

# Performance Evaluation of Carbon Fiber Reinforced with Polyethylene Terephthalate Glycol (PETG) in Additive Manufacturing

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**Abstract.** This research worked on the mechanical properties of Carbon Fiber Reinforced Polyethylene Terephthalate Glycol (PETG) for applications in 3D printing. Carbon fiber reinforcement was incorporated into PETG and pellets as the base material. Tensile and compression tests were conducted on Carbon fiber-reinforced PETG and PETG to appraise the respective mechanical strength and stiffness. The results of these test coupled with comparisons between the two materials, provided valuable insights into the performances and potential application of Carbon fiber-reinforced PETG in additive manufacturing. The research contributed to understanding Carbon Fiber Reinforced PETG's mechanical behavior, decisive for engineering applications. The highest tensile strength recorded for Carbon Fiber PETG was 38.51 MPa, achieved in sample 7 by infill density of 100%, a layer height of 0.30mm, and a printing speed of 40mm/s. The highest compression strength recorded for normal PETG was 52.29 MPa, observed in sample 8. under different parameters infill density of 100%, a layer height of 0.18mm, and a printing speed of 60mm/s.

**Keywords:** 3D printing, FDM machine, PETG, Carbon fiber, Extruder Machine and Composite filament

## 1. Introduction

FDM is a widespread additive manufacturing technique recognized for its versatility and cost-effectiveness. One key area of interest within FDM is filament making, where the quality and properties of the filament directly impact the final printed part. Carbon fiber reinforcement significantly improves mechanical properties, including strength and stiffness, making it an attractive option for enhancing FDM filaments.

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PETG is a thermoplastic polymer known for its excellent layer adhesion, and chemical resistance, making it ideal for 3D printing applications. By joining Carbon fibers into PETG filaments, the mechanical performance of the resulting composite could be significantly enhanced. This study aimed to explore the process of filament-making for FDM machines, concentrating on the incorporation of carbon fibers into PETG to produce high-performance filaments.

The improved mechanical properties of the carbon fiber-reinforced PETG filament hold great promise for a wide range of applications automotive, aerospace, and biomedical industries. By improving the mechanical performance of FDM filaments, this research contributes to advancing the capabilities of additive manufacturing technology.

## 2. Literature review

Dame Ayane Tolcha et.,al.[1] determined the best combination of a FDM filament. Various composite 3D printing filaments were successfully created from plastic waste and different weight fractions of glass fiber. Filaments of 1.75-mm diameter were produced using pure rHDPE, and rHDPE/rPET with 15% & 30% weight portions of SGF. The addition of SGF increased tensile strength but caused samples to become more brittle. Incremental SGF addition reduced deformation and improved dispersion, minimizing voids and preventing nozzle clogging.

M. Cali et., al. [2]investigated the properties of PLA and agricultural waste materials for biomedical applications in FDM printing. HEMP with 20% canapule powder filler, shows notable tensile strength due to its high silicon content, surpassing hemp fiber and wood sawdust. Its elastic modulus is more than double that of PLA (+133%), with a 16% increase in yield strength. WEED, using 20% hemp inflorescences powder filler, exhibits a higher elastic modulus but slightly lower yield and ultimate stress compared to PLA. However, WEED experience significant plastic deformation due to cannabinoids, increase the elongation at rupture from 3% to 9% with the addition of 20% of hemp flower powder.

Jelena Djokikj et.,al. [3] investigated PLA, PC, and PETG, designed to ASTM standards and fabricated under identical parameters. Tensile tests reveal PLA as the most rigid, exhibiting the highest mean Young's modulus, while PC shows the highest tensile strength, and PETG displays the greatest elongation. PETG exhibited the distinct behavior, with no clear fracture and manual intervention required to end tests. Flexural tests showed PC and PETG reaching maximal stroke, while PLA specimens break before this point. PETG demonstrated the highest elongation, suggesting suitability for composite applications. Ultimate tensile stress (UTS) is highest in PC specimens, while PLA leads to maximum flexural stress.

Nicole E.Zander et.,al. [4] The objective of the study was to develop blends of first-use polypropylene (PP) with talc (PPt) and recycled polypropylene (r-PP) suitable for 3D printing via fused filament fabrication (FFF). The blends underwent characterization, melt compounding, and optimization using a design of experiments approach. The top-performing materials were chosen for filament production and subsequent FFF processing. The optimized blends exhibited favorable rheological behavior, thermal characteristics, and mechanical properties.

