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Natural sonic crystal absorber constituted of Aegagropilae fiber network

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Abstract
We present a 3-dimensional fully natural sonic crystal composed of Aegagropilae that are spherical aggregates resulting from the decomposition of Posidonia Oceanica. The fiber network is first acoustically characterized, providing insights on this natural fiber entanglement due to turbulent flow. The seagrass fibrous spheres are then arranged on a principal cubic lattice. Band diagram and topology of this structure are analyzed, notably via Argand representation of its scattering elements. This fully natural sonic crystal exhibits excellent sound absorbing properties and thus represents a sustainable alternative that could outperform conventional acoustic materials.

Keywords: Natural sonic crystal, Acoustic characterization of Aegagropilae, Perfect absorption, Topology.

1 Introduction

Complex biological structures usually result from the adaption of living bodies to their environmental constraints. These structures generally ensure several functionalities in nature [1]. Very few of them are the result of natural dynamic processes involving organic waste, apparently formed for no particular reason and without ensuring any specific functionality. Aegagropilae such as Posidonia balls are the archetype of these organic structures. They are natural spherical aggregates formed by entangled fibers as a result of the decomposition of Posidonia Oceanica.

2 Fully natural 3-dimensional sonic crystal

Aegagropilae spheres were cut into four parts, resulting in quarter-spheres. Six Aegagropilae quarter spheres of radii 20 ± 1 mm are placed in a square cross-sectional impedance tube with side $d/2 = 21.5$ mm, their centers being separated by a distance $d = 43$ mm. A finite depth perfectly periodic structure is created, composed of six layers incorporating spheres arranged over a square lattice, thus mimicking a finite depth primitive cubic system with a filling fraction $ff \approx 0.4$. The reflection and transmission coefficients are measured via 4 flush mounted microphones for frequencies below the cut-off frequency of the impedance tube.

Figure 1(a) depicts the absolute value of the reflection and transmission coefficients, $|R|$ and $|T|$, as well as the absorption coefficient $\alpha = 1 - |R|^2 - |T|^2$ measured experimentally and calculated by the Finite Element Method. Both measured and simulated coefficients are in good agreement assuming sphere radii of 19.5 mm and fiber network properties as determined previously. The Bragg interference is clearly noticed around $f_B \approx c_0/2d \leq 3950$ Hz, as highlighted by the grey regions. While Bragg interference is usually associated with a band gap, preventing the propagation of acoustic wave, therefore leading to a minimum transmission, the weak impedance contrast between the soft Aegagropilae spheres and the air medium almost prevents the band gap translation in the transmission coefficient. The quasi absence of band gap is also confirmed by the dispersion relation depicted in Fig. 1(b-c). In addition, the reflection coefficient presents five smooth peaks (and six minima) before the Bragg frequency corresponding to the Fabry-Perot interference arising from the six layers (see Fig. 1). These Fabry-Perot interferences are not visible in the transmission coefficient absolute value because of the attenuation.

To get further insights on the acoustic behavior of this primitive cubic system, the Argand diagram [2] of R and T, i.e., their values in the complex plane in function of frequency, are depicted in Fig. 1(d). Of particular interest is that R describes half a loop from the positive to the negative real half spaces within the first band gap as a translation of the topological character of the gap. Within the second bulk band, R goes back from negative to positive real half spaces around 5500 Hz as a manifestation of the symmetry inversion of the system [3]. This band is thus a nontrivial bulk band with two opposite edge states. A quasi-perfect absorption peak is also noticed around the symmetry inversion frequency at 5500 Hz. The absorption coefficient is higher than that of a full $6 \times d$-thick layer occupied by the fibrous materials as can be seen in Fig. 1(a) for most of the frequency range considered.

