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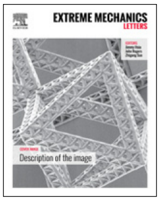

Coupling local resonance with Bragg band gaps in single-phase mechanical metamaterials

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ABSTRACT

Various strategies have been proposed in recent years in the field of mechanical metamaterials to widen band gaps emerging due to either Bragg scattering or to local resonance effects. One of these is to exploit coupled Bragg and local resonance band gaps. This effect has been theoretically studied and experimentally demonstrated in the past for two- and three-phase mechanical metamaterials, which are usually complicated in structure and suffer from the drawback of difficult practical implementation. To avoid this problem, we theoretically analyze for the first time a single-phase solid metamaterial with so-called quasi-resonant Bragg band gaps. We show evidence that the latter are achieved by obtaining an overlap of the Bragg band gap with local resonance modes of the *matrix* material, instead of the inclusion. This strategy appears to provide wide and stable band gaps with almost unchanged width and frequencies for varying inclusion dimensions. The conditions of existence of these band gaps are characterized in detail using metamaterial models. Wave attenuation mechanisms are also studied and transmission analysis confirms efficient wave filtering performance. Mechanical metamaterials with quasi-resonant Bragg band gaps may thus be used to guide the design of practically oriented metamaterials for a wide range of applications.

1. Introduction

Mechanical metamaterials are engineered periodic composites with exceptional dynamic properties. The possibility they provide to manipulate and attenuate elastic waves at various frequencies can be exploited for various applications, ranging from seismic shielding [1,2] or noise abatement [3] to subwavelength imaging [4] and thermal management [5]. These fundamental properties arise from metamaterial geometry and/or composition and are due to the existence of band gaps (BGs)—frequency ranges, in which wave propagation is inhibited. The frequencies and width of BGs depend on the contrast between mechanical properties of material phases and lattice parameters. Bragg BGs occur in Phononic Crystals (PCs) through destructive interference of waves scattered from periodic inhomogeneities at wavelengths comparable to the spatial periodicity of the lattice [6,7]. The resulting high operating frequencies make this type of structure unsuitable for noise mitigation or vibration isolation. Instead, hybridization BGs [8,9] are typically induced in metamaterials by resonant modes of the constituents, which interact with the wave field in the embedding medium [10]. These BGs are independent of the spatial configuration of the metamaterial and can be nucleated at much lower frequencies than Bragg BGs, but are usually rather narrow and require heavy resonators [10–14]. Thus, due to their complicated design or limited working performance [13,15,16], mechanical metamaterials are yet to become widespread in applications.

One promising solution to overcome these limitations is to exploit overlapping Bragg and local resonance BGs. The co-existence of both BG types in the same structure has already been demonstrated theoretically and experimentally for different systems at various frequencies [17–23], including in 3D sonic solid metamaterials with coated inclusions [24,25]. These studies

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