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Topological Design of Negative Poisson's Ratio Material Microstructure Under Large Deformation with a Gradient-Free Method

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ABSTRACT

Lightweight metamaterials with negative Poisson's ratios (NPRs) have great potential for controlling deformation, absorbing energy, etc. The topology optimization [1] technique is an effective way to design metamaterials. However, as studied in [2], the NPR metamaterial configuration obtained under small deformation assumption may not maintain the desired Poisson's ratio under relatively large deformation conditions. This paper focuses on the large-deformation NPR metamaterial design based on a gradient-free topology optimization method, i.e. the material-field series expansion (MFSE) method [3]. The metamaterial's performance is evaluated using the finite element method, taking into account the geometry nonlinearity. By considering the spatial correlation of the microstructural topology, the MFSE method significantly reduces the number of design variables. An optimization formulation is adopted to minimize the error between the desired and the current metamaterial performances, taking advantage of the MFSE topological parameterization. A two-step gradient-free optimization solution strategy based on the Kriging surrogate model is suggested. Several target NPRs design problems are considered in the numerical examples and the optimized metamaterial performances are checked with conformal mesh in the commercial software. The numerical calculation results show that this method can generate metamaterials that can maintain the required NPR well under large deformation conditions. This method does not require the non-trivial sensitivity derivation in the current design scenario, and provides an alternative way to design metamaterials with nonlinearities for engineers.

KEYWORDS

Topology optimization; negative poisson's ratios (NPRs); metamaterials; MFSE; kriging surrogate model

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