Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 3, 2435-2445
2025
Publisher: Learning Gate
DOI: 10.55214/25768484.v9i3.5817

Evaluation of bending property of 3D printed carbon fiber composite

Hind B. Ali[1*]
[1]Materials Engineering Department, University of Technology- Iraq; 130047@uotechnology.edu.iq (H.B.A.).

Abstract: Optimized printing configurations for additive manufacturing can produce complex geometries in polymers, ceramics, metals, and composites; hence, the process is often simply referred to as 3D printing. Thermoplastic materials, and within them, the most common ones applied through FDM extrusion-based 3D printing, are indeed the thermoplastic composites or the fiber-reinforced ones. It is used in general as it is easy to operate, change materials, cost-effective, and produces long and short fiber-reinforced products. Carbon fiber-reinforced polymer composites are commonly used in several industries due to their enhanced mechanical properties. Specifically, these composites have high specific stiffnesses and tensile strengths. However, access to composite materials in various forms is now limited by the production restrictions associated with different technologies. The primary purpose of carbon fiber-reinforced polymer is to augment the capabilities of polymer-based components. However, several different factors, including the manufacturing method, matrix material, fiber orientation, and length, affect the properties of composite materials. Our objective in this endeavor is to utilize FDM 3D printing to combine thermoplastic and carbon fiber to create a continuous composition of carbon fiber and thermoplastic (CFRC). The composite specimen that is added is submitted to a flexural test that follows the manufacturing process. The test of flexibility revealed delamination. This led to the research, analysis, and exploration of the interface between research. Ultimately, suggestions for additional research, enhancements to research, and recommendations were made.
Keywords: *3D printing, ABS filament, Bending property, Carbon-fiber reinforced polymer.*

1. Introduction

The mechanical properties of many materials can be enhanced by combining them, a procedure called composite materials. A composite material is typically composed of two parts: a dispersing phase and a matrix phase that is continuous. One may differentiate between three different types of composite materials. The first is structural composite, the second is fiber-reinforced composite, and the third is particle-reinforced composite [1]. Fiber-reinforced composite is more popular than the other two. Common materials with a fiber content of around 50-60% include aramid, carbon, and glass fiber with a polymeric matrix. Many factors, including the properties of the raw materials, the volume fraction of fibers, their length, and their orientation, have an effect on the mechanical properties of fiber-reinforced composites. Stiffness and strength increase with the length of the fiber [2]. The distribution of fibers and their orientation have a significant impact on the properties. Three varieties of fiber alignment—random, perpendicular, and parallel to the direction of loading—are typically altered by the manufacturing process. When contrasted to other fiber types, carbon fiber has beneficial properties including high strength, low weight, and a strong electrical and thermal conductivity [2-5]. Carbon fibers with a diameter of 5 to 10 micrometers and a carbon content of 90% or more are commonly incorporated into composite materials. In the manufacturing industry, 3D printing is typically used to refer to any of several techniques for creating three-dimensional objects by overlying a single 2Dimensional sheet on top of another. In general, it is the fixation or solidification of a liquid or powder

History: Received: 22 January 2025; Revised: 13 March 2025; Accepted: 17 March 2025; Published: 27 March 2025
* Correspondence: 130047@uotechnology.edu.iq

