Buckling strength topology optimization of 2D periodic materials based on linearized bifurcation analysis

Low density cellular materials may offer excellent mechanical properties and find wide applicability in lightweight design and infill structures for additive manufacturing, yet currently existing material structures are still far away from their theoretical limit in terms of compressive strength. To explore the existing potential, this paper presents a topology optimization framework for designing periodic cellular materials with maximized strength under compressive loading. Under this condition, the limiting factor of strength is the failure mechanism of buckling instability in the microstructure. In order to predict microstructural buckling, a simplified model based on homogenization theory, a linearized stability criterion and Floquet-Bloch theory is employed. Subsequently, a gradient-based topology optimization problem is formulated to maximize the buckling strength of the most critical failure mode. The framework is utilized to optimize square, triangular and hexagonal microstructures for three different macroscopic load conditions including biaxial, uniaxial and shear loading, and performance assessments are conducted by computation of associated failure surfaces in macroscopic stress space. In all cases, the optimized designs turn out to be first-order hierarchical type microstructures which offer major improvements of strength compared to the initial zero-order designs, however, the gains come at the cost of reductions in stiffness. Furthermore, it is illustrated how imposing geometric symmetry constraints can be exploited to control the shape of the failure surfaces.

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