

Backing effects on the underwater acoustic absorption of a viscoelastic slab with locally resonant scatterers



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ARTICLE INFO

Article history:

Received 19 July 2012

Received in revised form 22 July 2013

Accepted 25 July 2013

Available online 25 August 2013

Keywords:

Underwater acoustics absorption

Resonance modes

Locally resonant scatterers

Steel backing

ABSTRACT

Backing effects on the underwater acoustic absorption of a viscoelastic polymer slab embedded with locally resonant scatterers are reported. The polymer slab is embedded with two layers of locally resonant scatterers, i.e. Al spheres coated by soft silicon rubber. Theoretical absorption coefficients of the polymer slab under different backings using a layer multiple scattering method show good agreement with the experimental results, which supports unambiguously the experimental observation. Then relations between the resonance modes and the low-frequency absorption peaks of the composite slab are clarified to address the absorption mechanisms. It shows that the mass of the steel backing affects evidently the low-frequency absorption, the absorption peak shifts to lower frequency range while increasing the backing mass.

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1. Introduction

Locally resonant sonic materials (LRSMs) are generally known as composite epoxy embedded with various heavy spheres coated by soft rubber with periodic or random position [1]. It has been shown that the soft coating layer and the heavy core are responsible for a band gap at low frequency about two orders of magnitude lower than that predicted by Bragg's condition. For practical applications, much effort has focused on air sound isolation induced by the gaps of different LRSMs [2]. Our investigations in acoustic dissipation by LRSMs have shown the low frequency acoustic absorption while considering the damping between the components [3,4]. Motivated by understanding of the energy dissipation in LRSMs, the locally resonant scatterers (LRSs) are introduced to improve the low-frequency acoustic absorption of the water impedance-matched polymer. Experimental measurement for acoustic absorption of viscoelastic polymer slabs embedded with LRSs has been reported [5]. The fundamental mechanism operating in the localized resonance for acoustic absorption has been investigated by referring the mode conversions during the Mie scattering of a single scatterer. Further, the shape of the scatterer has also been taken into account [6].

In fact, viscoelastic polymers with various shapes of cavities [7–14] or solid scatterers [15,16] are widely used in modern underwater acoustic applications. In most cases, scattering resonances including monopole and dipole types have been used to enhance

the low frequency absorption of viscoelastic composites. The monopole resonance may be induced by various cavities [7–14] and the dipole type may occur in case of heavy spheres [5,6,15,16]. For spherical scatterers, the absorption properties can be investigated conveniently by the layer multiple scattering method (LMSM), which is developed for gap analysis in phononic crystals [17,18]. The computation is simplified by using the Bloch theory. In comparison with the finite element method [9–11], although the flexibility in model is limited, there are two important advantages of the LMSM, one is the fast computation, and the other is the convenient understanding of the physical absorption mechanism.

For actual applications, the design of viscoelastic polymers embedded with locally resonant scatterers must consider the effect of the backing panel, which is not considered in our previous works [5,6]. The effects of the steel backing on the absorption are shown by the experimental and theoretical results in present paper. To address the absorption mechanisms, the relation of the resonance mode and the absorption peak of the composite slab is clarified based on the theoretical and experimental results. For comparisons, other backings are also considered.

2. Experiment

2.1. Model and sample

Fig. 1a shows a sketch model of an absorption structure including a sample slab and a backing under the Cartesian coordinates

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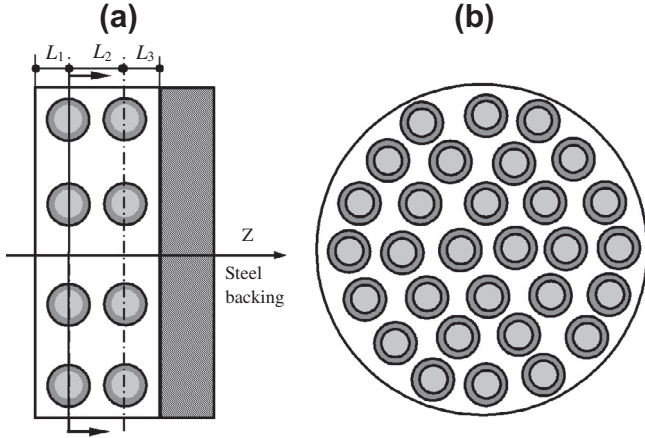


Fig. 1. (a) An absorption structure includes a composite slab and a steel backing. A plane wave is normally incident from the left along Z-axis. (b) Cross sections of the array of the scatterers of the sample in X–Y plane.

