Mechanical Testing of 3D-Printed, CereMat Resin-Based Carbon Fiber Composites

Advait Chordia[1], Asim Shahzad[2]

I. Abstract

This paper aims to investigate the mechanical properties of additively manufactured (AM) conti lnuous fiber-reinforced composites (CFRC) created using Continuous Fiber 3D Printing (CF3D®) technology, with CereMat resin as the matrix material. CF3D® technology involves in situ impregnation of continuous dry fiber tows with a low-viscosity polymer resin at once before deposition. This allows for precise fiber placement and the creation of complex shapes with fewer design restrictions, overcoming traditional manufacturability limitations.[3] The primary aim of this study is to experimentally determine the tensile and shear strengths of CF3D®-printed composite coupons, following standardized test procedures, including ASTM D3039 for tensile properties and ASTM D3518 for shear properties. Test coupons will be additively printed via CF3D® process, cut to specified dimensions through waterjet machining, and then subjected to mechanical testing. These tests will offer valuable insights into the structural performance of AM composites, specifically in CereMat resin, and will potentially enhance industry adoption of advanced additive manufacturing methods.

II. Introduction

Composite materials are important to modern high-performance applications—especially in fields like aerospace and automotive—due to their exceptional strength-to-weight ratios, durability, and resistance to corrosion. Currently, traditional manufacturing techniques, such as automated fiber placement and filament winding are used to produce high-quality composites. However, implementation of these methods is often limited by design complexity, lengthy production times, and high costs. In contrast, additive manufacturing (AM) offers an avenue for

[1] AE 298 student, Undergraduate student at the University of Illinois Urbana-Champaign
[2] Graduate Student/Menor at the University of Illinois Urbana-Champaign
[3] "CF3D®."

rapid prototyping and the fabrication of intricate geometries that were previously unattainable with conventional methods.[4]

The focus of this paper is to determine the mechanical properties of AM Continuous Fiber 3D (CF3D®) printed composites. It distinguishes itself by in situ impregnating continuous dry fiber tows with low-viscosity resins immediately before deposition. This process provides precise fiber placement of carbon fiber tows and minimizes manufacturing defects typically associated with pre-impregnated filament processes[5]. Early investigations into products developed through CF3D® printing have demonstrated mechanical properties at par with those of conventionally manufactured counterparts.

Despite these promising initial developments, comprehensive data on CF3D® printed composites, particularly those manufactured with resin systems such as CereMat, are limited. This paper is motivated by the need to evaluate mechanical behavior of these carbon fiber composites. Specifically, this study focuses on determining tensile and shear properties using standardized test methods—ASTM D3039 for tensile properties[6] and ASTM D3518 for in-plane shear properties[7] —to ensure the reliability and comparability of the obtained data.

The research method begins with an extensive literature review covering composite manufacturing, mechanics of fiber-reinforced materials, and the relevant ASTM standards that provide testing outlines. Test coupon geometries are then designed using CAD and exported as STEP files, ensuring precise control over specimen dimensions. These specimens are manufactured via the CF3D® process, followed by curing, waterjet cutting, and mechanical testing using an Instron Universal Testing Machine.

By integrating insights from both established and emerging research, this study aims to contribute significantly to the understanding of additively manufactured composites. The findings are expected to facilitate further development of CF3D® technology and support its broader adoption in industrial applications, ultimately enabling more efficient production of high-performance composite structures.

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[4] Ngo et al., "Additive Manufacturing (3D Printing)."
[5] Baur et al., "Mechanical Properties of Additively Printed, UV Cured, Continuous Fiber Unidirectional Composites for Multifunctional Applications."
[6] "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials."
[7] "Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate."