in each horizontal cross section of the object, necessitating a solid component; the process is analogous to the fused sheets of ink or toner within a printer, thus the term "printing" is applied to the process of creating a 3D printed object. The process is repeated multiple times as its vertical dimension increases. The practice of 3D printing is frequently employed to create new components, but it can also be employed to create finished products that are then marketed to consumers globally. Other than this, 3D-printed products include surgical implants for surgery, machine components, plastic figurines, and design models for molding. Large appliances like stoves and refrigerators may be able to accommodate 3D printing equipment. Fibre 3D printing is derived from the fused filament technique (FFF) that is currently popular. The procedure of employing the FFF technique typically involves heating a thermoplastic filament to soften it, then carefully extruding it onto the printing surface or previous layer in a raster pattern [6, 7]. Cooling of the thermoplastic ensues and in the end it hardens in place forming a bond with the interfacing substrate. The process is repeated for each layer until the part is completed. Composites are currently manufactured by the most traditionally practiced methodology, 'FFF spot-welding fiberglass or carbon fiber with thermoplastics. Apart from commonly stated applications within ABS El Moumen, et al. [1] and Love, et al. [8] and PA Aljaafari, et al. [5] and Yang, et al. [9] fibers can be intermixed with 3-D-printed polymers, too. More efficient fiber-routing products could be fabricated in FFF simply by feeding continuous fibers along traditional thermoplastic material into the extruder so that the fibers are impregnated in the filament's melted state or even stamping fiber layers –alternating with thermoplastic layers, into three-dimensional sculptures. Rule of mixtures is a theory that is supported by empirical research in literature. Filled thermoplastic materials tend to become brittle; however only then do their mechanical properties improve in certain aspects. For instance, Ning, et al. [10] found that a 10 wt% addition of carbon fiber to an ABS compound enhanced its tensile strength but reduced its elastic modulus, which had previously stood at 1.43 GPa with the same weight fraction of 10 wt%. A sudden dip in strength and elastic modulus might come from a sudden leap in material porosity, which is one of the most typical failings in FFF (fused filament fabrication) printed parts. Despite the omission of voids from insufficient layer bonding, the high level of porosity often appears as one of the problems with these failure-triggering defects in 3D printed laminated composites [3, 11]. However, Naranjo-Lozada et al. found that for continuous fiber-reinforced prints it was possible to obtain moduli up to 25 times those of chopped-fiber-reinforced nylon printing, and three times higher –around 2.97 times higher- than lone printed nylon's.

Modern methods can take anywhere from several hours to several days to build a model, it all depending on the strategy at play, and the size and complexity of the model. [12-15].

- Creating three-dimensional drawings
- This method is similar to the printing process of ink or toner, however, it employs a different method of achieving color.
- A mixture of liquid and solid materials is employed at every point in the horizontal cross section that contains solid material as desired.
- prototypes are incorporated into new part configurations.
- Complex components that require
- The ultimate product that is marketed.

Layered technology is based on the assumption that many layers of equal thickness can be combined to create a three-dimensional physical object called a "part". Every layer is contoured and overlaid onto the previous layer based on the relevant three-dimensional information gathering [16-21].

1. 3D Data: Every endeavor starts with a comprehensive 3D model that describes the portion of the object that we want to create.
2. File checking: Before beginning to produce the 3D data is beneficial.
3. The object's orientation in relation to the build platform - The object's properties might be profoundly affected by the way it is oriented with respect to the platform.

4. Nesting: The purpose of nestling is to maximize the number of components that can be printed in one job as much as possible. Typically, the slicer is employed directly, or it can be accomplished using third-party software.
5. Support structure generation: In order to create a particular item, specific 3D printing methods require the utilization of support structures. Third-party apps or supplementary services can be directly incorporated into the slicer.
6. Import to Slicer: A slicer that is typically associated with the 3D printer will cut your 3D model into virtual slices, which will then be used to create paths for theprinter's tools in order to prepare for printing.
7. Setting up print parameters - This stage typically involves establishing the print settings, including the material used, the thickness of the layer, and the mode of print.
8. Data transferred to aprinter - A computer's data is typically transmitted to a 3Dprinter viaLAN or Wi-Fi. When printing, theprinter attempts to locate the file in its internal storage. This facilitates the completion of the print job even when the computer is inactive.
9. 3D printing - It's possible to observe the procedure of printing on most printers via a network client or, at the most, the printer's screen.
10. Postprocessing: Depending on the type of 3D printing technology employed, the number of post-processing methods is different greatly. Postprocessing typically involves taking the printed parts out of theprinter, eliminating extra powder or resin, and, if necessary, cleaning the printed parts of any support structures by hand or in a warm water or chemical bath that dissolves the supports.
11. Extra processing and finalizing - This stage involves procedures that are optional, such as electroplating, painting, dyeing, and polishing.
12. Quality assessment: This step is not mandatory, but some apps may require it.

