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A Wide Band Strong Acoustic Absorption in a Locally Network Anechoic Coating *

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Composite materials with interpenetrating network structures usually exhibit unexpected merit due to the cooperative interaction. Locally resonant phononic crystals (LRPC) exhibit excellent sound attenuation performance based on a periodical arrangement of sound wave scatters. Inspired by the interpenetrating network structure and the LRPC concept, we develop a locally network anechoic coating (LNAC) that can achieve a wide band of underwater strong acoustic absorption. The experimental results show that the LNAC possesses an excellent underwater acoustic absorbing capacity in a wide frequency range. Moreover, in order to investigate the impact of the interpenetrating network structure, we fabricate a faultage structure sample and the network is disconnected by hard polyurethane (PU). The experimental comparison between the LNAC and the faultage structure sample shows that the interpenetrating network structure of the LNAC plays an important role in achieving a wide band strong acoustic absorption.

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In past decades, various kinds of underwater anechoic materials have been extensively studied.[1−5] Up to date, the research has shown that locally resonant phononic crystal (LRPC) can be employed to fabricate underwater anechoic coatings. In the LRPC, a sound band gap can be generated at a certain frequency under full elastic scattering conditions.[6−11] When considering viscoelastic deformation, the maximum viscoelastic energy dissipation is generated at a locally resonant frequency.[12−14] The LRPC material is produced by periodically embedding the metallic balls with the soft polymer coating layer into a hard polymer matrix. However, this traditional approach to making anechoic coatings usually results in materials with microstructures consisting of isolated phases embedded in another homogeneous matrix material. Only into a matrix can dilute concentrations of a dispersed phase usually be incorporated.[15] It should be noticed that composite materials with interpenetrating network structures are usually found to exhibit unexpected merit due to the cooperative interaction among their component materials, such as bones and muscle in mammals and the trunks and limbs in plants.[16] Some organic organizations with simple interpenetrating network structures were synthesized to emulate biomineralization and used as supporting biomaterials.[17−20] Inspired by the above research works, we introduced an interpenetrating network structure into the LRPC and developed a locally network anechoic coating (LNAC). The strong acoustic absorption effect is expected to work efficiently in sound energy attenuation due to the enhancement of the multiple scattering of sound in the network structure.

The most striking difference between the LRPC and the LNAC is the different resonant unit structures. Resonant units in the LRPC have the same size and distribute discretely in the polymer matrix. Those resonant units in the LNAC have different sizes and are physically connected by the porous metal and the filled polymers. Underwater acoustic absorbing materials usually need to be designed to have strong absorbance in a wide range of frequencies. However, the LRPC has a strong absorption just at a certain narrow frequency, which runs afoul of the above requirement. To solve this conflict, we fabricate the LNAC and report its underwater strong acoustic absorption capability. This study focuses on the sound attenuation mechanism of the LNAC. Through the production of faultage structure samples that network structures are disconnected from by hard PU, we discuss the impact of the interpenetrating network structure on a wide band underwater acoustic absorption capacity of the LNAC. It should be noticed that the interpenetrating network structure is different from the traditional structure of anechoic materials. Therefore, the acoustic absorbing effect should be carefully investigated.

According to the LRPC formation mechanism, three kinds of materials with different elastic modulus were employed to produce the LNAC. They

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were aluminum foam, soft polyurethane (PU) and hard polyurethane (PU). Soft and hard PUs were synthesized referring to the method reported in the literature.[21,22] The aluminum foam (the average pore size had 4 mm in diameter and the porosity was 81%, i.e. the relative density was about 0.19) was used as a supporting skeleton in the experiments. First, the uncured soft PU was infiltrated into the aluminum foam. The uncured soft PU induced the formation of a thin coating layer with a thickness of about 0.3–0.6 mm on the interior wall of the aluminum foam. Secondly, after completely drying off this soft PU layer, the uncured hard PU was filled into the above composite supporting skeleton to fabricate LNAC, as shown in Fig. 1. The volume ratio of the hard PU, soft PU and aluminum is 2:2:1 in this material. We fabricated samples of different thickness utilizing the same synthesis route.

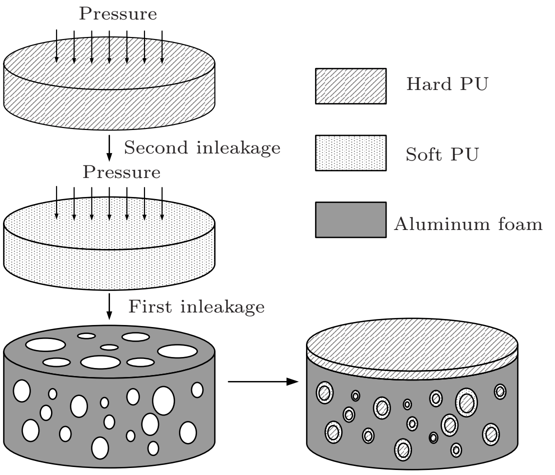

Fig. 1. A schematic of synthesis of the LNAC.

