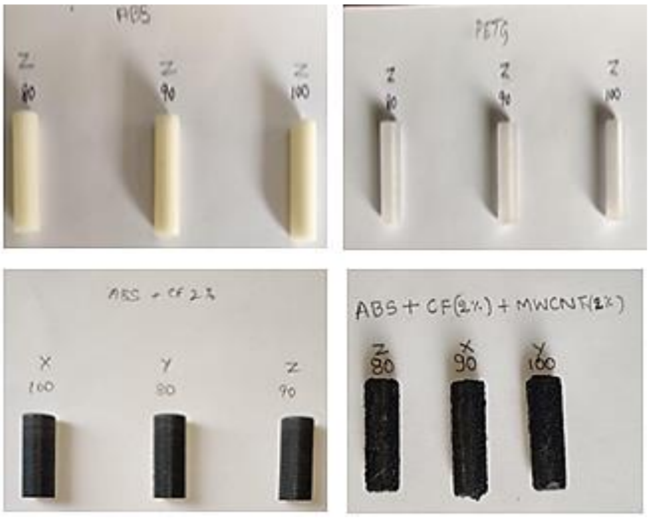


Figure 2.8. Wear testing samples

## 3. RESULTS AND DISCUSSIONS

Experimental investigations on wear rate at different build orientation x, y and z are explained upon in the following section.

### 3.1 Effect of Build Orientation on Wear Over Time (Build Orientation X80, Y90, Z100)

Figure 2.9 shows the rate of wear for PETG and ABS under 30 and 50 N loads. It is evident that there is a surge in wear rate with an increase in the time duration irrespective of the 3D printed material. Initially, the rate of wear is found to be high, attributed to sudden contact between the specimen and the counterpart. The two mating surface asperities are sheared, causing a faster rate of wear. As the mating surface experiences less wear, the asperities stabilize, the area of contact grows, and the exterior becomes work-hardened as the sliding distance increases. This tendency is consistent across all test settings, with the wear rate precisely proportional to the abrading distance and increasing correspondingly as the distance is increased. Irrespective of the build direction, among the tested materials, PETG wears out more rapidly in contrast to ABS due to its lesser hardness and inability to withstand the applied load

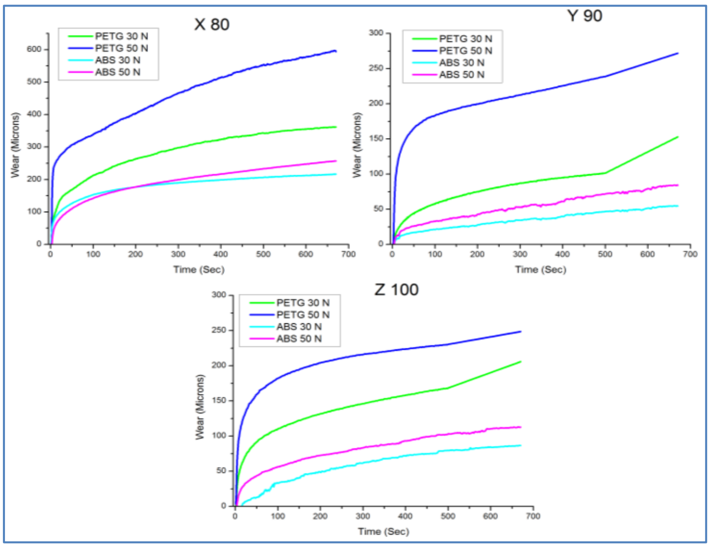


Figure 2.9.Wear v/s Time (PETG and ABS) Varying Load 30N, 50N

**3.2 Effect of Build Orientation on Wear Over Time (X100, Y80, Z90)**

It can be observed from Figure 2.10 that, under the same conditions, the rate of wear for the matrix materials is slightly beyond that of the composite specimens. For the same load and sliding distance, the effects of the reinforced composites reveal a similar trend, but the ABS+CF2 composites wear down more slowly than the PETG+CF2 specimens. The microstructural alterations brought about by the phase transformation in the composite material with ABS+CF2 improve the material's hardness, ultimately enhancing its wear-resistant properties. The existence of the carbon elements forms a protective layer on the surfaces in contact, leading to depletion in the contacting points and thereby reducing friction. This protective layer formation depends upon the matrix materials and their compatibility with the reinforcement material. If the bonding involving the matrix and reinforcement is good, the properties of the materials are expected to have a better life. Carbon can withstand higher temperatures and loads, making it feasible for wear applications

