

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

Manufactured Carbon

Ali Reza Kamali

A red circular graphic with a gradient, appearing as a semi-circle or a partial circle, located to the right of the author's name.

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Manufactured Carbon R.R. Paxton, 2018-01-18 This book discusses manufactured carbon for the purposes of being a self lubricating material for mechanical devices Topics include properties and graphite crystals properties of manufactured carbon the manufacture of carbon articles machining carbon carbon in mechanical seals carbon in bearings rotary pumps and motors metering devices and piston rings and cylinder liners *Green Production of Carbon Nanomaterials in Molten Salts and Applications* Ali Reza Kamali, 2020-01-10 This book focuses on the possible interactions that might occur between carbon materials and molten salts and discusses the mechanisms involved in detail highlighting possible future developments in the field Carbon materials can be exposed to molten salts in various technologically important applications such as in molten salt nuclear reactors and aluminum production electrolysis cells As such numerous studies have investigated the possible interactions between carbon and molten salts In addition various interesting carbon nanostructures have recently been produced in molten salts including carbon nanotubes graphene and nanodiamonds with a number of attractive applications With abundant images and graphs supporting the discussion this book appeals to researchers working in the field of carbon nanostructures carbon capture and conversion nuclear reactors energy storage molten salts and related areas of science and technology *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_2 Co_3O_4 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

Industrial Carbon and Graphite Materials Hubert Jäger, Wilhelm Frohs, 2021-03-05 Hochaktuelles Thema Kohlenstoff und Graphitmaterialien gehen aufgrund ihrer ausgezeichneten Eigenschaften und vielfältigen Anwendungsmöglichkeiten in unzähligen Bereichen von der Nanotechnologie bis hin zur Elektronik zu den interessantesten Verbindungsklassen Einzigartig und anwendungsorientiert Es gibt viele Publikationen die sich mit Materialien aus Kohlenstoff und Graphit beschäftigen Dieses zweibändige Fachbuch gibt jedoch einen ausgezeichneten Überblick über Fertigung Einsatz und Anwendung dieser Materialien in der Industrie Große Zielgruppe Chemiker aus den Bereichen Elektrochemie Lithium Ionen Batterien Maschinenbau Nukleartechnologie Nanotechnologie Katalyse Keramik Fasern Polymere und vieles mehr Exzellentes Referenzwerk mit mehr als 1000 Seiten von polygranularen Materialien bis zu Fullerenen von Nanoröhren bis zu aktiviertem Kohlenstoff alle wichtigen Kohlenstoff und Graphitklassen werden behandelt

Advances in Additive Manufacturing Volume—II Santosh Kumar, V. Prabhu Raja, P. Sharma, G. M. Karthik, 2025-05-15 This book presents a part of selected proceedings of the 9th International and 30th All India Manufacturing Technology Design and Research Conference AIMTDR 2023 It discusses the latest advances in hybrid manufacturing process and technology composites fabrication non traditional and advanced machining processes energy beam processing high performance cutting tools micro and nano machining of glasses and ceramics concurrent and reverse engineering modeling of machining processes intelligent machining and super finishing technologies among other areas The contents of this book are useful for researchers and professionals in the various fields of mechanical engineering

Handbook of Petroleum Product Analysis James G. Speight, 2015-02-02 Introduces the reader to the production of the products in a refinery Introduces the reader to the types of test methods applied to petroleum products including the need for specifications Provides detailed explanations for accurately analyzing and characterizing modern petroleum products Rewritten to include new and evolving test methods Updates on the evolving test methods and new test methods as well as the various environmental regulations are presented

Nanostructured Carbon Materials for Catalysis Philippe Serp, Bruno Machado, 2015-03-02 We heartily recommend this book to all readers who wish to gain a better understanding of nanostructured carbon materials surface properties and used in catalysis An Hui Lu ChemCatChem There is great interest in using nanostructured carbon materials in catalysis either as supports for immobilizing active species or as metal free catalysts due to their unique structural thermal chemical electronic and mechanical properties and tailorable surface chemistry This book looks at the structure and properties of different doped and

undoped nanocarbons including graphene fullerenes nanodiamonds carbon nanotubes and nanofibers their synthesis and modification to produce catalysts Special attention is paid to adsorption as it impacts the application of these materials in various industrially relevant catalytic reactions discussed herein in addition to photocatalysis and electrocatalysis Written by leading experts in the area this is the first book to provide a comprehensive view of the subject for the catalysis community

Descriptive Inorganic Chemistry James E. House, Kathleen A. House, 2010-09-22 Descriptive Inorganic Chemistry Second Edition covers the synthesis reactions and properties of elements and inorganic compounds for courses in descriptive inorganic chemistry This updated version includes expanded coverage of chemical bonding and enhanced treatment of Buckminster Fullerenes and incorporates new industrial applications matched to key topics in the text It is suitable for the one semester ACS recommended course or as a supplement in general chemistry courses Ideal for majors and non majors the book incorporates rich graphs and diagrams to enhance the content and maximize learning Includes expanded coverage of chemical bonding and enhanced treatment of Buckminster Fullerenes Incorporates new industrial applications matched to key topics in the text

Carbon Steel Wire Rod from Poland, Portugal, and Venezuela United States International Trade Commission, 1985 **Carbon Steel Wire Rod from Brazil and Trinidad and Tobago** United States International Trade Commission, 1983 *Carbon Steel Wire Rod from the German Democratic Republic* United States International Trade Commission, 1984 *Patty's Toxicology, 6 Volume Set* Eula Bingham, Barbara Cohrssen, 2012-07-31

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Evaluation of Commercially Available Flame Retardants for Production of Carbon Fabric Lilly O. Iwuchukwu BS. MSC,2017-02-21 This book compared the use of flame retardant chemicals known as pyroset TPO and TKC in the production of carbon fabrics from cotton precursors Information about the chemical was collected from the American Cyanamid company textile and chemical division Data was also furnished by the test fabric incorporated for the two fabrics it manufactured mercerize 100 percent cotton sheeting style 409 and unmercerized 100 percent cotton sheeting style 409 The percentage of carbon remaining from each sample in all the categories was obtained through carbon analysis conducted by Galbraith Laboratories Incorporated Percent char data were calculated from data obtained before and after pyrolysis The results are presented and discussed with the aid of a 2 5 factorial design pattern used for the overall design of the experiment Personal reflections on how to save the lives of infants and children even our geriatric parents that are trapped in a burning home with much higher statistics for rescuing them to safety More safety resulting in having flame retardant nightwear even home furnishings and more as time goes on Common sense logic and sensible ideology in our twenty first century Creating safety living all around should be a right and our responsibility a value that we should be well invested in Research funding in the textile industry and for educators has been seriously almost nonexistent that humanity is still struggling for a safe technology for utilizing materials for public safety Public trust must be secured by specifying performance of treated fabrics safe from fire and the extinguishing of flames less toxic to protect and enhance our democratic ideals of freedom living in the western hemisphere The world is in need of safe discovery for flame retardants material to be used in active wears home furniture establish standard of assessments and accountability measures to be the

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