# A Review on Fabrication and Printing of Carbon Fiber-Reinforced Composite Filaments using FDM Process

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**Abstract:** This review aims to provide a comprehensive overview of the fabrication and printing of Carbon Fiber-Reinforced composite filaments using the FDM process. Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF) is an Additive Manufacturing technology that uses the idea of melting the material and depositing it layer by layer. The filament for this is usually prepared by mixing the metal powder in a polymer. The material extrusion method is the preferred way to fabricate the 3D printed filament. In this article, the main processes behind various base polymers and combinations like PLA, ABS and PETG as base polymers and Carbon Fiber-Reinforced PLA, ABS and PETG as fillers have been discussed and various Mechanical Tests are also done by the 3D printed parts like Tensile, Compression, Hardness and Impact Test. It is concluded that the importance of Carbon Fiber composites in various industries, such as aerospace, automotive and consumer goods etc… the need for innovative manufacturing techniques like FDM.

Keywords: Additive Manufacturing, Fused Deposition Modelling, Carbon Fiber, Metal Polymer Composites (PLA, ABS, PETG).

## 1. INTRODUCTION

Additive Manufacturing, also known as 3D printing is the process of creating three-dimensional objects by adding successive layers of material. This is the opposite of subtractive manufacturing, which involves removing material from a solid block or sheet to create the desired shape. Unlike traditional manufacturing methods that rely on subtractive processes, such as cutting and drilling, additive manufacturing builds up parts by adding material where it is needed, enabling designers and engineers to create parts with intricate geometries and features that were once impossible to achieve. The process of Additive Manufacturing involves several steps, starting with the creation of a 3D model using computer-aided design (CAD) software. Once the design is complete, the 3D model is exported into the STL file and the STL file will be loaded into the Cura software to analysis and convert the STL file into the G-CODE file, then the G-CODE will be loaded into the 3D printing machine, which then begins to build the part layer by layer. The machine uses various materials, such as plastics, metals, ceramics, and composites, and can employ several techniques, including powder bed fusion, material extrusion, and vat photopolymerization, to create the desired part.

Additive Manufacturing also has the potential to significantly reduce waste and improve sustainability in manufacturing. Because parts are built up layer by layer, only the required amount of material is used, reducing the amount of waste produced during the manufacturing process. Additionally, additive manufacturing can help reduce the carbon footprint of manufacturing by enabling parts to be produced closer to where they are needed, reducing transportation costs and emissions.

This review explores the innovative techniques and advancements in the fabrication and printing of Carbon Fiber-reinforced composite filaments using FDM technology. Carbon Fiber-reinforced composites offer superior strength-to-weight ratios, making them ideal candidates for applications in aerospace, automotive, and various other industries. In this comprehensive review, we delve into the materials, manufacturing methods, properties, challenges, and emerging trends in this dynamic field. Understanding the intricacies of this technology is crucial for unlocking its full potential in creating lightweight and high-performance parts through additive manufacturing.

## 2. OBJECTIVES

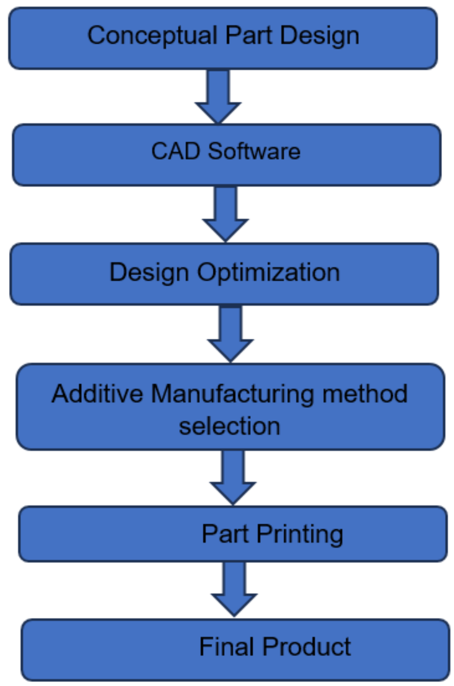
i. The main objective is to investigate the effects of different parameters on the mechanical properties of carbon fiber reinforced composite filament printed parts such as the printing temperature, printing speed, and fiber loading percentage.

ii. To fabricate different types of specimens like Tensile, hardness, compression, impact tests using different composite filaments (PLA, ABS, PETG as base filaments and carbon fiber reinforced PLA, CF ABS, CF PETG as reinforced composite filaments are used).

iii. To develop a machine learning model to predict the mechanical properties of carbon fiber reinforced composite filament printed parts from the printing parameters.

iv. To optimize the printing parameters for carbon fiber reinforced composite filament printed parts to achieve the desired mechanical properties.

