

## 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



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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

**Lingsheng Yao**



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