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Numerical studies on composite meta-material structure for mid to low frequency elastic wave mitigation

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Abstract: In the past decade, meta-materials have drawn increasing attention from researchers due to their unique properties, including wave attenuation with potential applications in acoustic engineering. A number of meta-material designs have been proposed for wave attenuation at different frequencies. In this work, a new configuration of chiral honeycomb composites is proposed for the attenuation of mid to low frequency elastic waves in structural applications. The dispersion characteristics of the proposed structure were investigated numerically. The results show that the proposed structure is able to create multiple bandgaps at mid frequency range. Interestingly, two extra bandgaps induced by local resonance effect can be created with slight reduction of the chiral angle of the structural unit cell, and one bandgap is located in the low frequency range. The wave attenuation performance of the proposed composite structure was also simulated using sound transmission loss finite element analysis, demonstrating its potential in real applications.

1. INTRODUCTION

Meta-materials have become a popular research topic due to their unique properties including auxetic behavior (also known as negative Poisson's ratio) [1-3], negative effective elastic constants [4, 5], as well as the properties of wave guidance and wave mitigation [6-8]. These properties can also be easily adjusted by manipulating spatial arrangement of the cellular structure, which provides opportunities for shape design and functional optimization.

Potential meta-material designs for wave mitigation are particularly attractive in acoustic engineering applications. Many different phononic structures have been proposed and examined by physicists and engineers. Work has also been done to determine the relationship between lattice geometry and phononic bandgaps [8, 9]. In several studies, phononic crystal structure was analyzed using equivalent mass-spring systems [10, 11]. Ruzzene *et al*. [12] claimed in his work that the re-entrant honeycomb geometries with negative Poisson's ratio were effective in constraining the direction of wave propagation. Most of the phononic structures reported previously exhibit wave attenuation properties within bandgaps due to the Bragg scattering phenomenon. However, this phenomenon limits the frequency range of waves that can be attenuated given the dimensional constraints of phononic structures. In order to tackle low frequency elastic waves, Liu *et al*. [13] proposed the concept of locally resonant structure, and the analytical solutions were provided in his later work [14]. Thereafter, more research has been done on locally resonant materials [4, 5, 15-19]. For the consideration of weight reduction, the membrane type metamaterial with negative effective density was also proposed [20-22].

In order to widen the bandgap range for the meta-materials, Liu *et al*. [23] and Zhu *et al*. [24] proposed to integrate the "coating ball" into the hexagonal chiral honeycomb base structure. Their work attributes the formation of low-frequency bandgap to the local resonance effect of coating ball, and the formation of higher one to the Bragg scattering effect induced by the base structure. The hexagonal chiral honeycomb structure had been proven to be a good candidate for the base structure in such design. Spadoni and Tee *et al*. [25-27] had done a comprehensive study on the phononic properties of hexagonal chiral lattices. His work suggests that the chiral structure has great potential benefits in terms of sound-transmission reduction and vibration isolation, and its design flexibility offers opportunities to enhance the structure-acoustic performance in different applications. In addition, Wang *et al.* [28] also proposed a locally resonant metamaterial with chiral comb-like interlayers, and established comprehensive analytical solutions to predict the band edges.

The main focus of this study is on the two-dimensional meta-material design for in-plane wave filtering within the mid to low frequency range (1-2300Hz), because wave mitigation at this frequency range will be of interest in structural applications. A hexagonal chiral honeycomb structure was adopted as the base structure. However, instead of placing the "coating mass" into holes of the base structure, which is the practice adopted by Liu et al. [23] and Zhu et al. [24], we propose a simpler composite meta-material structure by directly inserting mass inclusion into a chiral base structure. This design is simpler and easier to manufacture. In Section 3.2, it is shown that the formation of two original bandgaps is quite different from the reported cases in [23] and [24]. In addition, soft material was adopted for the hexagonal chiral honeycomb structure to lower the locations of bandgaps associated with the base structure. The dynamic characteristics of the proposed unit cell were analyzed numerically, and the band diagram of the proposed structure was generated. A parametric study was carried out to elucidate the tunability of the proposed structure and demonstrate the possible ways to enlarge the range of its bandgaps. Based on the results of parametric studies, a modified structure was then proposed, and the wave dispersion characteristics in the modified structure were analyzed. The modified structure was