Adam M. Pringle et.,al. [5]discussed the Michigan furniture industry's substantial wood-based waste served as a valuable resource for upcycling into a WPC. The research investigates the feasibility of utilizing this furniture waste as a feedstock for 3-D printer filament, specifically for producing furniture components. By grinding and milling board scraps from LDF, MDF, and melamine-particleboard-paper saturated with phenolic resins.

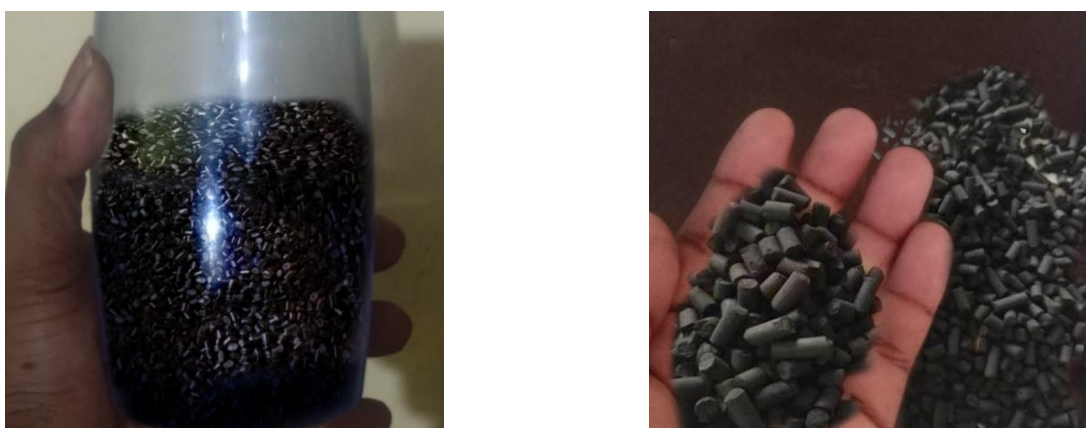
Chibu O. Umerah et.,al. [6]explored the utilization of carbon nanoparticles derived from waste coconut shells as a filler in biodegradable plastic. they blended BIOPLAST GF 106/02/PLA 75/25 with these carbon nanoparticles to create a novel material. The carbon nanoparticles were synthesized using a high-temperature/pressure reactor and characterized through techniques like SEM, XRD, and Raman Spectroscopy. The resulting polymer composite filaments, infused with varying amounts of carbon nanoparticles, exhibited

remarkable properties. the tensile strength increased by 50% associated to neat polymer filaments, demonstrating the potential of this material for 3D printing application.

### 3. Materials & Methods

#### 3.1 Raw materials

The recycled PETG Pellets used for this research work, shown in Fig. 1a, supplied by the CMR Technical campus, were used as a major matrix. Carbon fiber was used as an additive to reinforce recycled plastic. Fig. 1b is the Carbon fiber used in this research, supplied by the CMR Technical campus.



**Fig.1** (a) PETG Pellets (b) Carbon fiber Pellets

##### 3.1.1 PETG

Polyethylene Terephthalate Glycol (PETG) is a thermoplastic polymer that's commonly used in 3D printing shown in Fig.1 (a), as well as in various other applications such as packaging, bottles, and even medical devices. It's an interesting material because it combines the properties of both PET and glycol-modified PET.

PETG is used for its toughness and durability, create it resistant to impacts and shattering. PETG is transparent, similar to PET, which makes it suitable for applications where visibility or clarity is important. It is a popular filament material in 3D printing due to its ease of printing compared to some other materials like ABS. It has a lower printing temperature and less warping, which makes it more beginner-friendly. PETG is also recyclable, contributing to its appeal in environmentally conscious applications and PETG has low moisture absorption, which helps maintain its mechanical properties even in humid environments.

##### 3.1.2 Carbon fiber

Carbon fiber-reinforced filaments is a type of composite filament used and are made by combining thermoplastic polymers with chopped or milled carbon fibers shown in Fig.1(b). The result is a material that retains the benefits of both the polymer matrix (and the reinforcing properties of carbon fibers. The addition of carbon fibers to the polymer matrix significantly enhances the mechanical properties of the printed parts, making them stronger and more rigid compared to parts printed with standard filaments. Despite their increased the strength and stiffness, parts printed with carbon fiber filaments remain the lightweight. Carbon fiber-reinforced filaments exhibited the improved dimensional stability compared to standard filaments. This means that printed parts are less prone to warping or deformation, even under high-stress conditions or temperature variations. Parts

printed with carbon fiber filaments also tend to have enhanced abrasion resistance, making them suitable for applications that involve wear and friction.

