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PII: S0263-8223(17)30167-8
DOI: http://dx.doi.org/10.1016/j.compstruct.2017.01.073
Reference: COST 8207

To appear in: *Composite Structures*

Received Date: 18 January 2017
Accepted Date: 30 January 2017

Please cite this article as: Fabbrocino, F., Amendola, A., Discrete-to-continuum approaches to the mechanics of pentamode bearings, *Composite Structures* (2017), doi: http://dx.doi.org/10.1016/j.compstruct.2017.01.073

DISCRETE-TO-CONTINUUM APPROACHES TO THE MECHANICS OF PENTAMODE BEARINGS

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Keywords: Periodic Lattices, Elastic Moduli, Multiscale Approaches, Seismic Isolation.

Abstract

This work deals with the multiscale modeling of the mechanical response of pentamode lattices, and a preliminary study on engineering applications of structural bearings formed by pentamode lattices confined between stiffening plates. Numerical and experimental results show that the confinement effect played by the stiffening plates, the geometry and mechanical properties of the junctions strongly influence the overall stiffness properties of such structures. As a result, the mechanics of confined pentamode lattices significantly differs from that of unconfined lattices, being able to accommodate compression and tension vertical loads, and featuring performance-based response under shear loading. Their application for use in anti-seismic system development and/or as shear-wave band gap systems awaits attention.

1. Introduction

The class of "extremal materials" is attracting the attention from different research fields because of their unusual behavior [1]-[11]. These structures are called uni-mode, bi-mode, tri-mode, quadra-mode and penta-mode materials, accordingly to the number of the soft modes of deformation they can achieve [1]-[3]. Pentamode lattices are particular meta-materials belonging to the class of extremal materials, which feature a primitive unit cell equipped with four rods meeting at a point [4]-[11]. These structures are characterized by a very large value of the bulk modulus (B), compared to the value of the shear modulus (G), and behave very soft in five out of six principal directions of the elasticity tensor [1]-[3]. In the last few years, different 3D printing techniques have been used to manufacture pentamode lattice structures with different geometries and materials (refer, e.g., to [4], [5],[8] and references therein).

The peculiar mechanical behavior of pentamode lattices motivates researchers to investigate their use in transformation acoustics and elasto-mechanical cloak [6]. Their potential in different engineering fields, such as, e.g., structural engineering, has not been largely explored yet. In this area, what is particularly interesting is the use of pentamode structural "crystals" for the design of novel impact or seismic protection devices. Such a research line has recently appeared in the literature, with the aim of developing performance-based, vibration-isolation devices [8]-[11]. The results obtained so far in this field have shown several analogies between the mechanics of confined pentamode lattices [8]-[11] and that of elastomeric and triple friction pendulum bearings [12]-[21].

Elastomeric bearings include low-damping rubber bearings, high-damping rubber bearings and lead-rubber bearings [13]. In the latter, the energy characteristic dissipation is enhanced by the presence of one or more lead cores deformed during the motion. The mechanical behavior of the low-damping rubber bearings is essentially elastic, characterized by very low values of the Equivalent Viscous Damping coefficient. High-damping rubber bearings are made of elastomeric material with additives to increase the dissipative capacity of the system. The friction based isolators instead allow significant ranges of motion with devices of shallow profile that dissipate energy through the friction [18][19]. In some sliding devices the motion of a pendulum is reproduced in order to impose a specific design frequency to the possible motion of the structure [22]. The most common energy dissipation devices include viscous dampers, friction based devices and yielding based devices [12][13][14]. More recent advances in anti-seismic devices include elastomeric bearings equipped with stiffening plates made of fiber-reinforced composites [23]-[25], as well as devices that make use of shape memory alloys (SMAs) and shock transmitter units (STUs) [20]. SMAs offer complete shape recovery after experiencing large strains and offer significant energy dissipation. The advantage of STUs is that they