Mechanical Characterization of 3D-printed Polymers: Experimental Validation of a 2D Orthotropic Constitutive Model

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ABSTRACT

Components fabricated via Fused Filament Fabrication (FFF) fit well in applications with limited load and dimensions, even in critical fields; an example is given by the structural elements of Unmanned Aerial Vehicles (UAVs). FFF has a critical impact on the mechanical properties of the finished parts. The manufacturing parameters, the post-processing software, the 3D printer itself, and the specific filament lead to an anisotropic response, often associated with an intra-part and a part-to-part variation of the properties. Assessing the compliance of a part with the design criteria is complex, as the general anisotropy is associated with the absence of standardized analysis and characterization processes.

The authors proposed a solution by analyzing components featuring a linear infill with a 100% infill percentage. When the filaments develop in parallel, all oriented in the same direction, the geometrical pattern resembles that of a composite lamina with unidirectional long fibers. The presence of geometrical planes of symmetry might reduce the anisotropy of the parts to orthotropy.

The absence of a standardized approach requires an initial test setup design to standardize the method and define the test features. The parallel with Uni-Directional Composites (UDCs) helps adapt some methodologies: rectangular constant cross-section specimens are used for tensile and in-plane shear properties determination, instead of the classical dog-bones for polymers. The method received a preliminary and quick confirmation through thin components: predictions are excellent once the in-plane behavior is determined, and the Classical Lamination Theory extends to this field. This approach can be used in Finite Element Analysis by defining a 2D orthotropic material through a 3 X 3 reduced elastic coefficients matrix and introducing an infinite shear correction factor for the out-of-plane shear. Three-point bending, simple bending, and bending-torsion tests with different laminations qualify the method, showing higher deviation in deposition directions other than 0° and 90° with respect to the longitudinal direction. The source of this decline could be the kinematic model; a possible solution consists in improving the approach through the First Order Shear Deformation Theory (FSDT). This higher theory requires determining the out-of-plane shear properties to define the factors of the 5 X 5 reduced elastic coefficients matrix. It also enables the use of 2D orthotropic constitutive models in FEA without any additional hypotheses. This work deepens the extension of the approach, discusses the shear tests design through V-notched specimens, and proposes a further validation frame.

Keywords: *fused filament fabrication; PLA; experimental campaign; constitutive model.*

Biography: Roberto Torre received his BSc and MSc Degree in Aerospace Engineering at Politecnico di Torino in 2014 and 2016, respectively. In July 2021, he received his Ph.D. degree at Politecnico di Torino in Aerospace Engineering. During his doctoral career, Dr. Torre focused on Additive

Manufacturing, with FFF/FDM as a specific target. His first concern has been to understand the structural behavior of polymeric FFF/FDM printed elements to encourage their use in the production of functional components. His research activity won the quality prize for Ph.D. students in 2021. Currently, he holds a PostDoc position at the Department of Mechanical and Aerospace Engineering (DIMEAS) of Politecnico di Torino. His research activities are mainly focused on additive manufacturing, polymers, hygro-thermal stress analysis, numerical and analytical solutions for shells, and UAVs. He authored 15 papers published in international journals and serves as a reviewer for many international journals. In addition, he is Guest Editor for a special issue of the Journal of Composites Sciences.