**PROCESS FLOW OF ADDITIVE MANUFACTURIING**




## 3. LITERATURE REVIEW

Carbon fiber-reinforced composites have long been a staple in industries demanding high performance materials, such as aerospace and automotive manufacturing, due to their outstanding mechanical properties, corrosion resistance, and low weight. However, traditional manufacturing processes for carbon composites, such as layup and curing, are often result in material waste. FDM 3D printing offers an alternative solution, allowing for the creation of complex shapes and components with reduced material wastage. In this context, the extrusion of carbon fiber-reinforced filaments has emerged as a promising method to integrate the advantages of both carbon composites and 3D printing technology. Previous research in this field has focused on optimizing the composite filament's formulation, including the choice of carbon fiber type, matrix material, and their respective ratios. Additionally, studies have explored the influence of various process parameters during printing, such as nozzle temperature, printing speed, and layer thickness, on the mechanical properties and print quality of carbon fiber-reinforced parts.

**FILAMENT PREPARATION**

To completely rule out the risk of product deformation during printing due to inadequate filament quality, the components must be mixed properly. Both small batches and continuous mixing can be done. Screw extruders work well in the second scenario to improve homogeneity. The next step is to combine the metal powder with the binder system before feeding it into the extruder. In several texts, the filament production process is explained in a variety of ways. But the major goal is to provide the finished filament the proper amount of toughness, roundness, strength, and stiffness. Low strength and stiffness will cause the filament to break, whereas high viscosity, stiffness, and inadequate roundness will make it difficult to feed the filament. As a result, it's crucial to choose the proper extruder operating modes, production temperature settings, and shape control procedures while creating filament. The finalized filament is wound onto spools in the last step, which are then put right into a 3D printer to produce the object.

