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Viscoelastic Behaviour of Flexible Thermoplastic Polyurethane Additively Manufactured Parts: Influence of Inner-Structure Design Factors

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Abstract: Material extrusion based additive manufacturing is used to make three dimensional parts by means of layer-upon-layer deposition. There is a growing variety of polymers that can be processed with material extrusion. Thermoplastic polyurethanes allow manufacturing flexible parts that can be used in soft robotics, wearables and flexible electronics applications. Moreover, these flexible materials also present a certain degree of viscoelasticity. One of the main drawbacks of material extrusion is that decisions related to specific manufacturing configurations, such as the inner-structure design, shall affect the final mechanical behaviour of the flexible part. In this study, the influence of inner-structure design factors upon the viscoelastic relaxation modulus, $E(t)$, of polyurethane parts is firstly analysed. The obtained results indicate that wall thickness has a higher influence upon $E(t)$ than other inner-design factors. Moreover, an inadequate combination of those factors could reduce $E(t)$ to a small fraction of that expected for an equivalent moulded part. Next, a viscoelastic material model is proposed and implemented using finite element modelling. This model is based on a generalized Maxwell model and contemplates the inner-structure design. The results show the viability of this approach to model the mechanical behaviour of parts manufactured with material extrusion additive manufacturing.

Keywords: additive manufacturing; thermoplastic polyurethane; inner structure; mechanical properties; viscoelasticity

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1. Introduction

Continuous advances in additive manufacturing are broadening the field of application of resultant parts from mere prototypes to industrial-quality products [1]. During the last decade, sustained growth of additive manufacturing has evolved from a desktop-3D-printing oriented market to an increasing adoption of industrial additive manufacturing systems [2]. Although power-bed fusion and directed energy deposition processes have experienced a great impulse, MEX (extrusion based additive manufacturing) is still the most popular and widely used category of additive processes. In MEX, material is "selectively dispensed through a nozzle" to make parts layer upon layer [3]. Processes in this category commonly use a thermoplastic material as the feedstock [1].

Mechanical properties and structural reliability of additively manufactured parts have been under study for the past two decades [4]. It is well known that the layer-upon-layer deposition strategy leads to anisotropic properties and that additively manufactured parts present lower tensile strengths than the equivalent parts fabricated by injection moulding, due to voids formation and internal structure characteristics [5].

Moreover, Forster [6] discuss the inherent complexity of relating material properties in additive manufacturing, since manufacturers tend to determine the properties of a particular design, used as an example, rather than to establish standardized methods.