

# TOPOLOGY AND ORIENTATION OPTIMIZATION OF SHORT-FIBER REINFORCED STRUCTURES WITH MICROSTRUCTURE CONTROL

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## Abstract

Material EXtrusion Additive Manufacturing (MEX-AM) of fiber-reinforced components allows for the fabrication of complex geometries with an extreme stiffness to weight ratio. Here, we consider short fibers suspended in a two-component thermosetting polymer, whose mechanical properties are highly dependent on the fiber orientation. As fiber alignment is affected by the shear fields generated by manufacturing process, the final structural anisotropy is tightly coupled to the chosen deposition strategy. Recent studies have demonstrated how the microstructure of short-fiber reinforced materials can be controlled using multi-directional shearing of the nozzle during material deposition [1]. Building on these insights, we present a novel topology optimization method that simultaneously optimizes material distribution, fiber orientation and microstructure-dependent effective properties.

The material distribution problem is formulated through density-based topology optimization. The material orientation is parameterized using natural coordinates in the unit square. These variables are filtered to ensure smoothly varying fiber orientations and projected into physical orientations on the unit disc using isoparametric projection [2]. The effective properties of the material are governed by the microstructure and controlled by rotating the nozzle during the printing process. The microstructure control is investigated using a 3D CFD model developed in OpenFOAM. The model uses a moving overset mesh to simulate the deposition of material, and the microstructure is predicted using the Advani-Tucker model to transport the 2nd order orientation tensor [3]. The effective properties are determined from the simulated microstructures and parameterized as a function of nozzle rotation speed in the topology optimization framework.

Results from the CFD simulations show that fibers strongly align with the deposition direction when the nozzle is not rotating, while high rotation speeds induce significant reorientation, yielding more isotropic behavior. Modulating the nozzle

rotation speed therefore offers the possibility to locally control the level of anisotropy without changing the feedstock material.

The overall method is demonstrated on a few benchmark problems, and it is shown that regions primarily under uniaxial loading prefer highly aligned fibers while areas under shear or multi-axial stresses benefit from more isotropic properties, obtained by rotating the nozzle. This demonstrates the possibility to increase structural performance by producing structures with locally varying material properties with tailored microstructures obtained through understanding and control of the MEX-AM process

## References

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