IOP Publishing New J. Phys. 20 (2018) 073051 https://doi.org/10.1088/1367-2630/aad354

New Journal of Physics
The open access journal at the forefront of physics

Deutsche Physikalische Gesellschaft DPG
IOP Institute of Physics
Published in partnership with: Deutsche Physikalische Gesellschaft and the Institute of Physics

OPEN ACCESS

RECEIVED
5 April 2018

REVISED
9 July 2018

ACCEPTED FOR PUBLICATION
13 July 2018

PUBLISHED
31 July 2018

PAPER

Accordion-like metamaterials with tunable ultra-wide low-frequency band gaps

A O Krushynska[1,7], A Amendola[2], F Bosia[3], C Daraio[4], N M Pugno[1,5,6] and F Fraternali[2]

1 Laboratory of Bio-Inspired and Graphene Nanomechanics, Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano, 77, I-38123 Trento, Italy
2 Department of Civil Engineering, University of Salerno, Via Giovanni Paolo II, 132, I-84084 Fisciano (SA), Italy
3 Department of Physics and Nanostrucured Interfaces and Surfaces Centre, University of Turin, Via P. Guria, 1, I-10125 Turin, Italy
4 Engineering and Applied Science, California Institute of Technology, Pasadena, CA 91125, United States of America
5 School of Engineering and Materials Science, Queen Mary University of London, Mile End Road, London E1 4NS, United Kingdom
6 Ket Labs, Edoardo Amaldi Foundation, Italian Space Agency, Via del Politecnico snc, Rome I-00133, Italy
7 Author to whom any correspondence should be addressed.

E-mail: **akrushynska@gmail.com**, **adaamendola1@unisa.it**, **fbosia@unito.it**, **daraio@caltech.edu**, **nicola.pugno@unitn.it** and **f.fraternali@unisa.it**

Keywords: wave dynamics, elastic metamaterial, tensegrity structure, ultra-wide band gap, low-frequency range

Supplementary material for this article is available online

Abstract

Composite materials with engineered band gaps are promising solutions for wave control and vibration mitigation at various frequency scales. Despite recent advances in the design of phononic crystals and acoustic metamaterials, the generation of wide low-frequency band gaps in practically feasible configurations remains a challenge. Here, we present a class of lightweight metamaterials capable of strongly attenuating low-frequency elastic waves, and investigate this behavior by numerical simulations. For their realization, tensegrity prisms are alternated with solid discs in periodic arrangements that we call 'accordion-like' meta-structures. They are characterized by extremely wide band gaps and uniform wave attenuation at low frequencies that distinguish them from existing designs with limited performance at low-frequencies or excessively large sizes. To achieve these properties, the meta-structures exploit Bragg and local resonance mechanisms together with decoupling of translational and bending modes. This combination allows one to implement selective control of the pass and gap frequencies and to reduce the number of structural modes. We demonstrate that the meta-structural attenuation performance is insensitive to variations of geometric and material properties and can be tuned by varying the level of prestress in the tensegrity units. The developed design concept is an elegant solution that could be of use in impact protection, vibration mitigation, or noise control under strict weight limitations.

1. Introduction

Engineered composites capable of manipulating elastic waves in an unconventional way [1–3] are rapidly becoming attractive in multiple application areas, including seismic wave shielding [4, 5], sub-wavelength imaging [6], vibration abatement [7, 8], acoustic cloaking [9], sound control [10], etc. A distinguishing peculiarity of these materials, also known as meta-structures [11], is their ability to generate band gaps—frequency ranges with inhibited wave propagation. In phononic crystals, periodic patterning of constituents or material phases activates Bragg scattering [12] opening band gaps at wavelengths comparable with the spatial periodicity [7, 13]. Acoustic metamaterials exploit local resonances to induce low-frequency band gaps allowing the control of waves at much larger wavelengths than their microstructural scales [14–16]. The local resonance effect is induced by coated inclusions or pillars, increasing the total structural weight. In this case, wave attenuation is efficient only at the resonator eigenfrequencies and abruptly decreases away from them [5, 14, 17–19]. Therefore, broadband control of low-frequency waves using lightweight structures remains a challenge.