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Investigation on Wear Behavior of 3D Printed PETG and ABS Hybrid Polymer Composites

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Abstract:

Currently, polymers play a crucial role in tribo-systems, thanks to their outstanding physical attributes, including the ability to dampen vibration and energy, as well as resilience to corrosive and contaminated environments. These versatile materials find applications in various automotive components like seat backs, interior doors, fender aprons and even in airplane cabins. Acrylonitrile butadiene styrene (ABS), a thermoplastic polymer from the styrene ter-polymer family, stands out as one of the most frequently employed materials in engineering applications. Another notable thermoplastic polymer is PETG, known for its affordability, ease of production, and semi-crystalline nature. Despite being user-friendly for printing, PLA lacks the strength of ABS, which is preferred for items requiring enhanced durability. When prioritizing food safety, PETG becomes a preferred choice due to its excellent material qualities, despite potential challenges in the printing process. This study investigates the tribological behavior of PETG and ABS materials manufactured through 3D printing and reinforced with varying amounts of carbon fibers (CF) and multiwall carbon nanotubes (MWCNT). The findings highlight improved wear resistance properties with the addition of reinforcements, particularly carbon fibers, showcasing their superior properties. The study aims to provide insights into how these materials contribute to refining polymer properties, emphasizing the positive impact of reinforcement on wear resistance.

Keywords: 3D Printing, PETG, ABS, Carbon Fibre, Multi walled carbon nano tube.

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1.0 Introduction:

A well-known method that is gaining popularity is 3D printing to produce functional parts like membranes, shields, wearable sporting equipment, and prototypes. A unique approach for simulating failure in a 3D-printed cellular structure was developed to account for the significance of the impact of specific process parameters. Evidence suggests that there are not as many acceptable printing materials as there are standard materials. The effects of it can be explained by the constraints of 3D printing techniques regarding using a large variety of materials. 3D printing technology has been utilized extensively in several industries, including the military, for over and above a decade [1]. Using 3D printers the potential for innovations and opportunities, inspiring further research into the rapid production of complicated objects with improved material attributes. The user and low-performance commercial segments are where 3D printing has expanded most rapidly. The performance improvements that can be made to 3D printing knowledge that can satisfy the requirements of high-performance manufacturing, however, help the composites industry the most [2].

With the 3D printing fabrication technology, the polymers and their blends physical characteristics have been enhanced through the utilization of organic, inorganic, or powder-based metallic reinforcements or fillers. This type of process of manufacture leads creation of composite polymers with superior strength-to-weight ratios, elevated fracture toughness, and bending strength. Among the many other materials with carbon content formed in nano size (below 10 nm), graphene sheets and its outgrowth, carbon nano tubes (CNTs) have been broadly used to create contemporary production nano composites with enhanced and customized mechanical, electrical, and thermal properties, superior friction, and wear behavior [3].

Carbon fibre is used to reinforce 3D printer filaments like PETG and PLA, creating a remarkably hard and unyielding material that is also relatively light in weight. Such compounds excel in structural applications that must survive a wide range of end-use environments because of their excellent ductility, impact resistance, and higher strength than PLA-carbon fibre. Carbon Fiber-PETG filaments come in a variety of colors and diameters of 1.75mm, 2.85mm, and 3.0mm. The temperatures for printing and the bed are 230–250 °C and 80–100 °C, respectively. Applications include replacing a component in your model automobile or airplane and mechanical body components [4].

ABS, alias acrylic nitrile butadiene styrene, is a well-liked thermoplastic polymer that is normally used in injection molding applications. This engineering plastic is trendy as it is affordable to produce and simple to machine for plastic manufacturers [5]. Wear is the main reason for failure in the many mechanical applications of Acrylonitrile Butadiene Styrene (ABS), including gears, bearings, washers, etc. Therefore, by lowering it, we can lengthen life. In this case, ABS was strengthened with addition of carbon fibre.

