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Nonlinear wave propagation analysis in hyperelastic 1D microstructured materials constructed by homogenization

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Highlights

- Hyperelastic first and second gradient continuum models are identified for microstructured materials relying on a dedicated homogenization method.
- Wave propagation analysis is performed accounting for geometrical nonlinearities within microstructured beams submitted to tension.
- Two different wave propagation modes are obtained: an evanescent subsonic mode for a high nonlinearity, vanishing beyond a given value of the wavenumber k, and a supersonic mode for a weak nonlinearity.

Abstract

We analyze the acoustic properties of microstructured beams including a repetitive network material undergoing configuration changes leading to geometrical nonlinearities. The effective constitutive law is evaluated successively as an effective first and second order nonlinear grade 1D continuum, based on a strain driven incremental scheme written over the reference unit cell, taking into account the changes of the lattice geometry. The dynamical equations of motion are next written, leading to specific dispersion relations. The presence of second gradient order term in the nonlinear equation of motion leads to the presence of two different modes: an evanescent subsonic mode for high nonlinearity that vanishes beyond certain values of wave number, and a supersonic mode for a weak nonlinearity. This methodology is applied to analyze wave propagation within different microstructures, including the regular and reentrant hexagons, and plain weave textile pattern.

1. Introduction

The analysis of wave propagation in hyperelastic media depends initially on the type of constitutive law. When considering microstructured solids prone to large deformations, the effective constitutive law written in the large strains regime reflects the impact of the microstructure, and can be obtained thanks to suitable homogenization schemes instead of being postulated directly in a phenomenological manner.
In recent years, different materials have been analyzed in the context of anisotropic finite-strain elasticity; these include composites, foam-like structures, 2D and 3D textile preforms and synthetic solids [1-3].
We shall in the current paper use the discrete asymptotic homogenization method [3-5] which is perfectly suited to the discrete architecture of different types of networks which can modeled with beam like structural elements, in order to compute their effective nonlinear static and dynamic response. Due to the very small bending rigidity of the beams building such networks, the nonlinear response is essentially due to the change of network configuration, meaning that the beam orientation and length change with ongoing deformation. We shall thus mostly account for geometrical nonlinearities at the microlevel of the network. The geometrical nonlinear behavior of cellular structures and network materials has been extensively studied in [6, 7, 8, 9], considering especially foams, and using simplified pin jointed models for which the bending contribution of the skeleton struts has been neglected. A lot of attention has been paid so far in the literature to the propagation of elastic waves in the linear context [10-13], whereas only a few authors analyzed so far wave propagation in nonlinear media. The propagation of elastic waves in nonlinear materials and structures is accompanied by a number of new phenomena such as amplitude-dependent dispersion relations, or the