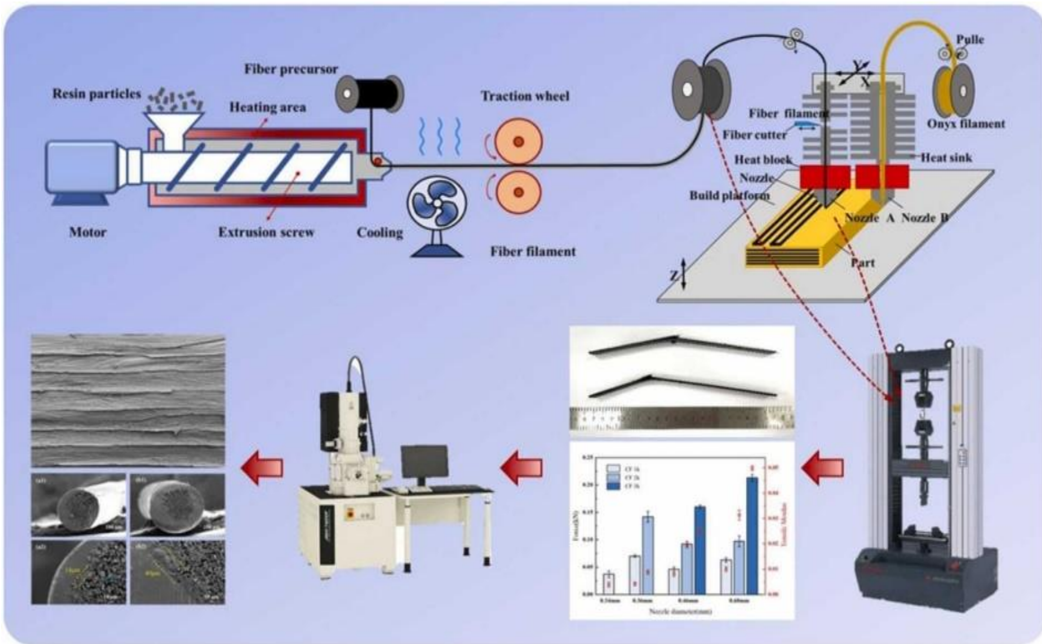



**Figure 1:** Preparation of composite filament

### CARBON FIBER-REINFORCED COMPOSITE FILAMENTS

The Carbon Fiber-Reinforced composite filaments are made in a similar process as discussed above. Metal- Fused Filament Fabrication (MFFF) is a method for producing metals additively that relies on highly filled metal powder-polymer filaments. There are several phases involved in getting Carbon Fiber-reinforced composite filaments ready for 3D printing. First and foremost, it's important to choose the best carbon fibers and matrix materials for the job, guided by the intended use and desirable mechanical properties.

To improve their adhesion to the matrix material, the carbon fibers may need to have their surfaces treated. Following the selection of the components, a homogenous composite formulation is produced by adding the components in precise ratios and thoroughly mixing them. The mixture is then heated and pressed through an extruder to create continuous filaments that are homogeneous in diameter and composition. This process is known as melt extrusion. The filaments are sized, spooled for storage, and cooled after extrusion.

The filaments are carefully placed onto the printer and set with the proper printing parameters, such as nozzle temperature and print speed, when they are prepared for 3D printing. To create the finished 3D item during printing, the material is deposited layer by layer. The object's look and attributes can be further improved by post-processing procedures to guarantee that they meet the requirements for the usage for which they are intended.

### 4. METHODOLOGY

A systematic process was used to conducting a review on the fabrication and printing of carbon fiber-reinforced composite filaments using the FDM process.

### 3D CAD DESIGN

Initially a selection of 3D CAD models that represent different complexities and geometries of objects to be designed using 3D CAD software (IRONCAD). In this review we are designed the 3d specimens like tensile test, compression test, hardness test and impact test that are designed with the astm E-8 standards.