2. Materials and Methods

2.1. Carbon fiber composites Material

CFRP composites are powerful, lightweight materials that are employed to create many common objects. Carbon fiber composites and compounds, as well as fiber-reinforced compounds, are typically referred to as CFR. To summarise, this phrase is used to describe fiber-based composites and compounds, and shows that the "P" in CFRP is derived from the word plastic, rather than from the word polymer." [22-24]

2.2. Characteristics of CFRC

Carbon fiber-reinforced composites are distinguished by their unique composition, which includes fiberglass or aramid fibers as matrix materials. Among the beneficial properties of CFR composites are the following:

Lightweight: A typical composite made of 70% glass fibers and continuous glass fibers has a density of 0.06 Psi per kg because of the low weight of glass.

CFRP is composed of two different types of fibers. One variation is comprised of 30% polyester and 70% nylon [25]. Twenty percent nylon and sixty percent polyester make up the second type of fibre [26]. Other than being more powerful and stiffer per mass unit, the lighter carbon fiber composites also possess these properties. With fiberglass, this is the case, but with metals, this is even more true [27].

2.3. 3D printing Machine

Using a single version of the WINBO 3D PRINTER that employed a single nozzle, samples were created (figure 1). The Bowden extruder on this device has a closed cabinet that promotes consistent temperature control. The samples were printed in a small space with a temperature of 20 degrees Celsius and a humidity of 60%. The following variables were used to control the printing process with the WINBO 3D PRINTER:

1- One machine with a single nozzle
2- STL to Cura machine
3- Sample installment
4- constructed in a digital format
5- FDM type based on the CFC's material type.
6- machine test

Figure 1.
The 3D-printer used for the manufacture of the specimens.

SolidWorks CAD software was employed to create the models of the specimens that were investigated in this research. To acquire the Gcode necessary for printing the samples, the created model was transferred to Cura 5.1 slicer software (Ultimaker, USA) in STL format. Figure 2 depicts this configuration and the measurement data associated with it Albar, et al. [16] and Goh, et al. [19]. The sample was printed using a 3D printer called WINBO. Because of the printer's ease of use and simple design, it was popularized..