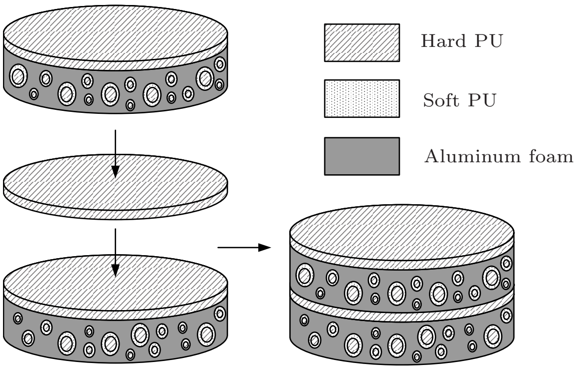

Fig. 2. A schematic of preparation process of the faultage structure sample.

In order to investigate the role of the interpenetrating network structure in a wide band underwater acoustic absorbing performance, we fabricated a faultage structure sample that the network was disconnected from by hard PU. Firstly, two LNAC samples of 0.5 cm thickness were produced by utilizing the above synthesis route. Then, both LNAC samples were glued together by a thin layer of uncured hard PU. Figure 2 shows a schematic of the preparation process for the faultage structure sample of 1 cm thickness. Other faultage structure samples of different thicknesses were prepared utilizing the same method.

Figure 3(a) displays interpenetrating network structures of the LNAC and (b) displays the faultage samples. The faultage structure sample with 2 cm thickness shown in Fig. 3(b) is fabricated utilizing four LNAC samples of 0.5 cm thickness to be glued together by hard PU. The paste interfaces of hard PU between adjacent layers can clearly be seen. The interpenetrating network structure of the LNAC is uniformly distributed in the sample. Because the hard PU coats some parts of the sample surface, the local network structure is comparatively fuzzy in the photos of Figs. 3(a) and 3(b). The underwater acoustic absorption coefficients of different samples were tested by a pulse tube in the air back mode at the Institute of Acoustics of the Chinese Academy of Sciences. To make experimental results comparable, all testing samples were fabricated with the same dimensions.

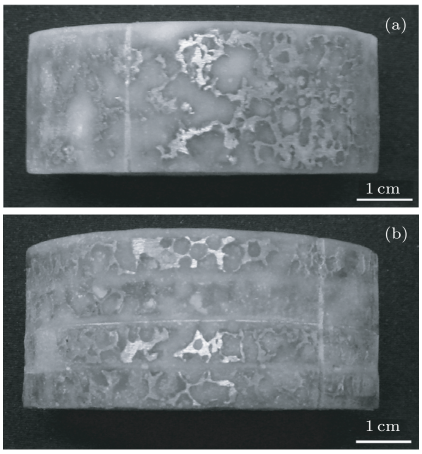

Fig. 3. Optical images of LNAC and faultage structure sample.

An LNAC resonator could be approximately described as coaxial cylindrical inclusions with two coaxial coating layers, as shown in Fig. 4(a). In some cases, the small unit of the LNAC could be seen as a similar structure of the LRPC. Figure 4(b) shows the cross-sectional image of a coated lead sphere that forms the basic structure unit in the LRPC.[6] In principle, the LNAC resonator has a resonant property similar to that of the LRPC.

Figures 5(a) and 5(b) illustrate the changes of acoustic absorption coefficients for the LNAC and faultage structure samples vs frequency. It can be seen that the spectra of sound absorption curves for the LNAC are different from that for the faultage structure sample. Figure 5(a) shows that the acoustic absorption coefficient of LNAC of 1 cm thickness is higher than that of the faultage structure sample in the frequency range between 14 kHz and 25 kHz. When the network integrity is completely preserved as for LNAC samples, the samples display a strong underwater acoustic absorption capability with absorption coefficients greater than 0.9 in a wide frequency range starting from 12 kHz. On the contrary, the underwater acoustic absorption coefficient of the faultage structure sample achieves its highest value at 12 kHz, beyond which the acoustic absorption coefficient decreases gradually with the increase of frequency. When the thickness of sample increases, the average acoustic absorption coefficients of the LNAC decrease and the maximum of acoustic absorption coefficients shifts to a low frequency. For the faultage structure sample of 2 cm thickness, the trend that the acoustic absorption coefficients decrease gradually with the increase of frequency does not change, as shown in Fig. 5(b). When the interpenetrating network structure is disconnected by hard PU, the acoustic absorption coefficient shows an oscillatory variation with the increase of frequency. It is noteworthy that the faultage structure sample of 2 cm thickness contains four folded LNAC layers and the faultage structure sample of 1 cm thickness contains only two LNAC layers. The acoustic absorption curve shows the increasing instable and oscillatory changes with the increase of the number of LNAC layers. Therefore, it is reasonable to deduce that the interpenetrating network structure plays an important role in keeping a stable wide band of strong acoustic absorption. The comparison of underwater acoustic absorbing experimental results between the LNAC and the faultage structure sample shows that the interpenetrating network structure impacts on achieving a wide band of strong acoustic absorption.