2. Literature Survey

A sort of additive manufacturing called 3D printing makes it possible to fabricate intricate objects using existing production processes. In order to deposit successive layers of molten thermoplastic on top of one another, the FDM 3D printing facility includes moving a nozzle between three forms in the x, y and z axes. Tensile testing has been done to assess the characteristics of the construction direction SEM images were generated and demonstrated that the carbon filler and polymer matrix were well mixed even after a tensile test, in which the physical bonding was determined to be insufficient, and fibres were torn out. Considering the difficulties in testing upright prints, the author began work on a new test specimen type to measure Young's modulus and delamination force in a vertical direction to the FDM printing base [6].

It's crucial that researchers discovered PETG qualifies as a material that may be used to create effective impact protection gear using a standard 3D printer. Future uses of 3D-printed composite materials may result in smaller fibre diameter, which could be very interesting. While other filaments produced worse outcomes, PETG and ABS produced better results while having trouble retaining the preceramic polymer after soaking. According to research, 3D printing had a favorable 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 fibre 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 fibre reinforced composites (CFRP) offer several advantages over conventional materials, including high specific strength, high specific modulus, and light weight. Carbon fibre 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 fibre reinforced resin matrix composites. The fibres 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 behavior is close. [9].

The research of the mechanical and nature of wear of nano composites made of blends 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].

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. This is called 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].

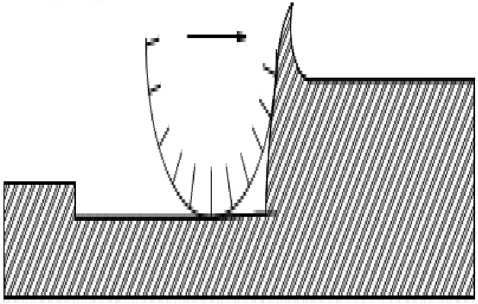

Figure 2.1. Abrasive wear

Abrasive wear generally comes in two different forms. In the initial scenario, the surface which is harder than the other one (two-body abrasion) is called the hard surface. This scenario occurs, for instance, in mechanical activities like grinding, cutting, and milling. In the second instance, a third body is considered as hard surfaced body which is typically a small abrasive particle, this will be introduced between the two other surfaces. This third body is sufficiently harder to be able to remove particles of one or both mating surfaces (three-body abrasion), for instance during free-abrasive lapping and polishing. A three-body abrasive wear is frequently the result of an adhesive wear mechanism at the beginning, which produces wear particles that become lodged at the interface [12]. Figure 2.1 provides a schematic representation of abrasive wear.

2.1 Methodology

The methodology employed in the current work comprise of

- Selection of matrix and reinforcement materials.
- Choosing the weight percentage of matrix and reinforcement materials.
- Choice of processing technique.
- Choice of Build orientation.
- Processing and samples preparations.

3. Experimental Work

The features of the experimental work including the base materials selected, reinforcements, its weight percentage, processing methods employed, and testing parameters are reviewed in brief in this section.

3.1 Base Material

PETG: PETG or PET-G, otherwise known as polyethylene terephthalate glycol, is a thermoplastic polyester with notable chemical resistance, durability, and formability for manufacturing. Table 3.1 shows the physical properties of PETG.

Table 3.1. Physical Properties of PETG

Parameters	Value
Density	1.23g/cm^3
Shore Hardness	78
Yong's Modulus	2950MPa
Melting Temperature	260^{0}C

ABS: Acrylonitrile butadiene styrene, also known as ABS, is a popular thermoplastic polymer that is frequently utilized in injection molding applications. This engineering plastic is well-liked because it is inexpensive to produce and is simple for plastic makers to machine. Table 3.2 shows the physical properties of ABS.

Figure 3.1 a show the raw material in form of spool which happens to be white color with a diameter of 1.75mm. Figure 3.1 b shows the raw material in form of spool which looks crystal clear with a diameter of 1.75mm.