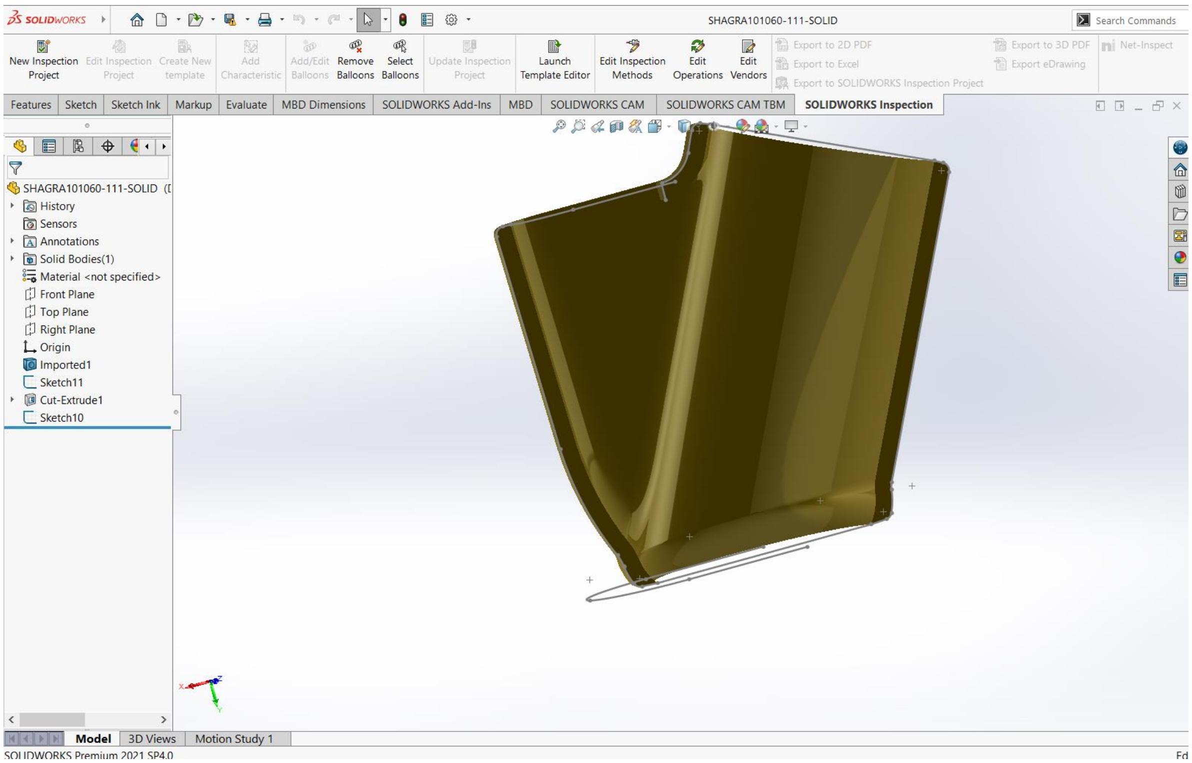

Figure 1.
Model 1 Tension sample - Software modeling.

Cura software g-code install for sample design, as shown in Figure 3.

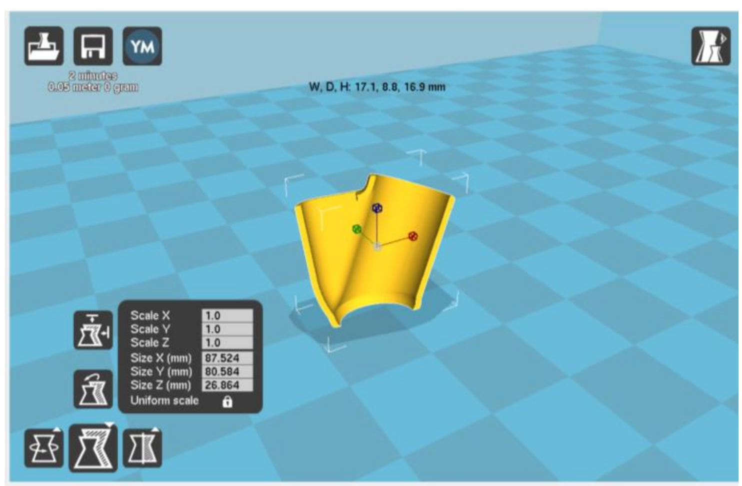

Figure 2.
Sample design for first attempt.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 3: 2435-2445, 2025
DOI: 10.55214/25768484.v9i3.5817

The initial layer thickness and minimal proportions of X = 17.1 mm, Y = 8.8 mm, and Z = 16.9 mm were planned to reduce the printing time from 40 to 2 minutes. Scale 0.1:1 mm. as shown in Figure 4.

Figure 3.
Sample after manufacturing.

Figure 5 shows the Second Attempt, with dimensions as follows: X = 169 mm, Y = 88 mm, and Z = 171 mm. The layer thickness is 0.2 mm. The time was increased to 3 hours because of supports created for an added 3 grammes over the total printed material weight of 18 grammes.

