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3D Printed PLA/Carbon Black Constructs for Self-sensing Applications: a Novel Characterization Framework

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Extended Abstract

Abstract

3D-printable conductive polymers have gained interest in the scientific community for diverse applications, including pressure sensors, interference shielding, flexible electronics, and damage detection. One strategy for making polymers conductive involves the embedding of functionalizing fillers, such as metal nanoparticles or carbon products (e.g., carbon nanotubes, nanofibers or nanoparticles), within a polymer matrix. Fillers are added in an amount exceeding a minimum threshold to allow the formation of a conductive path within the material. Any disturbance of such path, e.g., due to mechanical stresses, causes a change in the material's electrical response; such phenomenon is called piezoresistivity. Due to the complex microstructure of polymer nanocomposites, which is highly dependent on the manufacturing process used, in situ health monitoring systems are promising solutions to predict the failure mechanisms and residual lives of such materials under varying external loads. Specifically, self-sensing, as inherent ability of a material to detect damage-induced structural changes without the use of external sensors, is a functionality of great interest for the development of smart materials. In this context, additive manufacturing offers high design flexibility and low costs for polymer nanocomposites processing, allowing the design of structures that leverage the anisotropy induced by the manufacturing process. In the literature, experimental data on the piezoresistivity of polymer nanocomposites has been widely reported, mainly focusing on strain sensing applications. Damage sensing, instead, has been less explored. Also, it is not well understood how the onset of permanent damage correlates to the change in the electrical response for this material class. Specifically, it is not clear: (i) whether 3D printed PNCs can be used for damage sensing (yielding, fatigue) together with strain sensing applications, (ii) what characterization framework can be used for this purpose, and (iii) how the damage behaviour changes with printing layup. In this work, considering some key aspects of polymer mechanics, we characterise the mechanical and electromechanical properties of a 3D printed polylactic acid (PLA)/carbon black (CB) nanocomposite material to investigate its potential for damage sensing applications. Overall, this work demonstrates the damage sensing capabilities of additively manufactured PLA/CB samples while also presenting a novel framework for characterising the damage sensing properties of polymer nanocomposites. This research paves the way towards a better understanding of the damage mechanisms of polymer nanocomposites and their electromechanical behaviour for damage sensing applications. With the potential to be extended to a multitude of polymeric materials, this work contributes to the development of cost-effective, tuneable, 3D printed smart structures.

Keywords:

Self-sensing Piezoresistivity Smart Materials Polymer characterization Electromechanical testing Additive manufacturing