III. Methodology

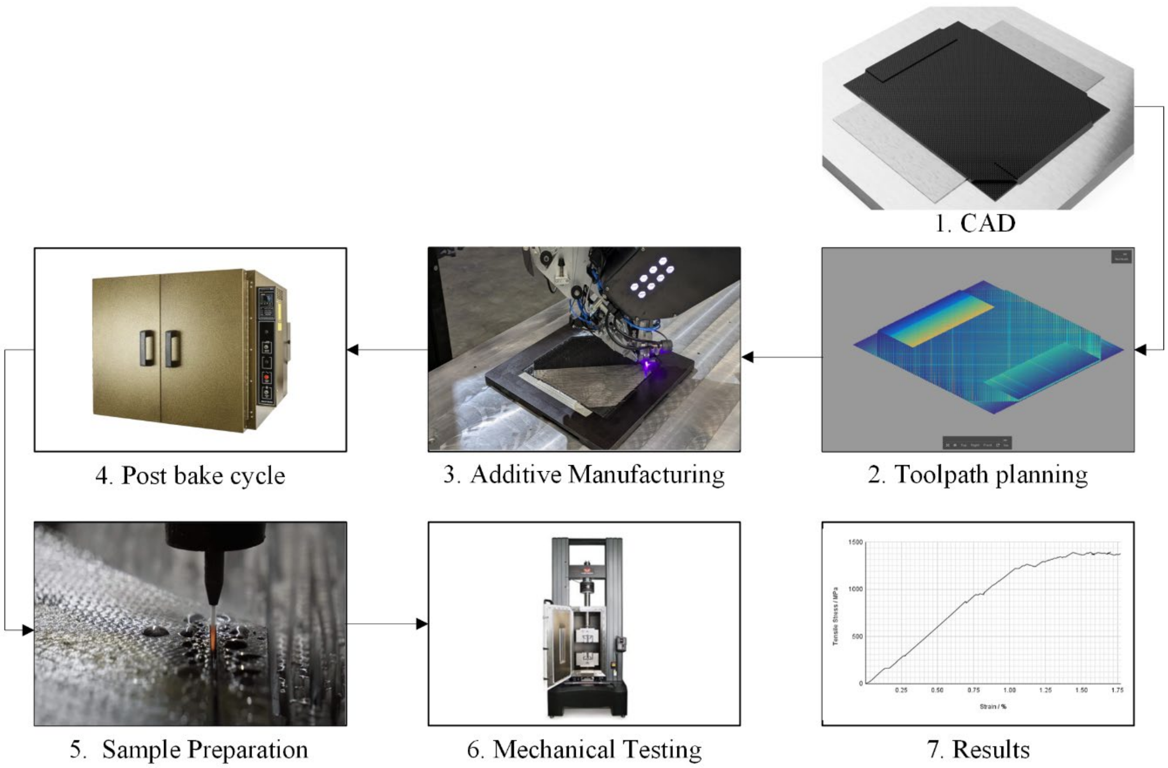

Figure 1: Methodology flowchart for CF3D® sample preparation[8] [9]

The methodology for this research is divided into multiple structured phases, beginning with a detailed review of ASTM standards D3039 & D3518 to understand the compliance requirements for mechanical testing of carbon fiber-reinforced (CFR) composites, specifically the longitudinal, transverse, and shear properties. Training sessions are provided on both CF3D® Studio, CF3D® printing technology (for sample fabrication) and the Instron Universal Testing Machine (UTM) (for evaluating mechanical properties).

Samples for mechanical tests are prepared per ASTM standards, involving printing with CF3D® technology, waterjet cutting for precise dimensions, surface finishing, tabbing, and labeling. Tensile and shear mechanical tests are conducted on these samples using the Instron

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[8] "Figure 3. Typical Compressive Stress-Strain Curve of a Carbon-Fiber..."
[9] Lab, "Quincy Lab."

UTM, which captures force-displacement and strain data. Results are analyzed by plotting load-displacement and stress-strain curves, as seen in Figure 3. These analyses are then interpreted to formulate conclusions, which will be incorporated into the final research paper and an accompanying poster presentation.

The CF3D® Studio software, essential for operating the CF3D® printer, is used to create the toolpath files for the printer itself. This process involved mapping and slicing the geometry of the component into individual layers, allowing for customizability of layer direction and orientation. This included the tabs and the coupons themselves. Subsequently, with the help of CF3D® Studio, the finalized stacking arrangement of these components is designed, producing a single, comprehensive toolpath file for printing.

The geometry of the test coupons is developed after considering the difficulties that come with additive printing. Unlike regular 3D printers that produce support structures/trees to hold up pieces that don't have a base, the CF3D® printer does not produce supports. As the tows are only partially cured, they can't hang in the air. To overcome this shortcoming of additive manufacturing, bevels are added along the long ends of the coupon. Coupon dimensions were specified per ASTM D3039 for tensile samples and ASTM D3518 for shear samples. Tensile samples measured 1 mm in thickness, 15 mm in width, and 150 mm in length, consisting of four layers of carbon fiber oriented unidirectionally. Shear samples were 3.6 mm thick, 25 mm wide, and 150 mm long, composed of 16 symmetrical ±45-degree layers about the center.