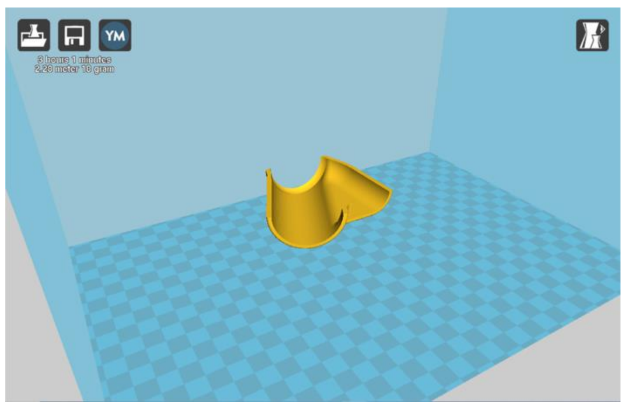

Figure 5.
Sample design for second attempt.

At the third try, dimensions are as follows: X = 169 mm, Y = 88 mm, Z = 171 mm as shown in figure 6. The layer thickness is 0.4 mm. The total weight of printed material increased to 10 grams with produced supporters, and the time was extended to 3 hours and 2 minutes.

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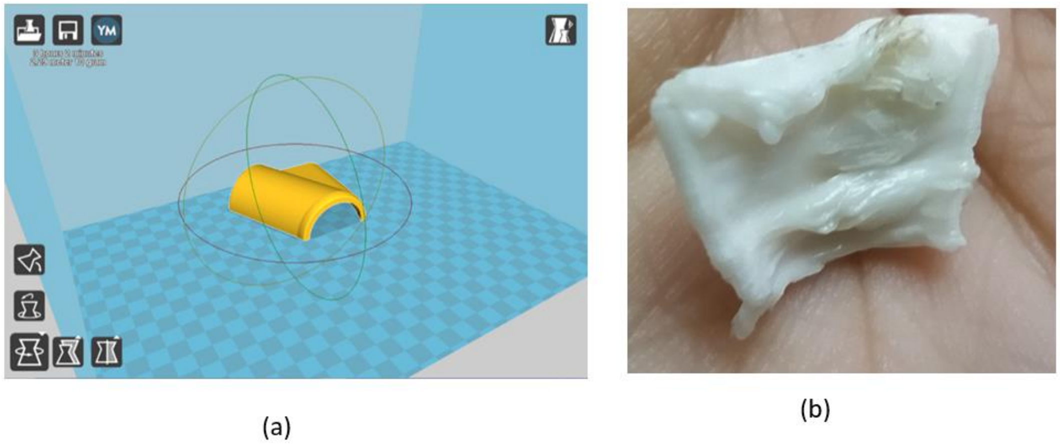

Figure 6.
(a) sample design for second attempt (b) sample after manufacturing.

2.4. Flexural Test

Flexural testing was adopted to verify the performance of the 3D printed CFRC specimens fabricated by FDM. Three specimens were fabricated for the test with different layer thicknesses i.e. (0.1, 0.2, 0.3 mm). The bending test was performed on H25KT universal testing machine of Tinius Olsen make which was three-point supported. This consisted of a loading nose at mid-span with two supports to a distance of 40 mm each from the loading nose. The rate of crosshead motion and span support length of the test were 1.35 mm/min and 51.2 mm respectively. The characteristic equations used in this case to obtain flexural strength and flexural modulus are as follows:

$$\sigma_f = \frac{3PL}{3bd^2} \quad (1)\ [28]$$

where, σf is the flexural stress, P is the load at a specific point on the load-deflection curve (N), L is the support span (mm), b is the width of the tested beam (mm) and d
is the depth of the tested beam (mm).

$$E_f = \frac{(\sigma_{f2} - \sigma_{f1})}{(\varepsilon_{f2} - \varepsilon_{f1})} \quad .(2)\ [28]$$

where, Ef is the modulus of elasticity, σf2 and σf1 are the stresses in the flexural direction at the pre-defined points on the load deflections curve, and εf2 and εf1 are the strains in the flexural direction at th e predetermined points on the load deflections curve.

Table 1.
3D Printing parameters on ABS-CF specimens.