### 3.1.3 Composite Filament

Carbon fiber PETG is a composite filament by combining PETG thermoplastic polymer with chopped carbon fibers. This combination offers the benefits of both materials, resulting in a filament with enhanced strength, stiffness, and heat resistance compared to traditional PETG filament. The accumulation of carbon fibers to PETG improves its mechanical properties, making printed parts stronger and more durable [7][8][9]. Similar to other carbon fiber-reinforced filaments, carbon fiber PETG retains its lightweight properties while offering increased strength and stiffness. This makes it ideal for applications where weight reduction is important, such as aerospace and automotive components. Carbon fiber PETG typically has higher heat resistance compared to standard PETG filaments. The presence of carbon fibers in the filament enhances the abrasion resistance of printed parts, making them suitable for applications that involve wear and friction. Carbon fiber PETG can be printed using standard FDM 3D printers equipped with a hardened nozzle, as carbon fibers could be abrasive. It might require slightly higher printing temperatures compared to standard PETG filaments. Like as other carbon fiber-reinforced filaments, carbon fiber PETG may require specialized post-processing techniques due to the occurrence of carbon fiber. Sanding and finishing may be more challenging, and suitable safety precautions must be taken when handling carbon fiber particles.

### 3.2 Extrusion Process

The process of extruding carbon fiber PETG filament on Well-zoom machine which was material preparation, extrusion, cooling, and spooling (Fig.2).



**Fig.2** Extruder Machine

#### 3.2.1. Raw Material Preparation

**PETG Polymer Pellets:** Ensure that the PETG pellets are systematically dried to eliminate any moisture content. A pre-drying temperature of around 80 to 100°C for approximately 4 to 6 hours is recommended to achieve humidity levels below 0.02%.

**Chopped Carbon Fibers:** The chopped carbon fibers must be high quality and uniform length. The carbon fiber lengths of around 3-6 mm are used, depending on the desired mechanical properties of the filament.

### **3.2.2 Mixing and Blending**

Using a suitable mixer to blend the PETG pellets with the chopped carbon fibers in the desired the ratio. The mixing process ensure uniform dispersion of the carbon fibers throughout the PETG matrix.

### **3.2.3 Extrusion**

**Barrel Temperature:** Heat the extruder barrel to the temperature of about 230-250°C to melt the PETG resin efficiently. This temperature range can vary depending on the specific characteristics of the PETG polymer used.**Screw Speed:** Adjust the screw speed to attain optimal mixing and homogenization of the PETG and carbon fiber blend. A screw speed of around 20 to 40 rpm is commonly maintained.**Die Temperature:** Preserve the die temperature at around 240 to 270°C to ensure proper shaping and extrusion of the filament.

### **3.2.4. Cooling and Sizing**

As the filament exits the die, it should pass through a cooling system to rapidly cool and solidify it. A water bath or air cooling system can be used for this purpose (Fig.. Control the cooling temperature to around 20-30°C to achieve rapid solidification without causing thermal stress or deformation in the filament. The filament should be sized to the desired diameter using a sizing mechanism. Carbon fiber PETG filament in diameters 1.75 mm

### **3.2.5. Spooling**

Wind the cooled and sized filament onto spools using a spooling machine. The diameter of the spool should be selected based on the intended use and storage requirements of the filament. A spool diameter of around 200-300 mm is commonly used for standard-sized filament spools. Ensure that the filament is wound evenly onto the spool to prevent tangling or jamming during 3D printing.

### **3.2.6 Quality Control**

Perform regular quality control checks throughout the extrusion process to monitor filament diameter, tensile strength, carbon fiber dispersion, and other relevant parameters. Adjust process parameters as needed to maintain consistency and quality in the final filament product.

## **3.3 Printing Parameters**

This research considered the following printing parameters:

### **3.3.1 Infill Density**

Infill density, determining the internal structure of the printed object, significantly impacts its strength and weight. The research evaluated different infill densities (60%, 80%, 100%) to assess their influence on the mechanical properties of the printed specimens.

### **3.3.2 Printing Speed**

Printing speed affects the rate of material deposition and the cooling time between layers, thereby influencing the adhesion and strength of printed parts. Various printing speeds (40 mm/s, 60 mm/s, 80 mm/s) were examined to determine their effects on the mechanical performance of the printed samples.