The reason for adding tabs (which are not a requirement for shear coupons) was to distribute the clamping forces produced by the Instron UTM across a larger surface area, and hence preventing localized stress concentrations, avoiding gripping damage and premature failure in compliance.[10]

The tabs for both samples were printed unidirectionally at a 0-degree angle, distinct from the ±45-degree ply orientation of the shear coupons. Due to the CF3D® printer's minimum tow length constraint of approximately 6 cm, rectangular coupons were impractical. For this reason, there was no work around for the excess material that had to be included along the width. The bottom tab was designed larger than the coupon, functioning as a platform for printing the coupon. In contrast, the top tab was indented, nesting precisely within the coupon's dimensions, ensuring material

[10] "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials."

efficiency by limiting usable areas to only essential regions for mechanical testing. This can be seen below in the exploded view of the print setup.

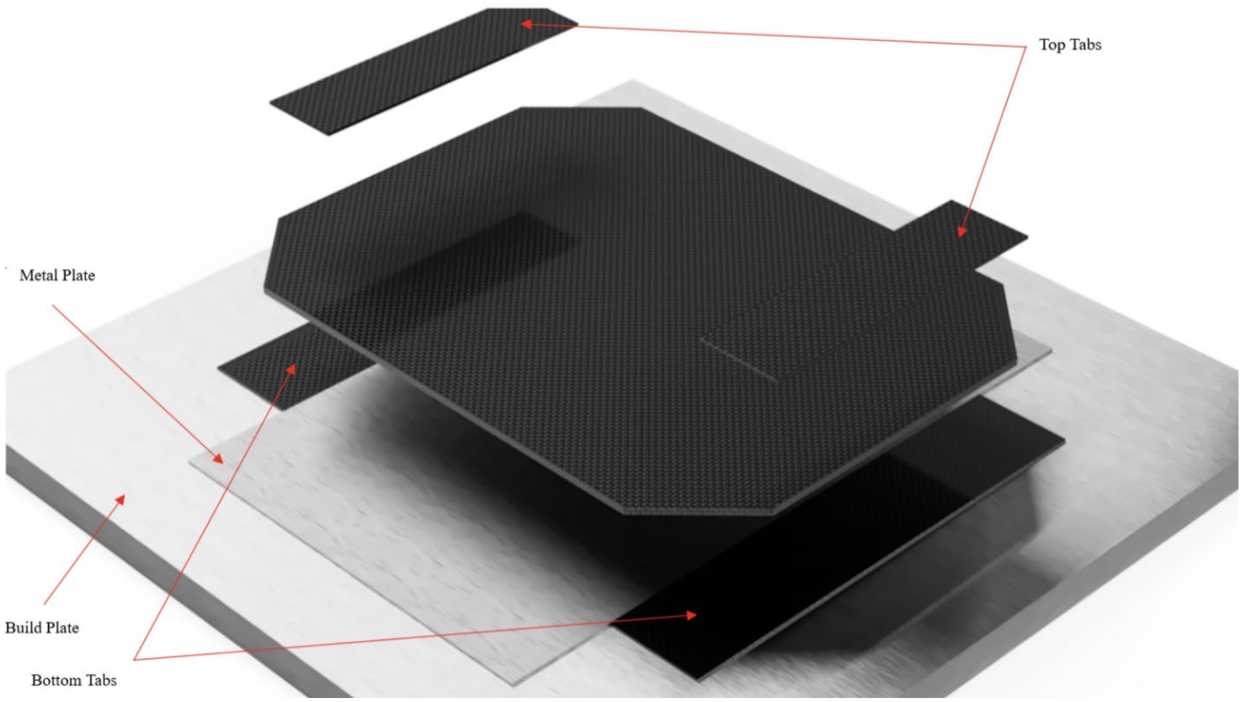

Figure 2: Exploded view of Shear Coupon samples CAD

As previously noted, the carbon fiber is only partially cured by the printer and requires subsequent heat treatment. The heat treatment procedure involves gradually heating the material from 25°C to 180°C at a rate of 3°C/min, holding it constant at 180°C for 4 hours, and then cooling it back down to room temperature at a controlled rate of -3°C/min. This is the required curing profile for CereMat resin.[11]

Upon completion of fabrication, tensile and shear mechanical tests were conducted using the Instron UTM, capturing detailed force-displacement and strain data. This data was subsequently analyzed through load-displacement and stress-strain curves to derive meaningful conclusions, which form the basis of the research outcomes presented in both the final research paper and accompanying poster presentation.