Printing variables	**Values**
Nozzle diameter (mm)	0.4
Diameter of filament (mm)	2.85
Infill density (%)	20
Speed (mm/s)	50
Shell thickness (mm)	0.8
Extruder temperature (°C)	215 – 250 C
Bed temperature (°C)	60

3. Result and Discussion

The CFRC specimens were printed using the FDM 3D method. The matrix material was heated to a temperature of 220°C. The extrusion temperature was selected in consideration of the producer's suggested temperature as the starting point for selection. Throughout the printing process, the same initial values of extrusion width, infill density, and printing speed were maintained. The matrix filaments that passed through the extruder were heated to 220 degrees Celsius, this temperature was chosen to bond with the carbon fibers in the printing head. These fibers were then extruded and printed onto the platform that had been built.

This is why the significant distance is mostly 6KN/m, the bend factor reached its maximum at the first attempt. The tangent combined with the plate's high temperature led to the minimum amount of flexing on the second attempt. Because of the increased internal layer strength, as illustrated in figure 7, this was the most difficult line for the machine to attempt on the third attempt.

Small bed, small layers, linear filling, and low bed temperature are all attributes of the first attempt at printing.

It has a fine mesh as well as a small number of steps to iterate over to assess the stress in the entire printed object. It passes through all of the cross sections in a given material in a systematic manner. The base's area is too small to conduct a practical bend test.

The second attempt has a nondetailed CFRC design; issues with layers because of supporter removal; a linear slope; and high bed temperature. The structure was constructed in large quantities with a small mesh that had the purpose of determining the optimal qualities of bending regarding the formation of the unfilled bend under the experimental conditions.

The outlined attempts have demonstrated limited success in terms of material layer resolution because the material's melting temperature is around 220°C. Internal tension on the layers causes gaps between the profile and support.

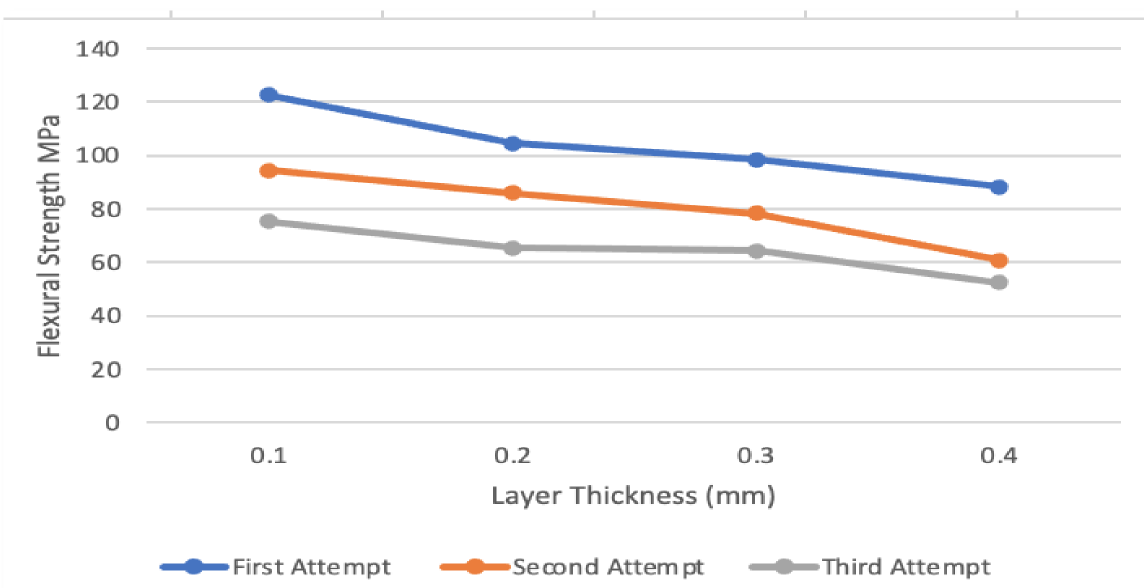

Figure 4.
Effect of layerthickness on felxural strength.