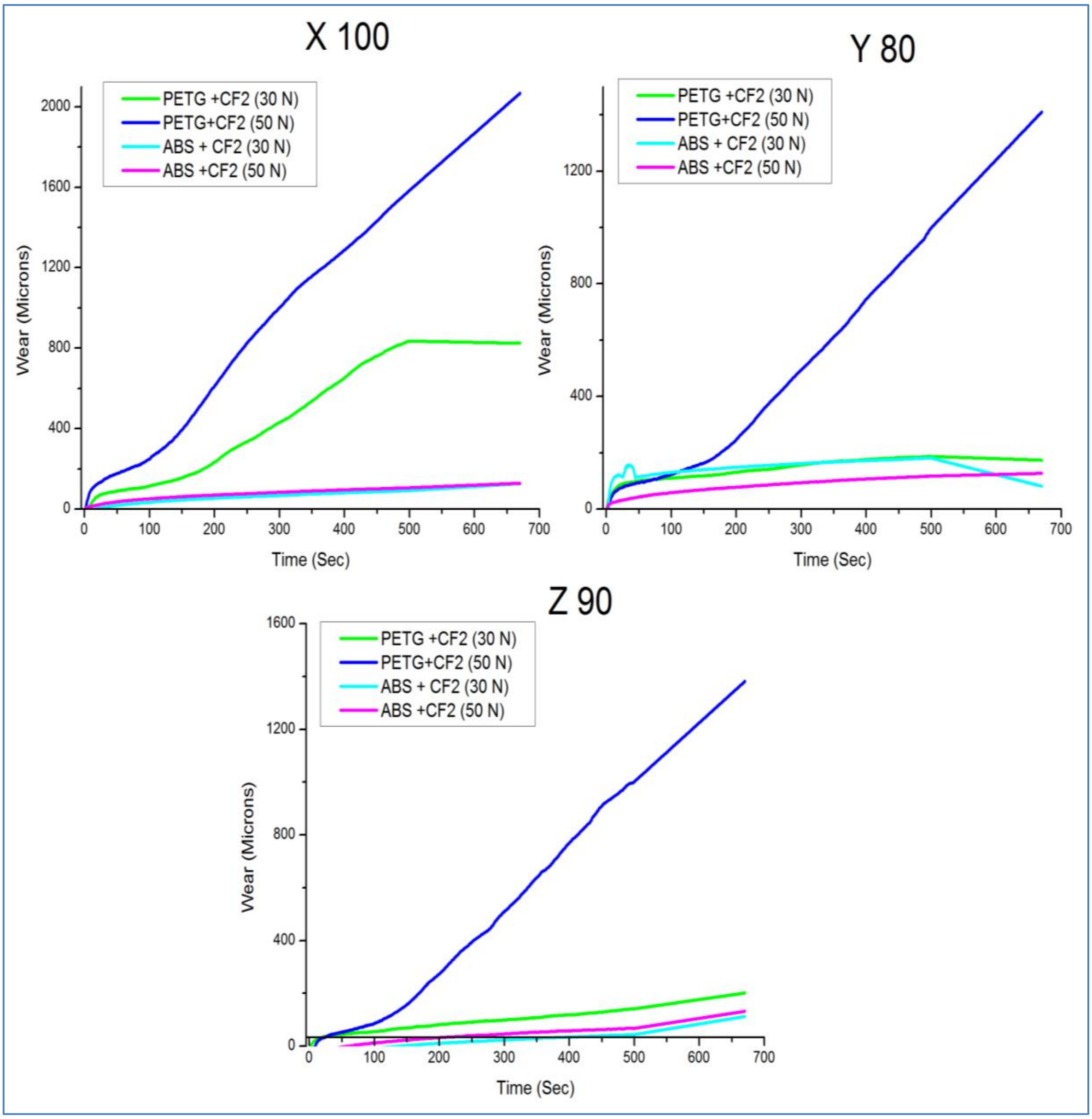


Figure 2.10. Wear v/s Time (PETG+CF2 and ABS+CF2) Varying Load 30N, 50N

**3.3 Effect of Build Orientation on Wear Over Time (Build Orientation X90, Y100, Z80)**

Figure 2.11 depicts the wear rate variations for hybrid reinforcement. Witnessing the plots, it becomes obvious that as the normal load increases, the wear rate also increases gradually. However, an analysis of wear behavior across different composite specimens reveals notable inconsistencies in wear rates between base alloy specimens and reinforced materials, especially at lower loads. As the load increases further, the differences in wear rates among various specimens become minimal. The reinforcement plays a crucial role in reducing wear; it is evident that the hardness of reinforced materials plays a significant role and consequently enhances the wear resistance properties. Notably, among the materials assessed for tribological properties, PETG exhibits higher wear due to its lower hardness, leading to a faster rate of wear. This is showed by a decrease in material dimensions by half at the end of the test, indicating reduced wear resistance properties. Despite reinforcement with carbon fibers, the enhancement in wear resistance for ABS is comparatively minimal.