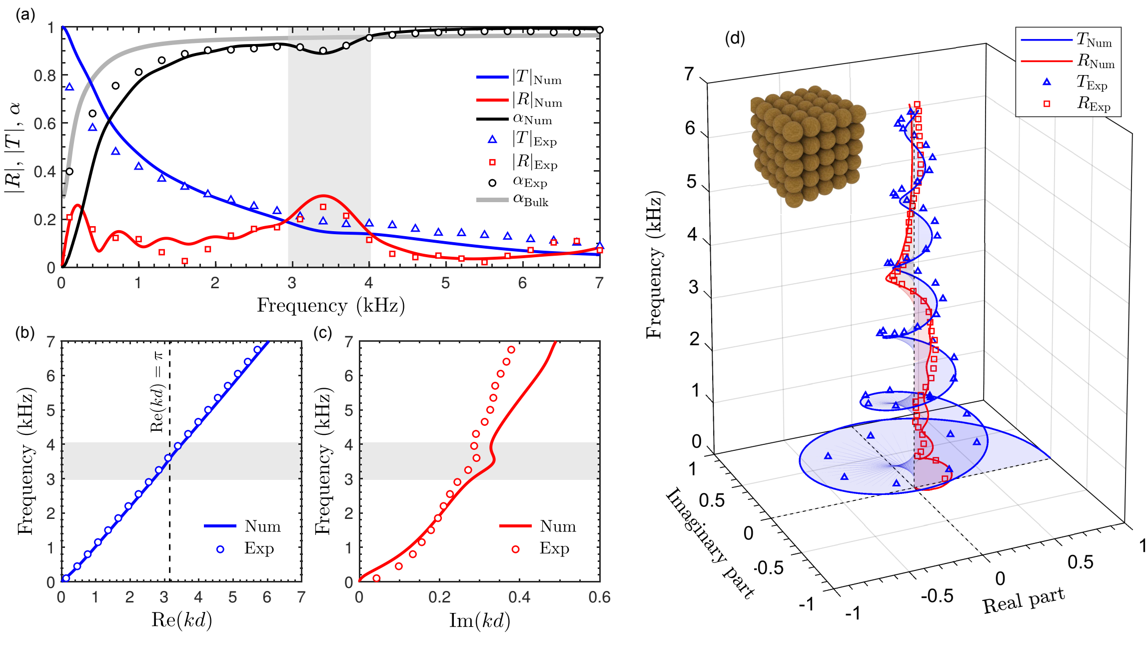

Figure 1: Scattering properties of a 3D primitive cubic arrangement of periodicity $d = 43$ mm, made of $N = 6$ Aegagropilae spheres of radius 19.5 mm. (a) Absorption, reflection and transmission coefficients calculated numerically (black, red and blue continuous curves) and measured experimentally (open black circles, open red squares, and open blue triangles). The grey continuous line represents the absorption coefficient of a bulk material of identical thickness. (b) Real and (c) imaginary parts of the complex wave number reconstructed numerically (continuous lines) and experimentally (markers). (d) Argand diagram of T (blue curve) and R (red curve) over the frequency range [0 Hz,7000 Hz] obtained numerically (continuous) and experimentally (markers).

3 Conclusions

The acoustic behavior of this fully natural Aegagropilae sonic crystal reveals several outstanding aspects of the fiber network structure and sonic crystals constituted of soft and dissipative medium scatterers, but also links between sonic crystal topology and acoustic properties in the day to day life. First, the fiber network micro-structure has been assessed by acoustical means. The acoustic properties of the Aegagropilae core are found highly correlated to information provided by stereo microscopic image. Acoustic characterization is thus a cheap, easy and efficient tool to study natural fiber entanglement and so Aegagropilae formation. Second, the dissipative and soft natural sonic crystal was found to exhibit specific fetaures, notably the almost unique translation of the Bragg interference in the reflection coefficient. Nevertheless, the Argand diagram of both R ad T are found highly informative for the edge state qualification. The second bulk band of this sonic crystal is a nontrivial one with a symmetry inversion. Third, topology analysis of the sonic crystal explains the absorbing efficiency of the structure that largely overcome that of a layer of identical thickness and material. Aegrophilae fiber sonic crystals are also fully natural structures that outperform acoustic properties of usual acoustic material, the use of which does not require transformation. In terms of proving the existence of natural acoustic/elastic metamaterials, Aegagropilae are excellent candidates. More information can be found in Ref. [4].

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