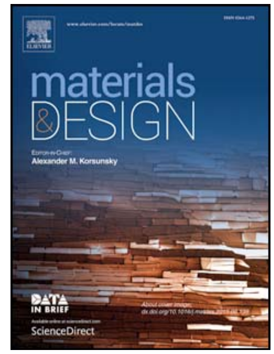

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Abstract

This paper presents an experimental investigation on the influence of process parameters such as part orientation, air gap and number of contours along with their interactions on the creep behaviour of fused deposition modelling (FDM) processed polycarbonate (PC) parts. Due to the lack of creep curve data with parts processed by FDM, this research gives a first quantitative approach to the time-dependent mechanical properties. This study not only varies significant process parameters viz., part build orientation, raster to raster air gap and number of contours, but also applies different loads to the samples to further understand primary and secondary creep behaviour for PC, providing the creep curves. Furthermore, two mathematical models are used to fit the experimental data, which can be used in numerical modelling. The first model is the well-documented and commonly used Bailey-Norton equation. As a second model, the fractional Voigt Maxwell in series (FVMS) is proposed to use. This model applies fractional calculus to reduce the number of parameters to be calculated. Conclusions obtained about how process parameters affect the creep behaviour are in agreement with previous research in mechanical properties of FDM parts.

Keywords: Creep, Fused Deposition Modelling, Polycarbonate, Process Parameters, Analytical Model

1. Introduction

Fused deposition modelling (FDM) is a growing additive manufacturing (AM) technology, which has found application in various areas including biomedical [1–3], aeronautics or aerospace engineering [4, 5], among others. This is by far the most common extrusion-based AM technology. The FDM process uses a heating chamber to liquefy polymer that is fed into the system as a filament. The filament is pushed into the chamber by a tractor wheel arrangement and it is this pushing that generates the extrusion pressure [6].

Considerable research has been done in optimizing FDM processing parameters to improve the static and dynamic mechanical properties of manufactured prototypes. Nevertheless, to the knowledge of the authors, little research has been carried out addressing time-dependent mechanical properties. Two similar studies from the same authors were found that establish the relation between FDM process conditions and creep properties [7, 8]. Yet, both studies were carried out with polycarbonate-acrylonitrile butadiene styrene (PC-ABS), at a single stress and at a single temperature. Therefore, the quadratic models used in both articles do not consider either stress or temperature. Another study presented how printing direction affects relaxation properties in compression uniaxial tests, for ABS specimens, but at a single strain and temperature [9]. D.Türk et al. characterized flexural creep modulus of three AM polymeric materials (ABS, Polyamide 12 and DuraForm HST Composite) made by selective laser sintering (SLS) and FDM at elevated temperatures and two different part build orientations through three-point bending creep tests [10]. Hence, since creep is an important phenomenon in plastic materials, it is essential to analyse the tensile creep characteristics of parts manufactured by FDM.

This research investigates the primary and secondary creep characteristics of polycarbonate (PC) parts varying some process parameters at different stresses. Furthermore, two methods and equations are used to predict the long-time endurance of these parts (one is the fractional Voight-Maxwell in series, and the other is the Bailey-Norton law, also called power law, used in many papers for different purposes [11]). In addition, tensile tests have been carried out in specific configurations, since no data were available.

In the following section, both analytical approaches for fitting experimental data are presented. Section 3 provides the experimental procedure used for manufacturing the specimens, briefly explaining the process parameters chosen as well as the tensile and creep tests carried out. Subsequently, results of the investigation are presented and discussed in Section 4, reviewing also the validity of both analytical models. Finally, the conclusions of the study are summarised in the last section.

2. Analytical approach

The use of constitutive equations to describe the creep in viscoelastic materials has been the object of study for many years. Nowadays, the use of constitutive equations based on fractional calculus is increasing. For instance, fractional calculus is being applied to multiple applications from biomedical science and engineering [12] to geotechnical engineering [13–15], because

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