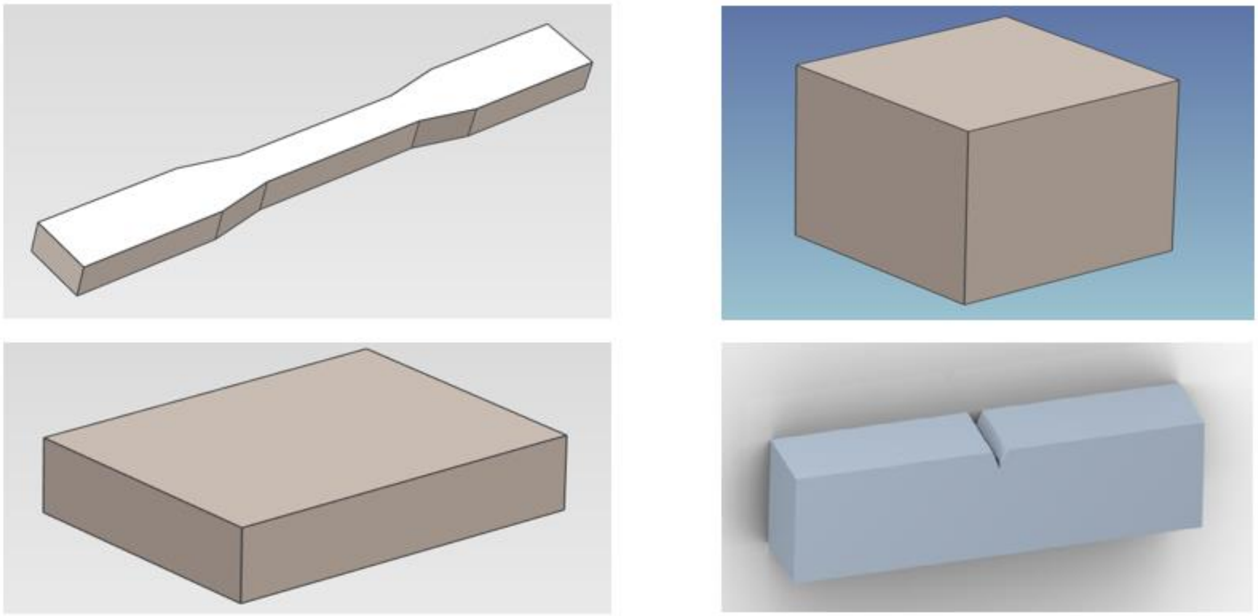


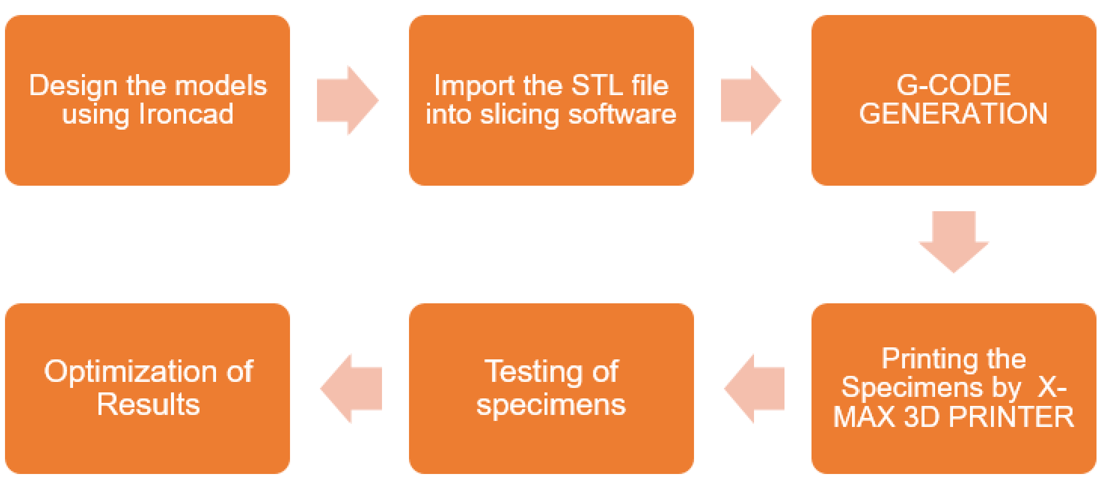
**Figure 2:** Design specimens in Ironcad

### CURA SOFTWARE ANALYSIS

The CAD models are imported into Cura Software and a thorough analysis is conducted to evaluate the software's functionality in terms of slicing, support generation, and toolpath optimization. The software's compatibility with carbon fiber-reinforced filaments, including material settings and print profiles, is assessed.

#### i. INFILL PERCENTAGE

object and various infill percentages serve different purposes. In the we use 80% infill are chosen for balances strength and efficiency, making it suitable for general purpose prints like brackets In 3D printing infill percentage determines the amount of internal structure within a printed and functional parts. When higher structural integrity is required and providing greater strength for load-bearing components or parts under mechanical stress. The choice of infill percentage depends on the specific application and the desired balance between strength, weight, and resource efficiency in 3D-printed objects.




#### ii. INFILL PATTERN

The internal structure of an object generated by Cura software is greatly influenced by the infill patterns used. As implied by its name, the "Triangle" infill pattern builds a lattice of triangular structures inside the item. While preserving resources and speeding up print time, this pattern provides strong structural support. It is frequently employed for lightweight, low-load components.

The "Grid" infill pattern, on the other hand, creates a network of intersecting horizontal and vertical lines, resulting in a solid interior structure. It has exceptional strength and stability, making it perfect for parts that need to be long-lasting and load-bearing.