[11] "CereMat Data Sheet."

IV. **Results**

After the coupons were waterjet cut and subsequently dried to remove residual moisture, they were mechanically tested using an Instron Universal Testing Machine (UTM) in accordance with ASTM D3039 for tensile tests and ASTM D3518 for shear tests. An extensometer attached to each coupon recorded elongation and force applied during testing. Data collected were normalized, processed, and averaged across each sample group to yield representative mechanical properties. During the tests, individual carbon fiber tows occasionally ruptured, momentarily displacing the extensometer and generating artifacts in the data. These artifacts were identified and excluded to maintain accuracy.

The results of the mechanical tests are summarized in Table 1 below:

Table 1: Summary of Mechanical Test Results

Sample Type	**Ultimate Tensile Strength (MPa)**	**Strain at Failure (%)**
Tensile (0° Unidirectional)	1394.94	1.77
Shear (±45° Orientation)	66.59	6.38

Figure 3 below contains stress-strain curves generated using the processed data, illustrating the material behavior. Using the graph, the elastic and plastic regime for each sample can be clearly seen, as well as the point of failure. and clearly identifying regions of elastic deformation, ultimate strength, and failure point.

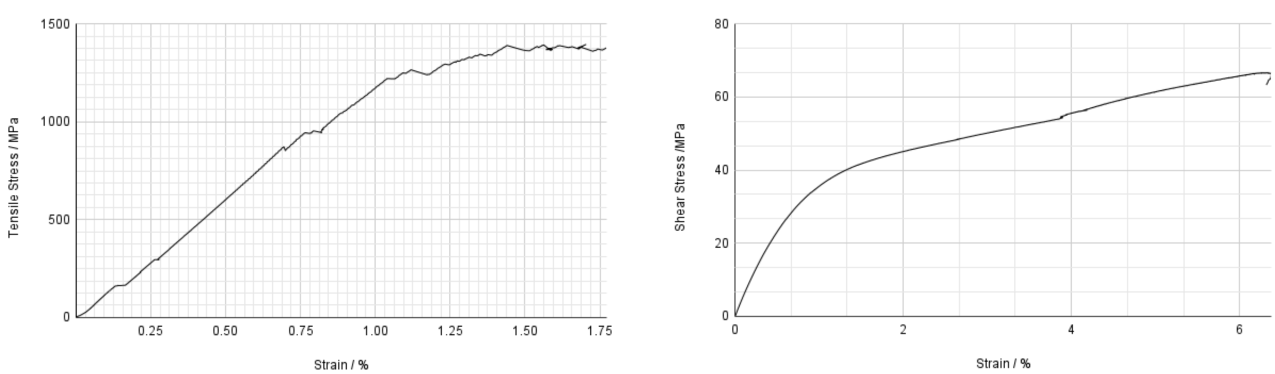

Figure 3 a & b: (a) Stress vs Strain of Tensile sample, (b) Stress vs Strain of Shear Sample

The tensile strength of the unidirectional CF3D® printed composite samples was determined to be 1394.94 MPa, closely aligning with literature values typically reported for continuous fiber-reinforced polymer composites, which range from approximately 1000–2000 MPa[12]. The measured shear strength of 66.59 MPa also falls within commonly reported ranges for ±45° carbon fiber laminates, generally around 60–100 MPa[13]. These results demonstrate that the CF3D® printed composites using CereMat exhibit mechanical properties comparable to those produced via conventional composite manufacturing methods, validating the potential of CF3D® technology for high-performance structural applications.

V. Conclusion

This study investigated the mechanical properties of continuous fiber-reinforced composites fabricated using CF3D® printing technology with CereMat resin. Tensile and shear tests conducted in accordance with ASTM D3039 and D3518 standards demonstrated that CF3D® printed composites exhibit robust mechanical performance, achieving an ultimate tensile strength of 1394.94 MPa and shear strength of 66.59 MPa. As expected, the results closely align with typical mechanical properties of conventionally manufactured composite materials, confirming the viability and potential of CF3D® technology for producing structurally reliable and high-performance composite components.

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[12] Baur et al., "Mechanical Properties of Additively Printed, UV Cured, Continuous Fiber Unidirectional Composites for Multifunctional Applications."
[13] *Materials Science And Engineering Callister*.

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