

INTEGRATED STIFFNESS AND STRENGTH OPTIMIZATION OF MANUFACTURABLE VARIABLE STIFFNESS COMPOSITE LAMINATES

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Keywords: Variable stiffness composites, Structural optimization, Composite laminates, Manufacturable design, Tsai Hill, Tsai Wu, Differentiable maximum approximation

Abstract

Recent advances in manufacturing technologies, including additive manufacturing and automated fiber placement, have enabled the fabrication of composite laminates with spatially varying stiffness through curvilinear fiber paths. Effectively leveraging these capabilities requires optimization strategies that simultaneously account for anisotropic material behavior, structural performance, and manufacturing feasibility. Previous work has explored level set based approaches for the design of fiber reinforced composites produced with direct ink writing, primarily focusing on stiffness driven formulations. These approaches incorporated manufacturability constraints through implicit descriptions of fiber trajectories. More recent developments extended these methods toward strength based optimization using classical failure criteria combined with smooth aggregation techniques. However, these formulations considered strength independently and did not explicitly address its interaction with stiffness in a unified design framework.

This work presents an integrated optimization approach that simultaneously considers stiffness and strength in the design of variable stiffness composite laminates. The problem is formulated as compliance minimization subject to global strength constraints derived from Tsai Hill and Tsai Wu criteria. Manufacturing constraints are explicitly enforced, including constant tow spacing, avoidance of gaps and overlaps, and limits on fiber curvature. To ensure differentiability and enable efficient gradient based optimization, several smooth aggregation strategies are employed, including p-norm based, p-mean based, Kreisselmeier-Steinhauser, mellowmax, and Boltzmann type functions. The structural response is modeled using classical laminate plate theory combined with a conforming finite element formulation, and sensitivities are computed through an adjoint approach. Numerical studies demonstrate the inherent trade off between stiffness and strength, as well as the impact of manufacturability constraints on achievable designs. The proposed framework generates feasible fiber layouts that balance structural efficiency and failure resistance, offering a practical methodology for the design of advanced composite laminates with spatially varying properties.