A topology-based in-plane filtering technique for the combined topology and discrete fiber orientation optimization

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Abstract

This work proposes a filtering technique for the concurrent and sequential finite element-based topology and discrete fiber orientation optimization of composite structures. The proposed filter is designed to couple the morphology with the topology of the structural domain throughout the optimization process in a way such that it suppresses the impact of the close-to-void finite elements' morphology on the overall morphology of the structure while steering at the same time the local fiber orientation toward the neighboring topologically dense areas of the geometry. The functionality of the filter becomes crucial at the boundaries of the optimized structure, where the fiber orientation is forced to conform to the morphology of the local boundaries. The developed filtering technique is incorporated into both the concurrent and sequential finite element-based topology and discrete fiber orientation optimization problem, and the respective optimization problems are formulated for the compliance minimization of the composite structure. To assess the efficacy of the filter, it is demonstrated in the benchmark academic case studies of the 2D Messerschmitt-Bölkow-Blohm and cantilever beams when different state-of-art interpolation techniques are employed for modeling the discrete fiber orientation optimization problem.

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1. Introduction

The utilization of Fiber-Reinforced Composites (FRCs) has significantly increased over the last decades, especially in aeronautic and automotive sectors where the use of materials of high specific properties is required; the capability to tailor their anisotropy to suit the requirements of any given structural design gives them a significant edge over conventional homogeneous materials. This capability is further leveraged when utilizing Additive Manufacturing (AM) techniques such as Fused Filament Fabrication (FFF) as their manufacturing process. The recent advent of AM techniques has significantly contributed to the increased production of continuous FRCs, enabling the cost-effective and rapid manufacturing of complex-shaped FRCs [1]. The main limitation of the AM fiber deposition, however, lies in the layer-by-layer printing strategy that most AM methods are utilizing, constraining the fibers to be deposited parallel to the printing plane. This results in the design of the fiber orientation being mainly a 2D problem as, in general, to achieve optimal performance the fiber orientation must be parallel to the printing layer.

The prime parameter dictating the mechanical properties of FRCs is the fiber orientation angle, which constitutes a separate optimization problem itself. Designing for the optimal fiber orientation at the Finite Element (FE) level can be performed by employing either the Continuous Fiber Orientation Optimization (CFOO) or the Discrete Fiber Orientation Optimization (DFOO) scheme. In the first case, the fiber orientation is treated as a continuous design variable, freely varying within the $[0, 180]^\circ$ interval. Early works on CFOO optimization include the strain-based and stress-based methods presented by Pedersen in [2] and Cheng et al. in [3], respectively. These methods utilize the major principal strain or stress trajectories as reference points to direct the fiber orientation during the optimization process. They proved, however, to be highly dependent on the initial conditions of the optimization problem, namely the initial fiber orientation. On the other hand, the objective of the DFOO scheme is to identify for the FE the most suitable fiber

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