Table 3.2. Physical Properties of ABS

Parameters	Value
Density	1.04g/cm^3
Shore Hardness	100
Yong's Modulus	3200Mpa
Melting Temperature	200^{0}C

(a) (b)

Figure 3.1. (a) PETG Spool **(b)** ABS Spool

3.2 Reinforcement Materials

Carbon Fibre: Graphite fibre and carbon fibre are both types of polymers. It is made up of a highly lightweight material that is also very robust. Carbon fibre is twice as rigid and five times stronger than steel. Table 3.3 shows the physical properties of Carbon Fibre. Figure 3.2 shows the carbon fine in powder form.

Table 3.3. Physical Properties of Carbon Fibre

Parameters	Value
Density	1.75g/cm^3
Hardness	50.5 HRC
Yong’s Modulus	183Gpa
Melting Temperature	1500^{0}C

Figure 3.2. Carbon Fibre

Figure 3.3. MWCNT

Multi Walled Carbon Nano Tubes: One way to think of WNTs 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 3.4 shows the physical properties of MCNT. Figure 3.3 shows the MCNT fibre in the powder form.

Table 3.4. Physical Properties of MWCNT

Parameters	Value
Density	1.72g/cm^3
Shore Hardness	70 HRC
Yong’s Modulus	270Gpa
Melting Temperature	3550^{0}C

3.3 Processing Technique

3D printing technique is utilized for processing the polymer material, Figure 3.4 shows the apparatus for fabrication employed in the current work. Figure 3.5 shows the build orientation of X, Y and Z. Table 3.5 indicates the percentage of matrix material and supplementing material used during the processing of polymer composites.

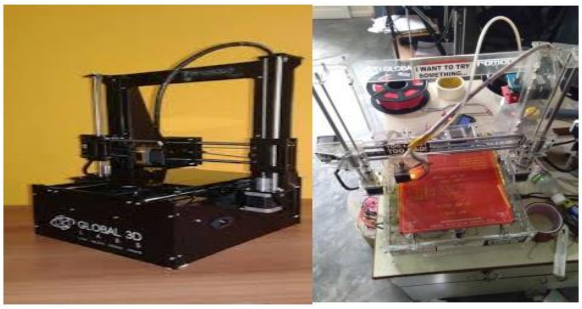

Figure 3.4. FDM apparatus used

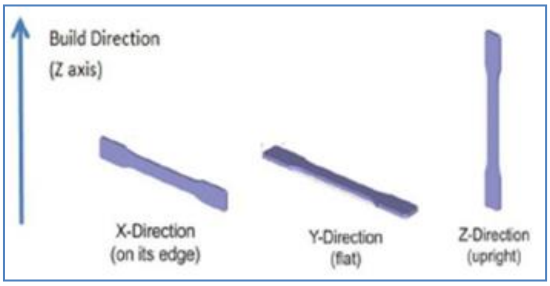

Figure 3.5. Build Orientation

TABLE 3.5. Matrix and Reinforcement Details

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

PETG and ABS composites are processed directly as, it is in the form of fibres. For processing the composite materials, especially the carbon fibre and MWCNT fibres the reinforcements will in the form of the powder which will be blended in mixing chamber with adhesive agent, further the materials will be compacted in the die and materials will be extruded to obtain it in the form of fibres. These fibres will be built on the required direction to changes in weight percentages.

3.3 Tribological Wear Study

Tribological wear study conducted with the parameters is show in the Table 3.6, the particulars of the apparatus used is shown in the Figure 3.6.ASTM G99 standard sample is used for the test with the dimension of 8mm dia and 28mm length as seen in the Figure 3.7.

