

MANUFACTURABILITY-AWARE ANISOTROPIC TOPOLOGY OPTIMIZATION FOR CONCURRENT DESIGN OF FIBER ORIENTATION AND LAYUP SURFACES

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Abstract

Variable axial composites (VACs) have attracted considerable attention because they enable high structural performance through spatially varying fiber orientations. By steering continuous fibers appropriately, VACs provide enhanced stiffness-to-weight ratios, improved load transfer, and greater design flexibility than conventional laminates with uniform orientations. However, despite recent progress in anisotropic topology optimization, a significant gap remains between optimized orientation fields and manufacturable layup definitions. In practice, the translation of numerically optimized fiber paths into feasible layup surfaces often relies on manual interpretation, which limits repeatability and may compromise structural performance as well as manufacturability.

This study presents a manufacturability-aware anisotropic topology optimization framework for the concurrent design of fiber orientation and layup surfaces in composite structures. The proposed method is intended for continuous fiber-reinforced composites, especially VAC configurations produced by advanced fiber placement technologies, such as Tailored Fiber Placement, TFP. In the framework, orientation tensors are introduced as primary design variables to represent local anisotropic fiber orientations within a continuum setting. In addition, an auxiliary design variable field is introduced to describe the volumetric distribution of the surface normal directions associated with layup surfaces. By coupling these two fields, the method simultaneously optimizes in-plane fiber steering and the geometry-related characteristics of layup surfaces.

The key idea of the proposed formulation is to embed manufacturability considerations directly into the optimization process, instead of addressing them only after structural optimization. The coupling between fiber orientation and layup surface variables promotes tangential alignment of fibers with structurally favorable directions while suppressing nonphysical or impractical out-of-plane orientation distributions. As a result, the optimized solutions are expected to better satisfy the geometric and process-related constraints inherent in composite manufacturing.

This concurrent treatment provides a more realistic representation of the design space than approaches that optimize material orientation alone.

From a computational design perspective, the proposed framework extends anisotropic topology optimization toward a tighter integration of structural performance and fabrication feasibility. It enables the automatic exploration of design candidates in which load-path-driven fiber orientation and manufacturable layup surface descriptions are consistently coordinated. Such an approach is particularly relevant for the design of lightweight composite components where both anisotropic performance and process compatibility are critical.

The proposed methodology is expected to contribute to a more systematic design-to-manufacturing workflow for VAC structures by reducing dependence on manual post-processing and designer intuition. Ultimately, the framework aims to support the generation of high-performance composite designs that are not only structurally optimized but also better suited for practical fabrication.