Experimental and numerical characterization of 3D-printed PLA under uniaxial high strain-rate loading

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ABSTRACT

The present paper aims to determine the response of PLA 3D-printed parts, manufactured by Fused Deposition Modelling (FDM), under uniaxial high strain-rate loading and to assess its effectiveness when used in a sacrificial cladding layer. First, quasi-static uniaxial compression tests were used to verify the existence of anisotropic behaviour and determine the optimal layer orientation. It was possible to verify that, for compressive loadings, the optimal layer orientation is perpendicular to the direction of the load. Next, the existence of size effects is investigated and the response of 3D-printed PLA under uniaxial high strain-rate loading determined using an electromagnetic compressive split Hopkinson bar.

INTRODUCTION

The defence of civilian and military infrastructures and population against blast attacks is a complex and extensive task. Over the last decades, several terrorist attacks increased the demand of research on the protection of engineering structures against explosions. One of the protective solutions draws from the concept of a sacrificial cladding design [1, 2]. These solutions allow to shield structural elements from a direct and indirect blast action by introducing an energy absorption wallcovering, which aims to dissipate the energy of the explosion through large plastic deformation of very ductile panels, and to minimize the peak force transferred to the structural elements. This allows for effective protection of structural elements and reduces the risk of building collapse.

Material selection in protective solutions design process is very important, as to ensure that the final product will be able to dissipate considerable amounts of blast energy. The selected material must be resistant to the peak force and flexible to dissipate blast energy through inelastic deformation. Lightweight and easy-to-process materials must be considered to enable a low cost of production, such as easy to install and maintain. Plastic materials are able to meet such requirements for durability, low cost, water resistance, lesser energy requirements in manufacture, good compatibility with fibres and are lightweight. On the other hand, additive manufacturing, or 3D printing, has grown in interest in the research and academic communities. This manufacturing solution can be defined as the process of joining materials to construct the complete three-dimensional model one layer at a time. Fused deposition modelling (FDM) 3D-printers are one of the most popular solutions, based on extrusion additive manufacturing, for creating polymer composites. This technique resorts to a spool of thermoplastic filament, such as PC, ABS and PLA, to be melted and extruded through a heated nozzle [3].

The present paper aims to experimental and numerically characterize the response of 3D-printed PLA when subjected to uniaxial high strain-rate loading. In this study, the commercial

PLA filament manufactured from Ingeo Biopolymer with a diameter of 1.75 mm was used. The specimens were manufactured resorting to a Prusa i3 MK2S 3D printer with a 0.4 mm nozzle. A preliminary quasi-static compression test was performed in order to confirm the existence of anisotropy and determine the optimal layer orientation when the specimen is subjected to compressive stresses. The specimens consisted of cylinders with a diameter of 6 mm and a height of 6.4 mm. Table 1 presents the employed printing parameters, whilst Fig. 1 illustrates the considerer layer orientations.

Table 1 Printing parameters

Layer orientation	**Nozzle extrusion temperature [ºC]**	**Heat bed temperature [ºc]**	**Layer height [mm]**	**Printing speed [mm/s]**
(1)				30
(2)	210	60	0.1	30
(3)				30

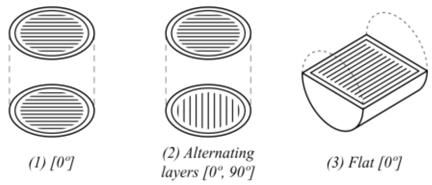
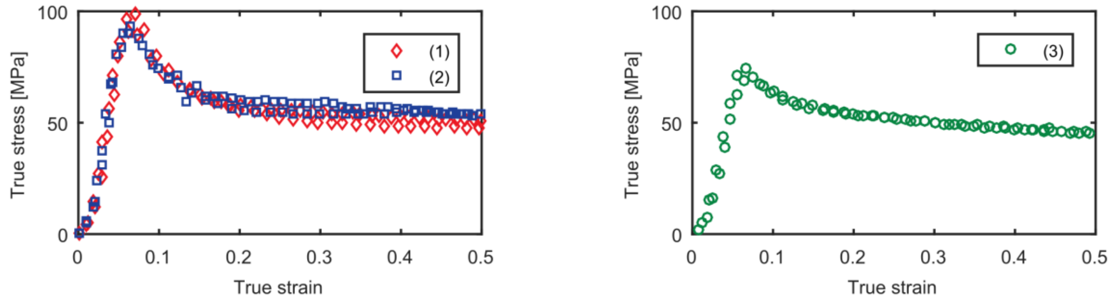


Fig. 1 Layer orientation

RESULTS AND CONCLUSIONS

Fig. 2 presents the obtained true stress-true strain curve for the preliminary test. Through the analysis of the figure, namely, through the comparison of the results determined with layer orientation *(1)* and *(2)* with the ones attained with orientation *(3)*, one can confirm that, due to the layer-by-layer manufacturing process, 3D-printed specimens exhibit anisotropic behaviour. Nonetheless, contrary to the expectations, the differences between layer orientation *(1)* and *(2)* are not significant.



(a) Layer orientations *(1)* and *(2)*

(a) Layer orientation *(3)*

Fig. 2 Quasi-static uniaxial compression stress-strain curves

Therefore, only layer orientation *(1)* will be considered for the remainder of the present study. Scale effects will be studied to ensure a correct determination of the uniaxial response of 3D-printed PLA parts when subjected to high strain-rate loading, determined with an electromagnetic compressive split Hopkinson bar. Additionally, tensile tests will be carried out.

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