Table 3.6. Wear Testing Parameters

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

Figure 3.6. Wear Testing Apparatus

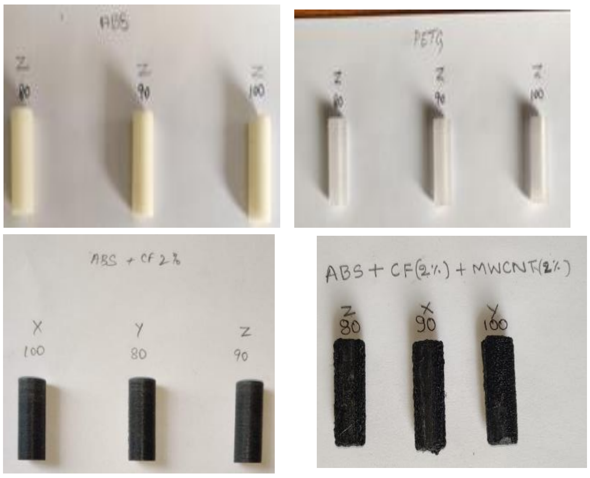

Figure 3.7 Wear testing samples

4. Results and Discussions

Tribological test is performed by considering 2 body wear mechanism of abrasive nature. The test is being conducted for a fixed time of 700sec at a constant speed of 320rpm, sliding velocity is maintained at 2m/s for a sliding distance of 1400m. Experimental work carried out shows a remarkable progress in the resistance of wear properties of the various materials. The load is changing from 30N to 50N, and the build orientation based on the analysis is diversified as well. Consequence of the above condition is being described in detail in the below section.

4.1 Wear v/s Time (Build Orientation X80, Y90, Z100)

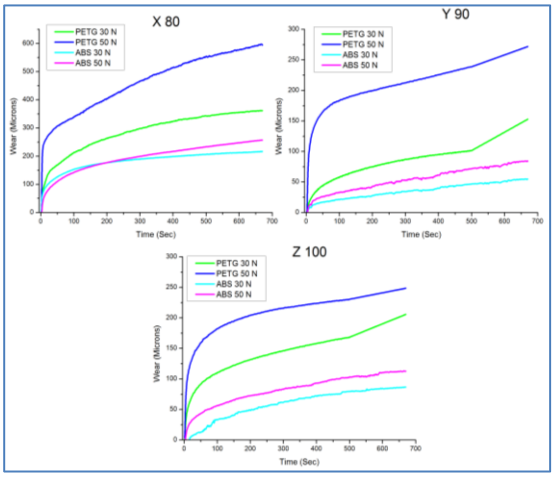

Figure 4.1. Wear v/s Time (PETG and ABS) Varying Load 30N, 50N

Figure 4.1 represents the rate of wear for PETG and ABS with different loads. It is evident from the figure that the surge in wear rate can be observed with increase in the time duration irrespective of the material. Initially the rate of wear will be high as there will be severity contact among the parts during the initial stages of wear and the two mating surfaces as well as the weaker material's asperities are sheared, causing a faster rate of wear. The mating surface experiences less wear as asperities become compensated, the area of contact grows, and the exterior becomes work hardened as the sliding distance increases. The 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 worn out rapidly in contrast with the ABS due to the lesser hardness of the PETG material which does not fight back against the load.