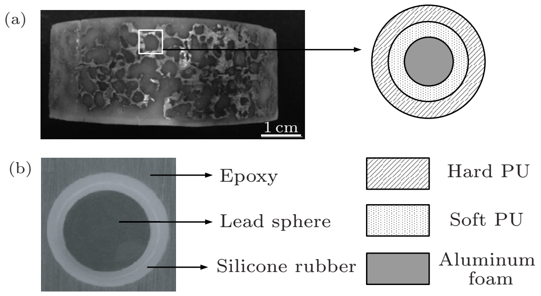

Fig. 4. Structure units of the LRPC[6] and the LNAC.

Composite materials with interpenetrating network structures are usually found to exhibit unexpected merit due to the cooperative interaction among their component materials. The LNAC presented here possesses resonator structure units similar to those in the LRPC, as shown in Fig. 4(a). From a geometrical point of view, these resonant units in the LNAC have a broad size distribution and vary in shape. They are substantively and closely connected by interpenetrating networks against discrete distribution of resonators in the LRPC. As mentioned in the introduction, the LRPC unit will exhibit strong resonant absorption in the band gap frequency region if the viscoelastic scattering is considered. Due to the fact that the cooperative interaction of the interpenetrating network structure exists in the LNAC, many overlapped locally resonant absorption band gaps can be generated at a continuous frequency. Therefore, the LNAC possesses a wide band acoustic absorption, as shown in the LNAC curve in Figs. 5(a) and 5(b). When the faultage structure exists in the sample, the cooperative interaction from the interpenetrating network structure is weakened seriously in the paste interface of hard PU between adjacent layers. Therefore, viscoelastic energy dissipation is invalidated in a wide frequency range due to the corruption of the network structure.

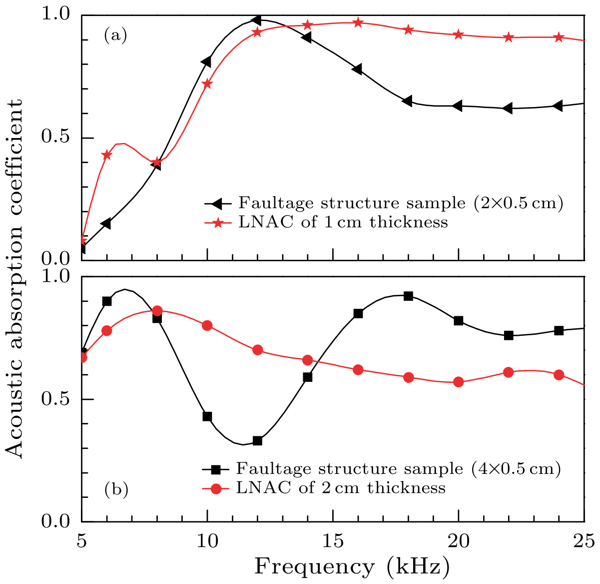

Fig. 5. Comparison result of underwater absorption coefficients for different samples in 5–25 kHz.

On the other hand, the interpenetrating network structure of the LNAC can help each component material to exert its own advantages. Aluminum foam, soft polyurethane (PU) and hard polyurethane (PU) can be treated as a solid core material with relatively high density, a coating of elastically soft material and the hard matrix material of the LRPC, respectively. Different multiple scattering units consist of the above three kinds of materials. It is well known that an acoustic wave could be largely attenuated by multiple scattering effects in materials.[3,23] Multiple scattering effects, in most cases, can be greatly strengthened by this kind of dense network linkage.[5] Due to hard PU with characteristic impedance matching with water, the incident sound wave could be introduced in most extents into the LNAC. If this network structure of the

LNAC is complete, the incident sound wave can evenly propagate along the thickness direction of the sample. When the sound wave propagates in the LNAC, it is reflected ceaselessly by the interpenetrating network structure. Strengthened viscoelastic locally resonant multiple scattering effects result in the continual attenuation of sound wave. Thus the LNAC shows a wide band of strong acoustic absorption as shown in the LNAC curve of Figs. 5(a) and 5(b). When the faultage structure exists in the sample, a part of a sound wave propagates in the paste interface of hard PU between adjacent layers. Due to hard PU with characteristic impedance matching with water, sound wave propagating in the middle hard PU layer again entered into water. The faultage structure results in the loss of a wide band acoustic absorption capability, as shown in faultage sample curve of Figs. 5(a) and 5(b). The impact of locally resonant units on underwater acoustic absorbing effects will be discussed in another article.

Based on resonator units of the LRPC and the interpenetrating network structure, we developed a new metal-rubber hybrid anechoic coating material that can achieve a wide band of strong acoustic absorption. The experimental results and the phenomenological analysis show that the interpenetrating network structure of the LNAC plays an important role in achieving a wide band of strong acoustic absorption. The present material design concept can also be extended to make other functional materials.

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