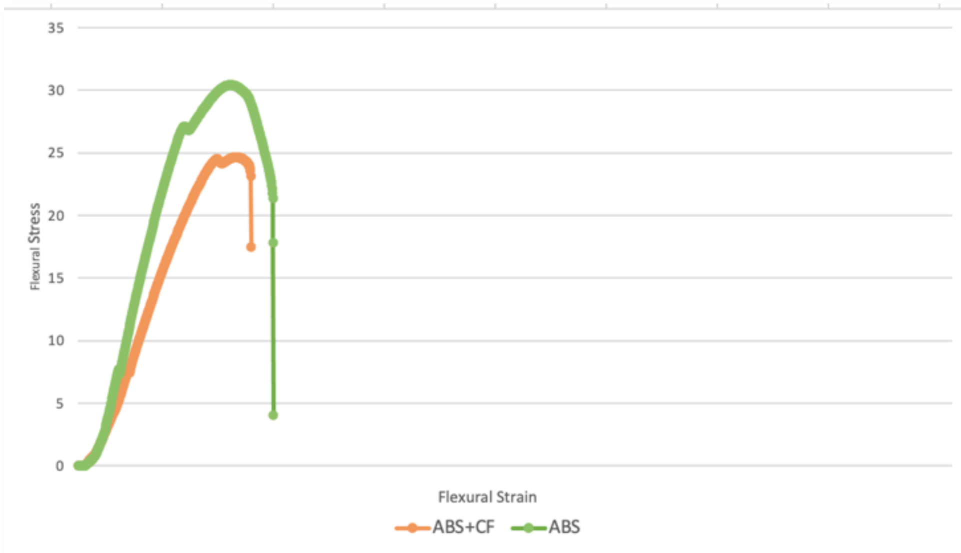

Figure 8.
Typical flexural stress-strain curve.

Figure (8) shows a typical stress strain graph and a 3 point bend configuration that is typically used in flexure. The CFRC sample's maximum tensile strength was 122.7 MPa, and its modulus of elasticity was 10.26 GPa, both of which are exhibited by the stress strain graph. By contrasting the flexural strength of the composite with that of pure ABS and CFRC fibers, the increases are 63.55% and 70.21%, respectively. The stretchiness of the composite is documented in Table 2.

Table 2.
Results of flexural properties measured.

Specimens	Flexural strength (MPa)	Flexural Modulus (GPa)
CFRC	122.7	10.26
	104.6	10.4
	98.5	9.54
	88.2	9.02

Using a mechanical test as a guide, the research determines the behavior of failure by creating a chain. As such, mechanical testing is beneficial for investigating the results of single extrusion projects.

The practice of maintaining a bending property was maintained in this study. The investigation of mechanical properties and the effect of different parameter values in material composition is complementary in this study. The results have a positive impact on the expansion and utilization of fiber-reinforced components in the manufacturing industry.

These often occur due to a weak interface between the printed layers. During the mechanical exam, the lines of the composite component are split by the applied pressure, this causes gaps between the layers to appear towards the sides.

4. Conclusion

The FDM method was employed to create the CF and ABS composite, which resulted in the creation of theCFRC structure. The non uniform extrusion of the matrix material led to some regions that were empty following the manufacturing process. Instead of fracturing during the flexural bend test, the composite material fails.

The experimental results indicate that, in comparison to other parameters and composition, fiber-added composites enhanced ABS with different layer heights and angles at the direction of travel have a superior mechanical capacity. After experiencing a flexural test, the sample's results showed that the cause of this event was a weakness in the reinforcing material and the matrix material, which led to a separation and the generation of gaps. With the utilization of optimized printing parameters, this bond between CFR and ABS could be enhanced and utilized in structural applications.

Transparency:

The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Copyright:

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