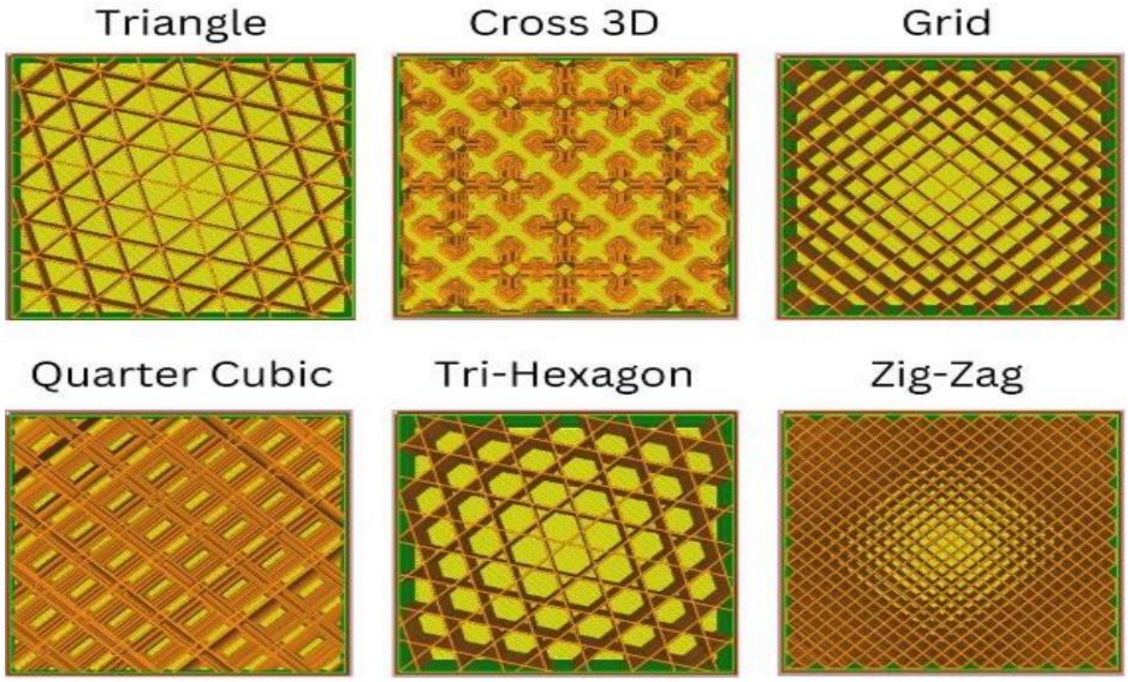



**Figure 3: Infill patterns printed in the specimens**

Based on their unique requirements and preferences, users inside Cura can choose between various infill schemes. Options for customizable infill density enable fine-tuning of the material application.

### iii. G-CODE GENERATION

The most important step in the workflow for 3D printing is the production of G-code. Cura acts as a slicer software that converts 3D models into codes that direct the motions and extrusion procedures of the 3D printer. To begin this complex procedure, a 3D model must be loaded into Cura. From there, users can customize various print parameters to meet their unique needs.

Here's some Sample G-CODE of Specimen

**Starting code:**

```
;FLAVOR:Marlin
;TIME:4037
;Filament used: 11.9433m
;Layer height: 0.4
;MINX:71.8
;MINY:113.72
;MINZ:0.3
;MAXX:278.2
;MAXY:140.12
;MAXZ:9.9
;Generated with Cura_SteamEngine 4.11.0
```

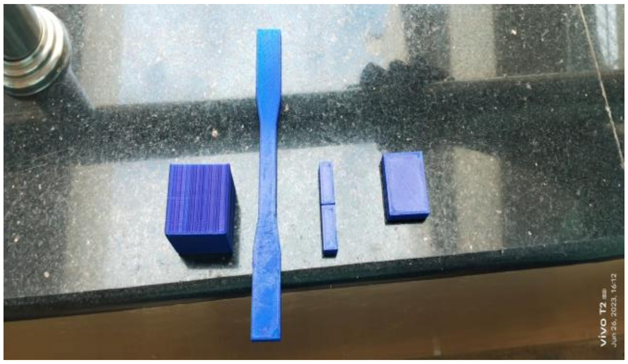
**Ending Code:**

```
;TIME_ELAPSED:4037.977846
G1 F1500 E3618.79688
M140 S0
M107
M104 S0
M140 S0
;Retract the filament
G92 E1
G1 E-1 F300
G28 X0 Y0
M84
M82 ;absolute extrusion mode
M104 S0
;End of G-code
```

Users can adjust settings including layer height, print speed, infill density, support structures, and print temperature using Cura's user-friendly interface. The final outcome, strength, and beauty of the printed product are directly impacted by these settings. Additionally, users can choose the right parameters for the particular filament type being used, whether it is PLA, ABS, PETG, or exotic materials like carbon fiber-reinforced filaments, thanks to Cura's rich material profiles.