### 3.3.3 Layer Height

Layer height, representing the thickness of each printed layer, was varied to study its impact on surface finish and mechanical properties. Different layer heights (0.18 mm, 0.24 mm, 0.30 mm) were investigated to understand their implications on the printed components.

**Table.1** Input parameters in 3D printing

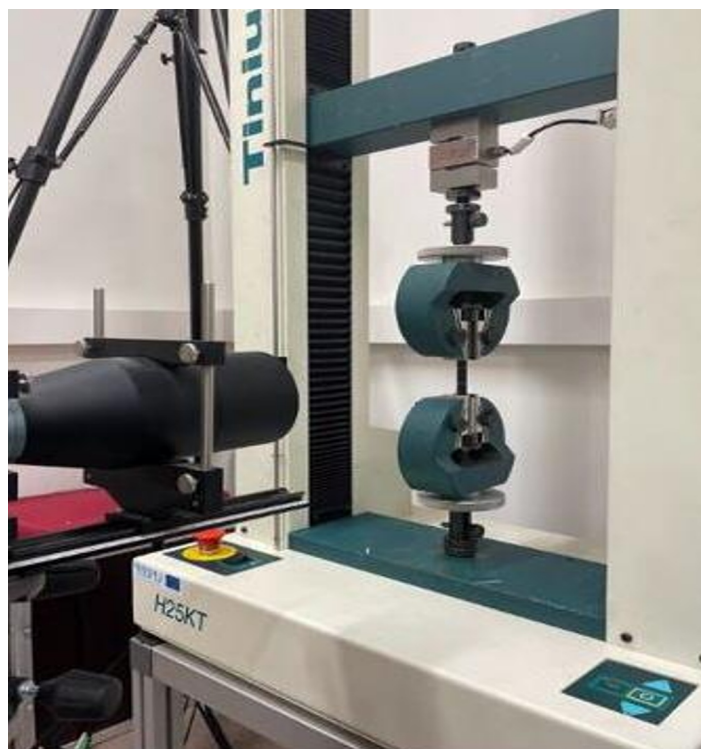
S.No / Parameters	Infill density	Print speed	Layer height
1	60	40	0.18
2	60	60	0.24
3	60	80	0.30
4	80	40	0.24
5	80	60	0.30
6	80	80	0.18
7	100	40	0.30
8	100	60	0.18
9	100	80	0.24

### 3.4 Design of Experiments (DOE)

To systematically explore the effects of printing parameters on the mechanical properties of Carbon fiber-reinforced PETG, a Design of Experiments (DOE) approach was adopted [10][11][12]. The DOE considered factors such as infill density, printing speed, and layer height, each varied at multiple levels to capture a broad range of conditions and interactions in Table.1. This facilitated the optimization of printing parameters to achieve the desired mechanical performance in 3D-printed parts.

