
Multi-scale experimental characterisation and modelling of the thermo-electro-mechanical behaviour of 3D printed conductive composites

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Abstract

Additive manufacturing (AM) allows for the fabrication of complex-shape components with multifunctional properties, as conductive composites. In these materials, the conductive particles embedded in the polymeric matrix allow for a current flow. The electrical response is bidirectionally coupled with the thermal state, via resistivity modulation with temperature and heating generation due to Joule effect. In the same manner, the mechanical behaviour also affects its electrical counterpart. In addition, the use of 3D printing techniques carries the formation of defects that alter the response of these materials at a functional level. Given the nature of these materials, a comprehensive characterisation cannot be tackled only from a macroscopic or functional point of view. In this regard, the problem should be addressed following different approaches, attending to the different scales (i.e., micro, meso and macroscale) as well as to the different physical interplays (i.e., thermal, electrical and mechanical responses).

In this work, we conducted a multi-responsive characterisation of Carbon Black (CB) filled composites, using two different matrices; a thermoplastic (polylactic acid, PLA) and an elastomer (polydimethylsiloxane, PDMS). This characterisation was performed at: i) a material level, discarding the structural effects derived from the printing process; and ii) at a functional-level, accounting for the effects of the printing process. In addition, computational approaches were employed to model the multi-physical interdependencies that appear at both material and functional levels.

From an experimental perspective, we tackle the problematic by performing tests where pairs of physics were isolated. In this regard, different sets of experiments were performed, e.g., electro-thermal, analysing the material heating caused by the application of an electric field; or mechano-electrical, measuring the variation of electrical properties when deforming the composite. For our modelling approaches, full-field homogenisation techniques as well as macroscopic continuum techniques were employed to simulate the interdependencies observed in our experimental campaign.

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The results obtained in this work show the strong thermo-electro-mechanical interdependencies in conductive composites. Additionally, it has been proven that our *in-silico* methodology has a great potential for conductive composite manufacturers to optimise their material properties and 3D printing users to do the same with the printing parameters.