ANALYTIC MODEL OF ACOUSTIC SUPERABSORPTION INDUCED BY METAMATERIALS

Yong Cheng, Yanfen Jiang, Linlin Geng, Yunhong Liao, Jianzhu Dong, and Xiaoming Zhou*

Key Laboratory of Dynamics and Control of Flight Vehicle, Ministry of Education and
School of Aerospace Engineering, Beijing Institute of Technology, Beijing 100081, China
(*zhxming@bit.edu.cn)

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ABSTRACT

The classical composite bounds suggest that effective damping of a composite cannot surpass the damping of constituents. Recent studies have shown that the bounds can be broken at a finite frequency due to the presence of metamaterial inclusions [1] and an acoustic superabsorption can be achieved [2]. In this work, we study comprehensively the acoustic superabsorption phenomenon by establishing an analytic model consisting of a lossy acoustic medium embedded with thin-plate metamaterial inclusions. The results have shown that effective acoustic damping of composites can be greater than that of constituents.

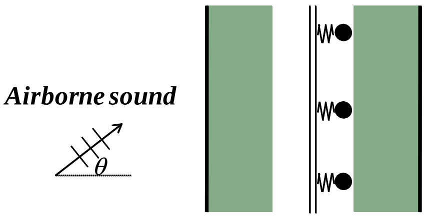

Figure 1: Schematics of absorptive metacomposite consisting of a lossy matrix embedded with thin-plate metamaterial inclusions.

The studied acoustic model is shown in Fig. 1, where the matrix is an acoustic medium with losses and the inclusion is the thin-plate metamaterial. The metamaterial consists of a thin plate attached with mass (m) and spring (k) resonators with periodicity L. A plane wave is incident on the composite with the angle θ. Due to the periodicity of the structured plate, the transverse motion of the plate can be expressed as a series of space harmonics [3]

$$u(y,t) = \sum_{n=-\infty}^{+\infty} A_n e^{-j\left(k_{1y}+2n\pi/L\right)y} e^{j\omega t}\ , \tag{1}$$

Acoustic fields can also be written as spatially periodic functions. By use of the virtual work principle, acoustic field solutions can be analytically solved.

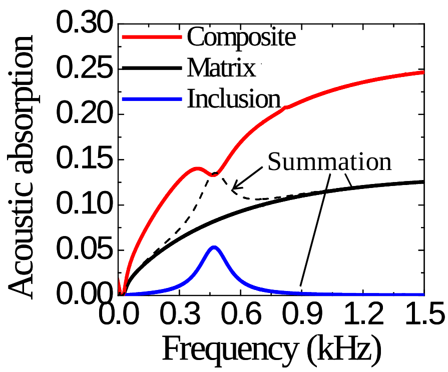

Figure 2: Sound absorption spectrum of the absorptive metacomposite and its constituent in the normal incidence case.

Figure 2 shows the sound absorption coefficient of the composite and its constituent in the normal incidence case. Note that absorption by metamaterial inclusion is only remarkable at its resonant frequency near 460Hz. It can be found that the overall damping of the composite is well beyond the summation of both matrix and inclusion absorptions. By analyzing acoustic fields inside the composite, we have found that this acoustic superabsorption effect is owing to the non-uniform acoustic distributions caused by the metamaterial. At the resonant frequency, the metamaterial becomes acoustically transparent. In this case, the overall damping is exactly the summation of dampings of constituents.

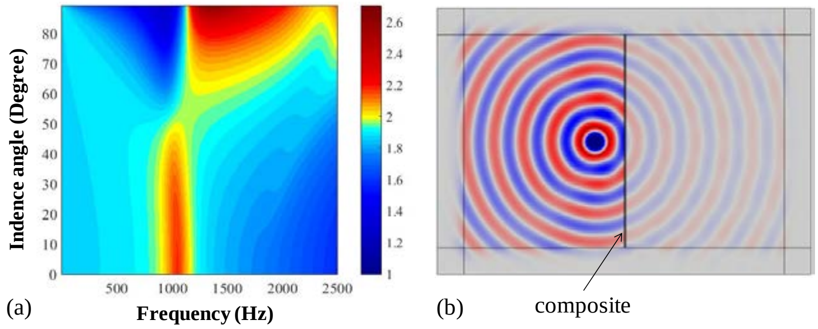

Figure 3: (a) Acoustic absorption of the composite versus that of the matrix in different frequencies and incident angles; (b) Acoustic field distribution produced by a point source that is incident on the absorptive metacomposite.

Figure 3(a) shows the ratio of acoustic absorption of the composite versus that of the matrix in different frequencies and incident angles. Note that lossless metamaterial inclusion has been considered in this example. Acoustic superabsorption can be observed in the entire range of frequency and angular spectra of our interest. In addition, by modulating the dispersion of the plate vibration, we have obtained an unusual acoustic absorption near 1kHz frequency, which is independent on the angle of wave incidence. The absorptive metacomposite with this effect can be used as a matched damping layer, which produces no reflections when dissipates sounds, as shown in Fig. 3(b).

In this work, we have studied the acoustic superabsorption in composites with thin-plate metamaterial inclusions. Underlying mechanism has been explored and the effect of metamaterial parameters has been identified. The experimental studies are being conducted.

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