## 4. Mechanical Characterization

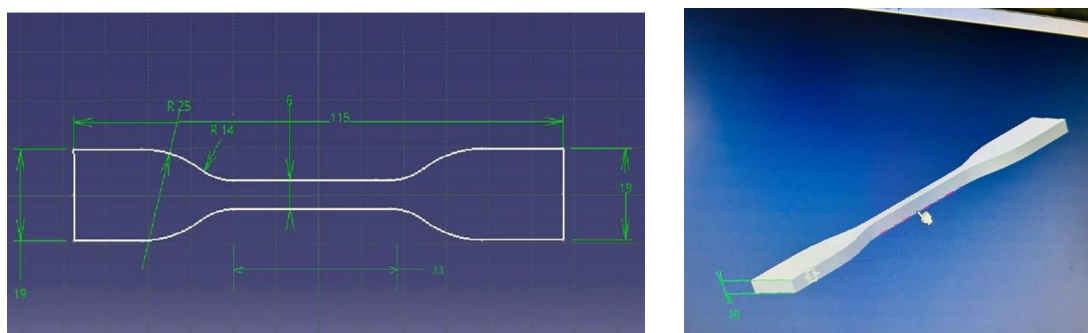
### 4.1 Tensile Testing



**Fig.3** Tensile testing Machine

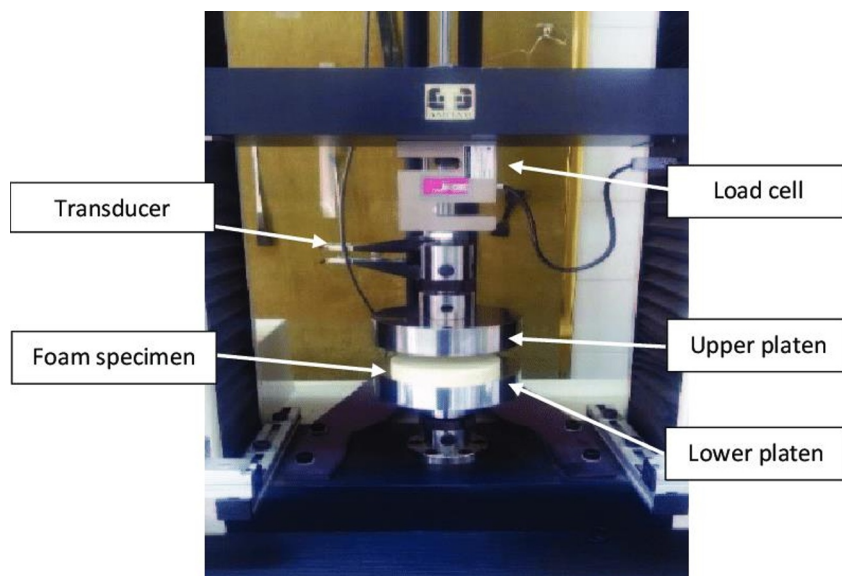
Tensile testing was conducted to evaluate the mechanical properties of the Carbon fiber-reinforced PETG specimens under tensile loading conditions (Fig.3). ASTM D638 standard procedures were followed using a universal testing machine in Fig.4. The specimens, designed using CAD software and 3D printed with varying orientations to assess anisotropic behavior, were subjected to axial loading until failure.

The addition of carbon fibers led to a significant increase in tensile strength and modulus compared to neat PETG. However, variations in mechanical properties were observed depending on the fiber orientation due to the anisotropic nature of Fused Deposition Modeling (FDM) printing.



**Fig.4** Dimensions of Tensile Specimens

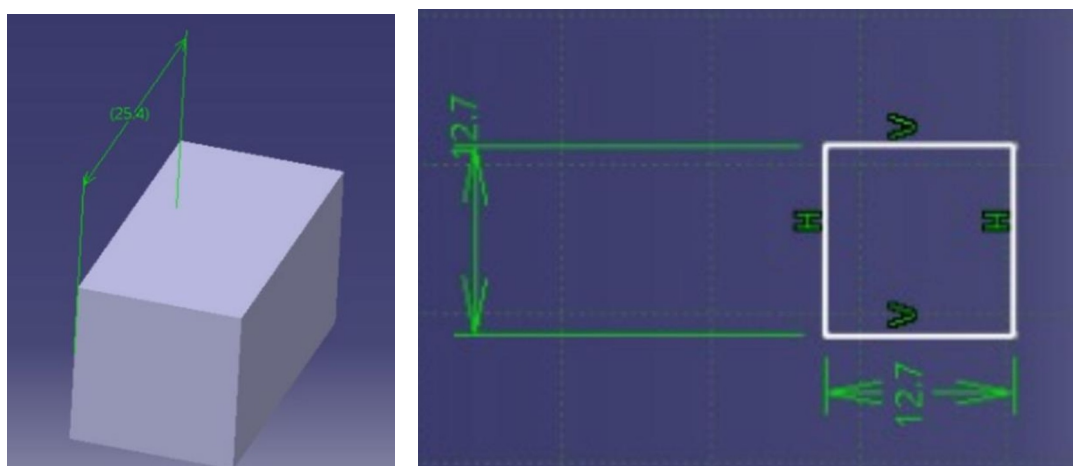
## 4.2 Compression Testing



**Fig.5** Compression testing Machine

Compression testing was performed to measure the compressive strength of the Carbon Fiber Reinforced PETG specimens (Fig.5). ASTM D695 standards were adhered to, and specimens were overloaded in the axial direction until failure using a compression testing machine (Fig.6). The maximum stress sustained by the specimen under compressive loading before failure.

The results designated that the addition of carbon fibers improved the compressive strength of the PETG material. These findings contribute to a comprehensive understanding of the mechanical behavior of Carbon fiber-reinforced PETG, thus informing its potential applications in various engineering fields, mostly in additive manufacturing.

