Tailoring Nonlinear Cellular Material Response through Topology Optimization

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ABSTRACT

Computational topology optimization is used to tailor the nonlinear response of periodic cellular materials. Material design via topology optimization has been achieved in the past for several linear properties, including (for example) elastic, thermal conduction, and fluid permeability properties, and various combinations thereof. We propose extending this successful design framework to properties governed by nonlinear mechanics, including strength and toughness. Different nonlinear mechanisms are considered, including plasticity and finite deformations, with the goal of manipulating these mechanisms through topology to gain desirable nonlinear material behavior. Numerical instabilities, including those associated with linear mechanics (mesh dependency, checkerboard patterns) and nonlinear mechanics (singularities, excessive element distortion), are circumvented by leveraging properties of Heaviside Projection. The approach is demonstrated on a case study considering cellular materials and different topologies are shown to result when maximizing for stiffness, first yield, or toughness, and that more useful combinations of properties result when optimizing for combinations of these properties. Optimized specimens and corresponding experimental results are also presented for comparison to computational predictions.