

## Article

# Additively Manufactured Carbon Fibre PETG Composites: Effect of Print Parameters on Mechanical Properties

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**Abstract:** This study investigates the quasi-static and viscoelastic properties of additively manufactured (AM) PETG reinforced with short carbon fibres. Samples were manufactured using different parameters in terms of the infill pattern, porosity, and annealing condition. Tensile and compressive tests were conducted to determine quasi-static properties such as Young's modulus and toughness, and dynamic mechanical analysis was used under a frequency sweep of 1–100 Hz to describe the viscoelastic behaviour of the composites. The major impacts and responses between the print parameters were quantified using Analyses of Variance (ANOVAs), which revealed the major contributor to each mechanical property. Fractography on the tensile samples using scanning electron microscopy demonstrated fibre pull-out, indicating poor fibre–matrix bonding, but also revealed interfacial bonding between raster lines in the annealed samples. This had a prominent effect on the properties of latitudinal samples where the force applied was perpendicular to the raster lines. Generally, porosity appeared to have the greatest contribution to the variance in the mechanical properties, with the exception of the tensile modulus, where the infill pattern had a more substantial effect. Annealing caused a consistent increase in the tensile modulus of the tested samples, which can be used to support the design and optimisation of AM parts when they are used under specific loading conditions.

**Keywords:** additive manufacturing; viscoelastic characterisation; carbon fibres; quasi-static; tensile; compressive; composite material; dynamic mechanical analysis



Citation: Economides, A.L.; Islam, M.N.; Baxevanakis, K.P. Additively Manufactured Carbon Fibre PETG Composites: Effect of Print Parameters on Mechanical Properties. *Polymers* **2024**, *16*, 3336. <https://doi.org/10.3390/polym16233336>

Academic Editor: Keon-Soo Jang

Received: 18 October 2024

Revised: 14 November 2024

Accepted: 28 November 2024

Published: 28 November 2024



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## 1. Introduction

Additive manufacturing (AM) is a key process for the rapid prototyping and development of products in modern industry. It is a product development method that diverges from traditional means of manufacturing such as injection moulding and CNC milling, as it consists of the addition rather than the removal of material from a manufactured part, which reduces the amount of waste and the overall cost, as well as the time required to make customised products [1]. Fused deposition modelling (FDM) continues to be the most popular method for producing AM structures due to its relatively low hardware costs compared to those of other AM processes (e.g., stereolithography, selective laser sintering), as well as the cost and variety of feedstock, which are higher in various other thermoplastic polymers. The most commonly found thermoplastics for AM are polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), and polyamide (PA/Nylon). The feedstock is extruded through a heated nozzle, and the molten polymer is deposited onto a heated bed, where the extruded material binds layer by layer to the previously deposited material via solidification. AM polymer structures typically have a lower strength and stiffness than their bulk polymer counterparts, as they have microstructural defects such as voids and porosity [2–4]. Additionally, poor parameter selection and hardware setup can lead to defects such as delamination of the printed layers [5,6].

Rapid prototyping remains limited in its applications due to restrictions in build size and material variety, as well as production time [7]; however, developments in material

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**Additive Manufacturing** Kun Zhou, 2022-10-31 This book focuses on the advances of additive manufacturing in the applications of wearable electronics energy storage biomedical implants and devices drug delivery and technologies for 4D printing large scale printing and ceramics printing It provides timely insights into the materials functionalities and applications of additive manufacturing

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**Proceedings of the Workshop on the Electrochemistry of Carbon** S. Sarangapani, J. R. Akridge, B. Schumm, 1984

*Certain Hot-rolled Lead and Bismuth Carbon Steel Products from Brazil, France, Germany, and the United Kingdom* United States International Trade Commission, 1992

**Carbon Steel Wire Rod from Brazil, Belgium, France, and Venezuela** United States International Trade Commission, 1982

Waste Recycling Technologies for Nanomaterials Manufacturing Abdel Salam Hamdy Makhlouf, Gomaa A. M. Ali, 2021-05-09 This book discusses the recent advances in the wastes recycling technologies to provide low cost and alternative ways for nanomaterials production It shows how carbon nanomaterials can be synthesized from different waste sources such as banana fibers argan *Argania spinosa* seed shells corn grains camellia *oleifera* shell sugar cane bagasse oil palm empty fruit bunches and leaves and palm kernel shells Several nanostructured metal oxides MnO<sub>2</sub> Co<sub>3</sub>O<sub>4</sub> can be synthesized via recycling of spent batteries The recovered nanomaterials can be applied in many applications including Energy supercapacitors solar cells etc water treatments heavy metal ions and dyes removal and other applications Spent battery and agriculture waste are rich precursors for metals and carbon respectively The book also explores the various recycling techniques agriculture waste recycling batteries recycling and different applications of the recycled materials

*Activated Carbon* Harry Marsh, Francisco Rodríguez Reinoso, 2006-07-12 Recent years have seen an

expansion in speciality uses of activated carbons including medicine filtration and the purification of liquids and gaseous media Much of current research and information surrounding the nature and use of activated carbon is scattered throughout various literature which has created the need for an up to date comprehensive and integrated review reference In this book special attention is paid to porosities in all forms of carbon and to the modern day materials which use activated carbons including fibres clothes felts and monoliths In addition the use of activated carbon in its granular and powder forms to facilitate usage in liquid and gaseous media is explored Activated Carbon will make essential reading for Material Scientists Chemists and Engineers in academia and industry Characterization of porosity The surface chemistry of the carbons Methods of activation and mechanisms of adsorption Computer modelling of structure and porosity within carbons Modern instrumental analytical methods

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## **Table of Contents Manufactured Carbon**

1. Understanding the eBook Manufactured Carbon
  - The Rise of Digital Reading Manufactured Carbon
  - Advantages of eBooks Over Traditional Books
2. Identifying Manufactured Carbon
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Manufactured Carbon
  - User-Friendly Interface
4. Exploring eBook Recommendations from Manufactured Carbon
  - Personalized Recommendations
  - Manufactured Carbon User Reviews and Ratings
  - Manufactured Carbon and Bestseller Lists
5. Accessing Manufactured Carbon Free and Paid eBooks
  - Manufactured Carbon Public Domain eBooks
  - Manufactured Carbon eBook Subscription Services
  - Manufactured Carbon Budget-Friendly Options

6. Navigating Manufactured Carbon eBook Formats
  - ePub, PDF, MOBI, and More
  - Manufactured Carbon Compatibility with Devices
  - Manufactured Carbon Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Manufactured Carbon
  - Highlighting and Note-Taking Manufactured Carbon
  - Interactive Elements Manufactured Carbon
8. Staying Engaged with Manufactured Carbon
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Manufactured Carbon
9. Balancing eBooks and Physical Books Manufactured Carbon
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Manufactured Carbon
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Manufactured Carbon
  - Setting Reading Goals Manufactured Carbon
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Manufactured Carbon
  - Fact-Checking eBook Content of Manufactured Carbon
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements



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