Doctoral Dissertation
Doctoral Program in Materials Science and Technology (34th Cycle)

Additive manufacturing of carbon fiber reinforced thermoplastic polymer composites

By

Federico Lupone

******

Supervisor(s):
Prof. Claudio Francesco Badini, Supervisor
Prof. Elisa Padovano, Co-Supervisor

Abstract

The objective of the dissertation is to establish a framework for the development of additive manufacturing (AM) technologies toward the fabrication of high-quality of carbon fiber reinforced thermoplastic polymer (CFRP) composites. AM offers valuable advantages with respect to conventional composites fabrication methods, including high design flexibility, near net shape processing of complex geometries with no need of moulds, tools or special equipment (e.g., autoclave), product customization, small material and energy consumption and capability of full automation. In this context, this dissertation analyzed the relation between processing, structure and property across the micro and meso length scales of both short and continuous fiber reinforced polyamide composites fabricated with powder bed fusion (Selective Laser Sintering, SLS) and material extrusion (Fused Filament Fabrication, FFF and Continuous Filament Fabrication, CFF) AM techniques. To this end, a detailed thermo-physical, morphological and mechanical characterization of the materials before and after the printing process was performed. Moreover, a novel approach was developed to rationalize process parameter optimization in SLS, while the ability to control fiber orientation in material extrusion AM methods was used to customize part stiffness and strength and mechanical anisotropy by aligning the fibrous reinforcements layer by layer in multiple ways. Current models used to predict the mechanical behaviour of fiber reinforced composites were also effectively adapted to AM parts by taking into account their peculiar microstructural features into the models. Overall, the results showed that the integration between microstructure control, effective modeling approaches and process optimization could drive the application of AM in the composite industry. The current issues related to the widespread adoption of composite AM, such as difficulties in void suppression, limitations in fiber length and content and other processing defects (interlayer bonding and fiber distribution) were also illustrated by comparing the microstructure and mechanical properties of 3D printed and conventionally manufactured components. Although short fiber reinforcements are preferred due to ease of AM processing, continuous fiber composites exhibited tremendous enhancement of mechanical properties, with potential to outperform the conventional fabrication methods where complex light-weight structures are needed. Finally, suggestions for possible processing and material improvements were proposed.