system. The whole structure can be considered as a sequence of different layers perpendicular to Z-axis. The sample is made of viscoelastic polymer embedded with two layers of LRSs. The inter-layer positions of the scatterers are denoted by L_i ($i = 1, 2, 3$), where L_1 denotes the center of the first layer of LRSs from the surface of the sample, L_2 is the distance between both the layers of LRSs, and L_3 denotes the space between the second layer of LRSs and the other surface of the sample. The thickness of the whole sample is 55 mm, and $L_1 = L_3 = 13.75$ mm, $L_2 = 27.5$ mm. Considering the limitation of the experiment apparatus, i.e. an impedance tube with an inner diameter $d = 120$ mm, the sample has an overall shape of short cylinder, which possesses a total diameter $D = 118$ mm. Each layer contains 30 scatterers, which are arranged in a quasi-triangular lattice with a mean adjacent distance 19.5 mm. The position of the scatterers is shown in Fig. 1b. Each LRS has a uniform spherical shape, in which a core sphere (radius r) coated by soft silicon rubber (with outer radius r_1), here $r = 5$ mm, and $r_1 = 7.5$ mm. In order to reduce the weight of the sample and facilitate the understanding of the resonance mode of the backing, we choose Al material as the core (which separates the resonances induced by the backing and the LRS). The soft coating is made of a type of two-component, room temperature vulcanizing silicone rubbers (RTV-2). It is available in a variety of hardness and suitable for various mold techniques. To begin, the core is coated by the silicon rubber using a self-made mold. Then the sample is fabricated by a hollow cylinder mold with an inner diameter $D = 118$ mm in the following procedure:

- (1) A polymer slab with thickness of $(L_1 - r_1)$ is made.
- (2) With a proper interval time, the coated scatterers are arranged on the surface of the polymer slab according to the design, and the rest space of the mold with a height $(L_1 + L_2 - r_1)$ is filled by the polymer.
- (3) The multi-layer sample is fabricated by an iterative procedure (2) according to L_i .

2.2. Absorption measurement method

Measurement of the absorption coefficient is conducted in a standard impedance tube apparatus. The steel tube has an inner (outer) diameter 120 mm (180 mm), and 5 m long. The schematic of the apparatus is showed in Fig. 2. The impedance tube is fully filled with water. A plane wave incidence is excited at one end of the tube while the sample is positioned at the other end, where various backings can be attached on the surface of the sample.

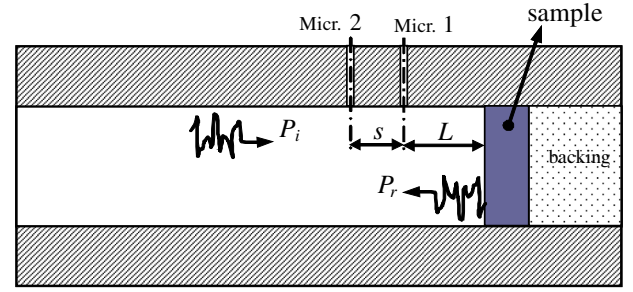


Fig. 2. Schematic diagram of the two-microphone tube apparatus.

Under normal incidence, unlike the backing, the impedance tube almost does not interact with the testing waves because the first order resonant frequency of the tube walls is higher than that of the upper cut-off frequency in the present test.

The experimental approach is based on a frequency response function method (FRFM) using two microphones [19]. One can get the frequency response function $\mathbf{H}_{12} = P_2/P_1$, P_1 and P_2 denoting the acoustic pressure measured by Micr. 1 and Micr. 2 respectively. The complex pressure reflection coefficient (R) is given by:

$$R = \frac{\mathbf{H}_{12}e^{ikL} - e^{jk(L+s)}}{e^{-jk(L+s)} - \mathbf{H}_{12}e^{-jkl}}, \quad (1)$$

where k is the wave number, defined as ω/c , and c is the acoustic velocity of the water. L denotes the distance between the Micr. 1 and the surface of the sample, and s is the spacing between two microphones. Considering the fully reflective termination in the experiment, the sound energy absorption coefficient (α) can be calculated from the following equation:

$$\alpha = 1 - |R|^2. \quad (2)$$

3. Discussion

3.1. Comparison of theoretical and experimental results

Generally, the steel backing can be considered as a finite steel slab followed by half infinite air. In order to understand the variation and the formation of the acoustic absorption of the sample under the steel backing, we compare the acoustic absorption of the sample under different backings in the experiment. We choose the backings as half infinite air (air backing in the following), steel

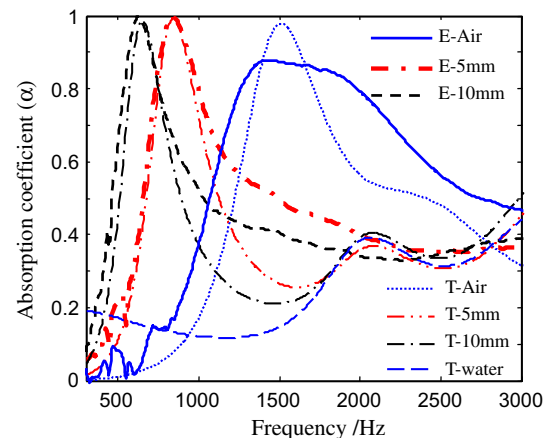


Fig. 3. Comparison of the experimental and theoretical results of the sample's absorption.

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