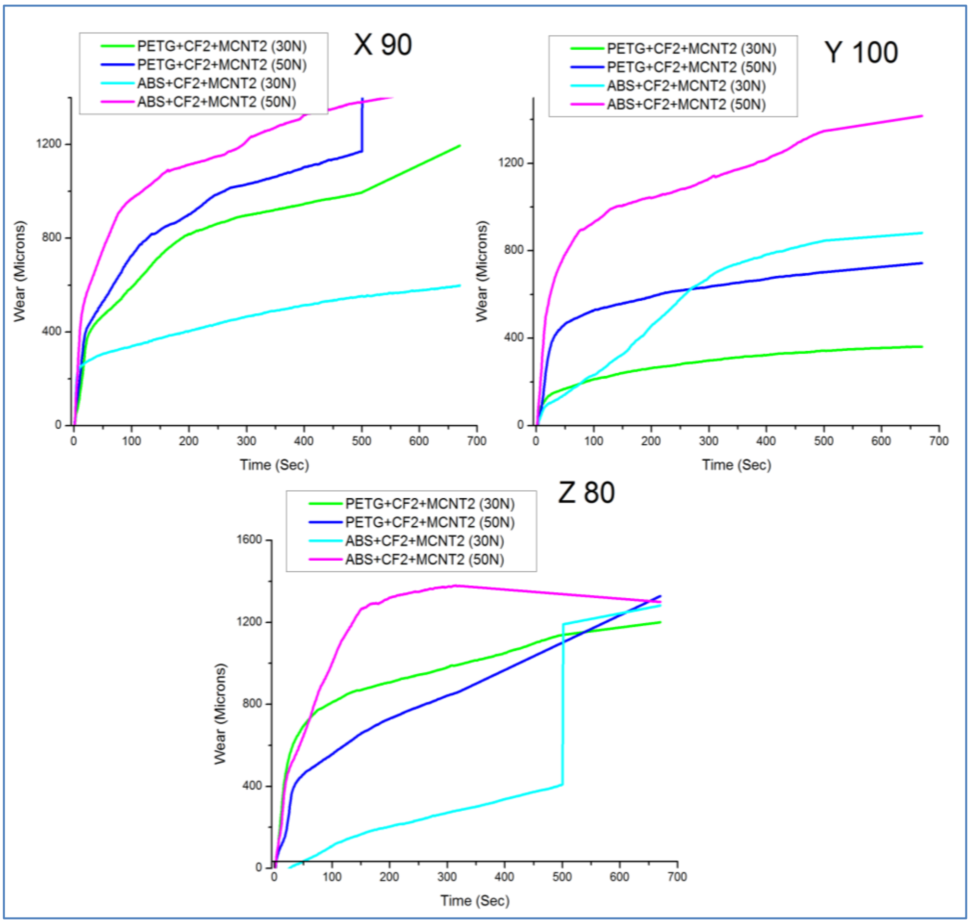


Figure 2.11.Wear v/s Time (PETG+CF2+MWCNT2 and ABS+CF2+MWCNT2)

## 4. CONCLUSIONS

The following are the conclusions which are drawn from the tribological investigations:

- Polymer composites comprising PETG and ABS are effectively processed using 3D printing techniques, resulting in defect-free specimen. The wear test indicates that PETG material wears out more rapidly than ABS under all loading conditions.
- The inclusion of Carbon Fiber led to enhanced wear resistance properties, with ABS containing 2% Carbon Fiber exhibiting less wear than PETG with the same proportion. This decrease in wear can be attributed to the higher strength of ABS and Carbon Fiber in comparison to PETG and Carbon Fiber. Similar outcomes were observed with Multi-walled nanotubes reinforcing both ABS and PETG.

- It can be inferred that material reinforcement improves the wear resistance of the polymer material. The build orientation has no significant impact on wear properties; instead, it is the hardness and interfacial bonding within the materials that play a significant role.

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