4.2 Wear v/s Time (Build Orientation X100, Y80, Z90)

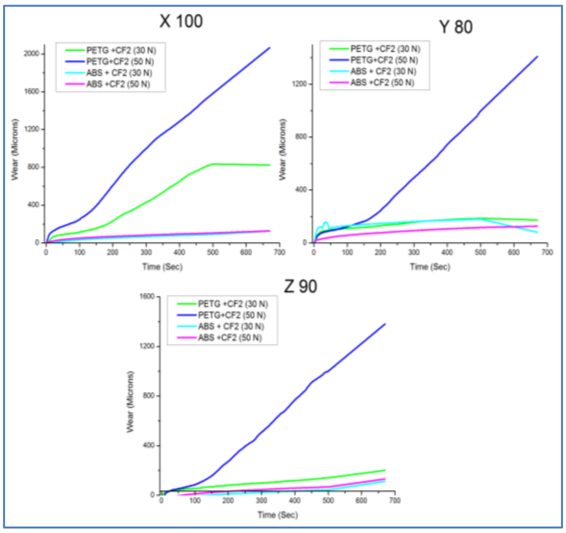

Figure 4.2. Wear v/s Time (PETG+CF2 and ABS+CF2) Varying Load 30N, 50N

It can be observed from the Figure 4.2, Under the same circumstances, the matrix materials rate of wear is slightly beyond that of the composite specimens. For the same load and sliding distance, the effects of the reinforced composites revealed a similar trend, but the ABS+CF2 composites wore 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, this ultimately enhances 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 there by reducing the friction. This protective layer formation depends upon the matrix materials and its compatibility with the reinforcement material, if the bonding involving the matrix and reinforcement is good, the property of the materials is expected to have a better life. Carbon can withstand higher temperature and load which makes it feasible for the wear applications.

4.3 Wear v/s Time (Build Orientation X90, Y100, Z80)

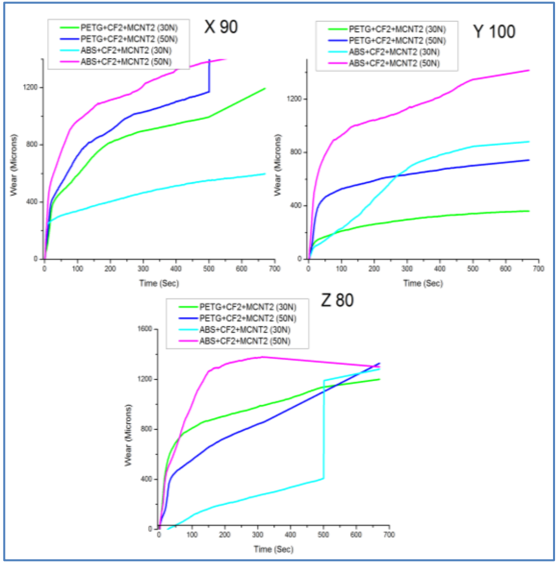

Figure 4.3. Wear v/s Time

(PETG+CF2+MWCNT2 and ABS+CF2+MWCNT2)

Figure 4.3 illustrates the changes in rate of wear with applied load for hybrid reinforcement. It can be noted from the plots that the rate of wear gradually increases with rise in normal load. Nonetheless, scrutiny of the wear behavior of different composite specimens reveals that there is significant variation between the rate of wear demonstrated by base alloy specimens in contrast with the reinforced materials particularly at lower loads. At greater loads, only minimal variation can be detected in the wear rate midst of various specimens. The reinforcement has a major role to play in the wear reduction, it can be observed that the reinforced material hardness is being increased which eventually improves the wear resistance properties. It appears that among the materials selected for the tribological properties evaluation, the PETG material experiences higher wear due to lesser hardness and the material worn out at lower rate itself. The difference in the proportion of the material will be half of the initial dimension at the end of the test. This signifies that the material has poor wear resistance properties. Despite the material is reinforced with the carbon fibres, the enhancement will be very less in contrast with that of the ABS.

5. Conclusions

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

- Polymer composites with PETG and ABS are processed successfully by the 3D printing techniques with no defects in it.
- Polymer composites with Carbon fibres and Multi walled nano tubes are also processed with a constant reinforcement's weight percentage of 2% by 3D process.
- Wear test is conducted for fabricated samples with varying load condition with a constant sliding velocity and sliding distance.
- Wear test implies that the PETG material worn out faster compared to ABS in all set of loading condition.
- Addition of the Carbon fibre showed an improvement in the properties of wear resistance, among the two materials ABS with 2% Carbon fibre experienced lesser wear compared to PETG with 2% Carbon fibre. Reason for the decline in wear is due to the elevated intensity of the ABS and Carbon fibre compared to PETG and Carbon fibre.
- Similar results are noted for the Multi walled nano tubes reinforced together with the ABS and PETG.
- It can be deduced that the reinforcement of the material enhances the resistance for wear of the polymer material.
- Build orientation has no influence on the wear properties, it is only the hardness along with the bonding towards the materials that plays a vital role.

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