**PRINTING**

A 3D printer printing process includes building material layers on top of one another to produce an actual object from a digital model. Here are some fundamental actions to take. Creating a 3D model of the product you wish to print is the first step. A model can be produced with 3D modelling software or downloaded from a collection of 3D models. Getting the model ready for printing After creating the 3D model, you must get it ready for printing. This involves "slicing" the model into tiny layers in order to produce the instructions the 3D printer will need to construct the thing.



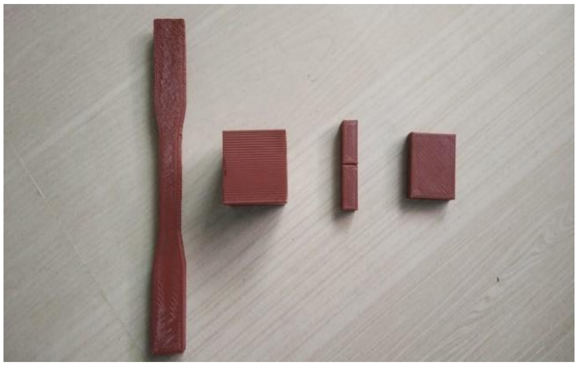



**Figure 4:** 3D PRINTINTED Specimens on X-MAX 3D Printer

The 3D printer needs to be set up next. In order to do this, the proper print settings must be chosen, including the layer height, print speed, and material type. Additionally, make sure the build platform is tidy and the printer is level. Load the content The kind of 3D printer you use will determine what you require to fill the printer with the proper substance, such as resin or plastic filament.

## 5. RESULTS AND DISCUSSIONS

Identifying the relationship between the fluctuation of various characteristics and the variation of various process parameters is important. Only after that can we decide on the ideal parameters for a given application's successful object printing. As was already said, the preparation of the filament, printing, and post-processing are the three primary phases in this procedure. Each stage requires the definition of a number of parameters. To get a filament with a uniform diameter, free of flaws, and with a homogeneous composition, for instance, we need to determine the best temperatures for each of the four heaters when using a single screw extruder.

When it comes to printing, a number of process variables, including build orientation, infill %, layer thickness, layer height, federate, etc., will have an impact on one or more mechanical properties.

For low-cost general purpose 3D printers with hardened steel nozzles, short CF reinforced PLA, PETG, ABS, etc. filaments are utilized as feedstock. Since the 3DP procedure for these materials is comparable to that for non-reinforced polymers, this review doesn't go into greater detail. However, two distinct 3DP procedures for continuous fiber reinforced composites are shown here: in-nozzle impregnation and continuous fiber fabrication.

## 6. CONCLUSION

It seems to be clear that the current study Additive Manufacturing based on fused deposition modelling (FDM) is used to create carbon-based polymer nanocomposite materials. The following are the main conclusions:

When compared to carbon finer reinforced specimens, the PLA has the lowest average tensile results. The study's tensile results show that when CF is added, the yield strength, ultimate tensile strength, and percent elongation all rise by about 37.38% when compared to PLA. The composites with printed carbon fiber demonstrated improved flexural properties in comparison to samples with unreinforced PLA. The flexural strength increased to 66.24% after carbon fiber was added, with a specimen reinforced with 20% carbon fiber yielding the best results.

Therefore, a model's strength is increased by using a larger infill density and a lower layer height. The model with the highest infill density and printed in the Y build orientation has the best tensile strength, followed by the X build orientation and then the Z build orientation, according to a comparison of the model's strength and infill density. The model with the least layer thickness has the highest strength when printed in the Y build orientation, according to our comparison of the model's layer thickness and build orientation. The strength of X&Z orientations is relatively lower.

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