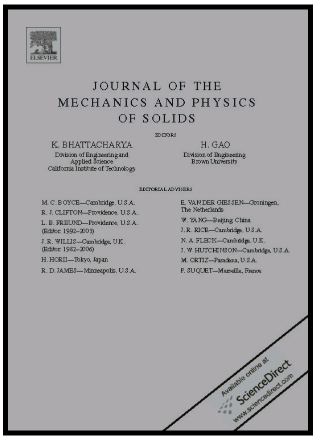

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Elastic wave propagation in finitely deformed layered materials

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Abstract

We analyze elastic wave propagation in highly deformable layered media with isotropic hyperelastic phases. Band gap structures are calculated for the periodic laminates undergoing large deformations. Compact explicit expressions for the phase and group velocities are derived for the long waves propagating in the finitely deformed composites. Elastic wave characteristics and band gaps are shown to be highly tunable by deformation. The influence of deformation on shear and pressure wave band gaps for materials with various composition and constituent properties are studied, finding advantageous compositions for producing highly tunable complete band gaps in low-frequency ranges. The shear wave band gaps are influenced through the deformation induced changes in effective material properties, whereas pressure wave band gaps are mostly influenced by deformation induced geometry changes. The wide shear wave band gaps are found in the laminates with small volume fractions of a soft phase embedded in a stiffer material; pressure wave band gaps of the low-frequency range appear in the laminates with thin highly compressible layers embedded in a nearly incompressible phase. Thus, by constructing composites with a small amount of a highly compressible phase, wide complete band gaps at the low-frequency range can be achieved; furthermore, these band gaps are shown to be highly tunable by deformation.

Keywords: Layered materials, Elastic waves, Finite deformations, Band gaps

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1. Introduction

Metamaterials have attracted considerable attention due to their unusual properties such as negative elastic moduli [6], mass density [14], and negative refractive index [31]. *Soft* metamaterials, capable of large deformations, open promising opportunities for tuning and switching acoustic properties by deformation [10, 38, 7]. Even relatively simple deformable homogeneous materials can exhibit switchable acoustic functionalities upon applied deformations [18]. Indeed, soft *microstructured* metamaterials possess even greater capability for transforming and tuning wave propagation by external stimuli, such as mechanical loading [38, 11], electric [21, 20] or magnetic fields [17]. Applied deformation can lead to a change in the internal geometry of a phononic crystal giving rise to formation and/or transformation of phononic band gaps (BGs) [28, 29, 46, 24]. Moreover, local material properties can also change as a result of inhomogeneous distribution of local deformation fields leading to local softening or stiffening [19]. In fact, these effects are of significant importance for understanding elastic wave phenomena in soft biological tissues that are frequently found in a deformed state due to growth or other biological processes. Large deformations together with material heterogeneity may give rise to elastic instabilities [12, 39, 30, 44] – a phenomenon actively used in material design by nature [15]. Recently, this approach has been employed to utilize instability-induced dramatic microstructure transformations and achieve remarkable tunability of acoustic metamaterials [10, 38, 7]. Inspired by possible applications – such as noise reducers, acoustic mirrors and filters, waveguides, to name a few – a number of recent works were dedicated to the analysis of influence of material parameters [51], topologies [33], deformations [10, 43],

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