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A Directional Analysis and Evaluation of Sound Power Dissipation in Porous Layers Periodically Embedding Rigid Inclusions

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ABSTRACT

When rigid inclusions are inserted in homogeneous porous layers in a periodic manner, sound absorption performance can be modified considerably. The resulting inhomogeneous porous layers, which can work as sonic crystals or metaporous layers, exhibit directional effects in dissipating sound power. While global quantities, such as the sound absorption coefficient and the surface impedance are typically used in evaluating sound absorption performance in porous layers, keen attentions to the directional characteristics in sound power dissipation may provide important insights to design sonic crystals or metaporous layers yielding highly enhanced sound absorption performance. In this work, we study the directional effects in dissipating sound power in a hard-backed porous layer embedding periodic rigid inclusions. Supported by analytical derivations, the amount of dissipated sound power is numerically divided along the thickness and lateral directions of the considered porous layer. The relative contributions of each direction in the total sound power dissipation are evaluated quantitatively over frequencies of interest. Numerical examples show that the present directional analysis and evaluation scheme of the dissipated sound power can be used effectively in the design of highly performing porous layers.

Keywords: Porous materials, Power dissipation, Directional contributions.
I-INCE Classification of Subject Number: 35

1. INTRODUCTION

Porous materials [1,2] are widely used for noise reduction by their superior sound dissipating capability. Since porous materials are generally most effective in sound dissipation in a relatively high-frequency range, installations of thicker porous layers are inevitable in order to absorb a large amount of lower-frequency sound. To overcome the

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limitation of the use of porous materials in low-frequency range, many attempts have been made in acoustic fields. Conventionally, additional uses of different acoustic elements have been employed with porous materials [3]. As a more systematic strategy, optimal sequencing [4,5] or shaping [6-8] of porous materials were also investigated.

Recently, many researches to adopt the concept of acoustic metamaterials to the porous materials have received much attention [9-18]; elaborately engineered periodic structures were embedded in porous layers to utilize the phenomena resulting from the Helmholtz resonances [11,12,14,16], trapped modes [9-14,16,17], resonance modes of elastic inclusions [17], wave path elongation [15] and slow wave propagation [18], etc. Such combinations of porous layers with the concept of acoustic metamaterials, which are usually referred to as metaporous layers, have been successful to realize enhanced performance in sound absorption. Among them, some works have investigated the characteristics of sound dissipation in metaporous layers, such as viscous and thermal losses [9,12], which originate from sound-absorbing porous media.

We focus on the directional characteristics of sound power dissipation in metaporous layers. In other words, this work is intended to provide a new insight for sound absorption performance of metaporous layers in the viewpoint of its directional properties. By focusing on the spatial variation of power flow in metaporous layers, we quantify the directional contribution of power dissipation on the sound absorption and explain different dissipation phenomena at peak frequencies. For this exploration, we propose to look into the sound power dissipation along the layer thickness direction and its normal direction, separately.

2. SOUND POWER DISSIPATION IN POROUS LAYERS

When the homogenization method widely adopted in the analysis of the acoustic metamaterials in subwavelength dimensions is used for metaporous layers, their sound absorption performance can be well predicted by means of global quantities, such as sound absorption coefficient and surface impedance under the plane wave assumption. Using these quantities, one can estimate the total amount of dissipated sound power inside metaporous layers, but it is not possible to identify the directional contributions of sound power dissipation inside the layers. In arguing the necessity to investigate the directional characteristics of power dissipation, we observed that a homogenous porous layer under plane acoustic wave incidence from air dissipates sound power only along the thickness direction. This unidirectional sound power dissipation pattern remains unchanged even if a sound wave is obliquely incident as shown in Figure 1(a).

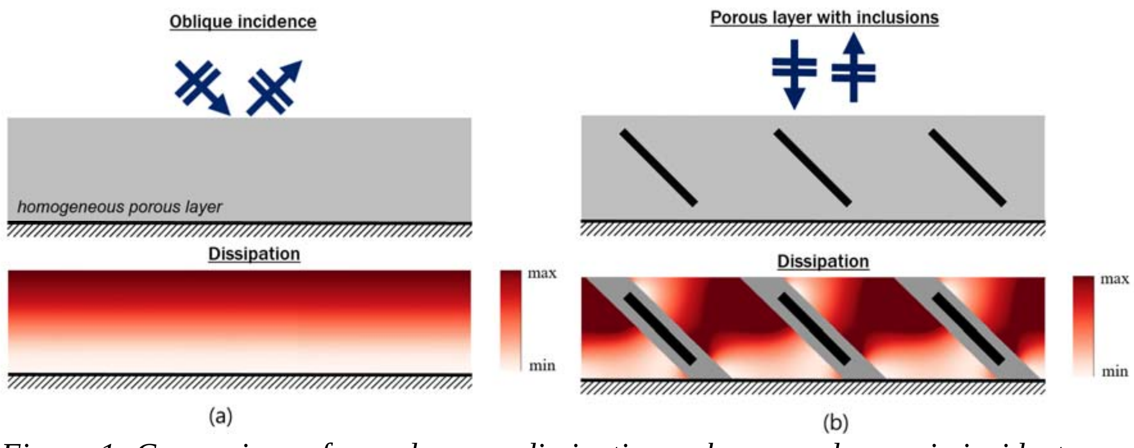

Figure 1. Comparison of sound power dissipations when sound wave is incident on a hard-backed (a) homogenous porous layer and (b) porous layer with rigid inclusions, respectively.

That is because a plane wave propagating inside homogeneous dissipative layers lose power along the direction perpendicular to the interface when it is incident from non-dissipative medium to homogeneous dissipative medium. Note that this finding also applies to sound dissipation in homogenized (or homogeneous) dissipative anisotropic media [19,20].

When rigid inclusions are inserted in the homogenous porous layer, on the other hand, the incident sound power can be dissipated in multiple directions due to the formation of additional interfaces inside the layer. Figure 1(b) suggests that the sound power dissipates not only along the thickness direction, but also along the lateral direction when the inclined rigid inclusions are periodically inserted. From Figure 1(b), it can be argued that this directional sound dissipation property affects the overall sound absorbing capability of a metaporous layer over a frequency range of interest.

To investigate the directional characteristics of the dissipated sound power, we carry out a decomposition of the dissipated sound power into two orthogonal directions by using spatial differentiations of time-averaged acoustic intensities. Although the dissipated power is a scalar quantity, the quantification of its directional contribution is quite useful to interpret the sound power dissipation directionally and also to design enhanced metaporous layers. For examples, we can investigate how distribution of the rigid inclusions inside a metaporous layer affects the overall and directional power dissipation. We can also examine which direction makes a dominant effect in the peaks of sound absorption coefficient curve. Finally, we can consider a design problem for highly performing metaporous materials by addressing the directional effects of sound power dissipation.

3. CONCLUDING REMARKS

We investigated the directional characteristics of sound power dissipation, which is found in metaporous layers embedding rigid inclusions, not in a homogeneous porous layer. The proposed directional concept of sound power dissipation offers a unique perspective into the dissipation performance of metaporous layers and is expected to play an important role in the design of various metaporous layers.

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