Design of materials with prescribed nonlinear properties

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Abstract

Over the last two decades, topology optimization methods have been employed to various design problems [1]. So far, most design problems have been done using linear finite element analysis by assuming small deformation. A small number of research works have considered structural responses under large deformation, including stiffness optimization and design of compliant mechanisms [2-4]. Based on the homogenization method, topology optimization has been demonstrated to be an effective approach to design novel materials with extreme properties [5], in particular negative Poisson's ratio materials, which are attractive for different applications, e.g. versatile motion transformers, hydrophones and other sensors. However, under large deformation, negative Poisson's ratio materials may exhibit nonlinear Poisson's ratio functions with respect to strain [6].

In this study, we design novel materials with prescribed nonlinear properties. The geometrically nonlinear behavior of the periodic microstructure is simulated using a total Lagrangian finite element formation, and solved by a Newton-Raphson algorithm. The optimization problem is formulated to minimize the errors between the actual and prescribed properties in a given strain range. Truss based materials have been designed to obtain different prescribed nonlinear properties. Materials with prescribed nonlinear strain-stress curves have been designed by minimizing the difference between average stresses in the microstructure and prescribed ones. It is shown that the optimized materials can achieve rubber-like response. Moreover, materials have been designed to obtain strain-independent Poisson's ratio. Different strain-independent Poisson's ratios, such as -1.0, 0.0 and 1.0, have been achieved by the optimized materials in a strain range of [0, 0.3].

It is expected to extend the current work to continuum structures. In the continuum problem, numerical instability may arise due to excessive deformation in low stiffness elements, and must be tackled during the optimization procedure.

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