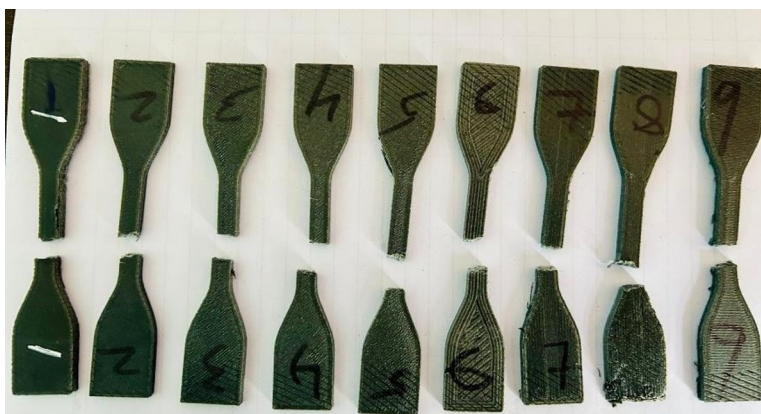


**Fig.6** Dimensions of Compressive Specimens

#### 4. Results and Discussion

The tensile test results exposed the mechanical performance of the Carbon fiber-reinforced PETG specimens under the axial loading (Fig.7 and Fig.8). The maximum tensile strength achieved was 38.51 MPa (Table.2), representing a significant development over neat PETG. This enhancement can be credited to the addition of carbon fibers, which provided reinforcement and increase the material's resistance to tensile force.

However, variations in mechanical properties were observed depending on the orientation of the carbon fibers within the printed specimens.



**Fig.7** Carbon fiber-reinforced PETG Tested Tensile specimens (ASTM D638)



**Fig.8** PETG Tested Tensile specimens (ASTM D638)

**Table.2** Results for tensile strength

S.No	Sample details	Results	
		Carbon fiber PETG(MPa)	PETG(MPa)
1	Sample-1	29.26	13.71
2	Sample-2	21.58	22.95
3	Sample-3	28.17	24.65
4	Sample-4	24.28	32.75
5	Sample-5	22.39	30.27
6	Sample-6	32.83	24.10
7	Sample-7	38.51	27.92
8	Sample-8	36.20	37.09
9	Sample-9	19.42	29.01



**Fig.9** Carbon fiber-reinforced PETG Tested Compressive specimens (ASTM D695)

Compression testing was conducted to measure the compressive strength of the Carbon fiber-reinforced PETG specimens (Fig.9 and Fig.10). The supreme compressive strength achieved was 44.87 MPa (Table.3), representing an improvement over neat PETG. This augmentation in compressive strength can be attributed to the reinforcing effect of carbon fibers within the polymer matrix. The compression test results indicated that the Carbon fiber-reinforced PETG material is capable of withstanding high compressive loads, making it suitable for applications requiring structural integrity and stability. These findings highlight the potential of Carbon fiber-reinforced PETG for various engineering applications, particularly in additive manufacturing, where high-strength materials are required.



**Fig. 10** PETG Tested Compressive specimens (ASTM D695)

**Table.3** Results for Compressive strength

S.No	Sample details	Results	
		Carbon fiber PETG(MPa)	PETG(MPa)
1	Sample-1	16.62	33.46

2	Sample-2	9.56	28.56
3	Sample-3	17.36	26.65
4	Sample-4	29.15	43.20
5	Sample-5	5.75	38.41
6	Sample-6	23.44	39.50
7	Sample-7	31.97	51.09
8	Sample-8	44.87	52.29
9	Sample-9	32.79	49.82

## 5. Conclusion

Based on the investigation conducted, it was observed that Carbon Fiber Reinforced PETG exhibited higher tensile strength compared to normal PETG. The highest tensile strength recorded for Carbon Fiber PETG was 38.51 MPa, attained in sample 7 by including an infill density of 100%, a layer height of 0.30mm, and a printing speed of 40mm/s. These parameters were found to optimize the mechanical properties of the filament, resulting in enhanced tensile strength. Conversely, in the case of compression strength, normal PETG demonstrated higher performance compared to Carbon Fiber PETG. The highest compression strength recorded for normal PETG was 52.29 MPa, observed in sample 8 by including an infill density of 100%, a layer height of 0.18mm, and a printing speed of 60mm/s. These parameters were found to optimize the compression properties of the filament, resulting in superior performance compared to Carbon Fiber PETG. Overall, these findings provide valuable insights into the optimization of printing parameters and material selection for achieving desired mechanical properties in FDM filament production.

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