

CONSTRAINED TOPOLOGY OPTIMIZATION OF CLOSED NURBS CURVES FOR CONTINUOUS FIBER 3D PRINTING

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Abstract

The growing demand for lightweight, high-performance components has driven significant advancements in Continuous Fiber Reinforced Composites (CFRC) manufactured with 3D printing. The design flexibility of 3D printing has enabled the integration of topology optimization as a potential design tool for this technology. However, complex geometries generated by topology optimization often present significant challenges for reinforcement with long continuous fibers, which have shown better mechanical performance compared to short-fiber alternatives. Continuous fibers require uninterrupted paths that are difficult to achieve with the complex layouts of optimized structures.

This work presents a topology optimization framework specifically designed for closed-loop continuous fiber reinforcement, compatible with offset infill manufacturing patterns, which are common in commercial 3D printers of continuous fibers. The proposed strategy models the reinforcement as a series of closed Non-Uniform Rational B-Spline (NURBS) curves. These curves are mapped onto the design space using a geometry projection method, where the coordinates and weights of the NURBS control points serve as the design variables.

To ensure the manufacturability of the optimized design, the framework incorporates a set of geometric constraints. Specifically, it enforces constraints on minimum curvature radii and minimum distances between control points to ensure numerical stability. In addition, a non-overlapping constraint is implemented to prevent both self-intersection of individual loops and mutual overlap between adjacent fibers within the printing plane. This approach ensures that the resulting designs can be directly fabricated using concentric offset strategies without path planning conflicts.

Numerical examples demonstrate the effectiveness of the method in generating optimized, multi-loop fiber reinforcement. The results confirm that the framework successfully balances structural stiffness with manufacturability, providing continuous, non-overlapping reinforcement patterns that preserve the high mechanical performance of long continuous fibers.