BUILDING-BLOCK-TYPE MICROPERFORATED ACOUSTIC METACOMPOSITES FOR BROADBAND SOUND ABSORPTION

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ABSTRACT

In this research, an acoustic metacomposite structure is proposed, which can realize ultra-broadband sound absorption in low frequency ranges. The single cells are designed based on the sound absorption theory of microperforated plates. The periodic arrangement of different single cells is combined to make broadband sound absorption a reality. In order to minimize the thickness of the structure, we designed the twisted cavity. The compact arrangement of single cells can significantly reduce the volume of the structure, by designing the twisted methods and structural parameters. In addition, the coherent coupling effect is used to explore the broadband sound absorption potential of single cell parallelism. We propose a building-block-type microperforated (BBTM) acoustic metacomposite for broadband sound absorption in low frequency ranges. Numerical and simulation verifications are conducted. The impacts of different parameters on low frequency broadband sound absorption are further discussed. The acoustic metacomposite structure we have designed have potential applications of noise control in various fields.

1 INTRODUCTION

How to achieve broadband sound absorption within low-frequency range has been always a fundamental challenge in aerospace, ground transportation and constructional engineering. On basis of exquisitely engineered microstructures, rather than their chemical constituents, acoustic metacomposites have provided new paradigms to noise and vibration control at subwavelength or deep subwavelength scale.

In the past 20 years, acoustic metacomposites have received a lot of attentions from researchers due to their excellent properties. The existing acoustic metacomposites have limited sound absorption frequency bands, which cannot achieve broadband sound absorption in the low frequency range. In addition, to achieve broadband sound absorption, a large number of single cells are necessary, which will consume a substantial amount of space. It is difficult to be widely used in reality. In application scenarios such as narrow environments and non-regular environments, there is a greater need for acoustic metacomposite structures that are suitable for different environments. Hence, it is important to design new acoustic metacomposites with compact architecture and broadband sound absorption [1-6]. We propose a building-block-type microperforated (BBTM) acoustic metacomposite for broadband sound absorption in low frequency ranges.

The design strategy is realized based on microperforated plates and twisted cavities. The theoretical and numerical models of the proposed meta-structure are established. Numerical and simulation verifications show that the proposed building-block-type acoustic metacomposite has a good performance in broadband low-frequency sound absorption. Tunable low-frequency absorption characteristics are achieved by adjusting the acoustic impedance matching behavior between single cells and other single cells. It can also achieve outstanding tunable function and perfect sound absorption in broadband with a compact footprint, which may offer a promising pathway for noise control.

2 DESIGN AND THEORY

2.1 Sound absorption theory

Generally, the sound absorption coefficient of an acoustic metacomposite can be calculated by

$$\alpha = 1 - |R|^2 = 1 - \left|\frac{Z_s - Z_0}{Z_s + Z_0}\right|^2 \tag{1}$$

where R is the reflection coefficient, $Z_0 = \rho_0 c_0$ is the characteristic impedance of air, in which ρ_0 and c_0 are severally the density and the sound velocity of air. Here, Z_s denotes the surface impedance of the proposed metamaterial.

In this work, the sound absorption performance of the structure is determined by the acoustic impedance. Based on the acoustic impedance calculation equation, we developed the impedance calculation equation for series, parallel, and series-parallel hybrid perforated plates [4].

$$Z = \left(\sum_{j=1}^{n} \frac{A_j}{Z_j}\right)^{-1} \tag{2}$$

By changing the main parameters of the structure: aperture diameter, plate thickness, cavity depth and perforation rate, the sound absorption performance of the single cell can be adjusted, and then by assembling in parallel, the perfect sound absorption of the broadband is achieved.

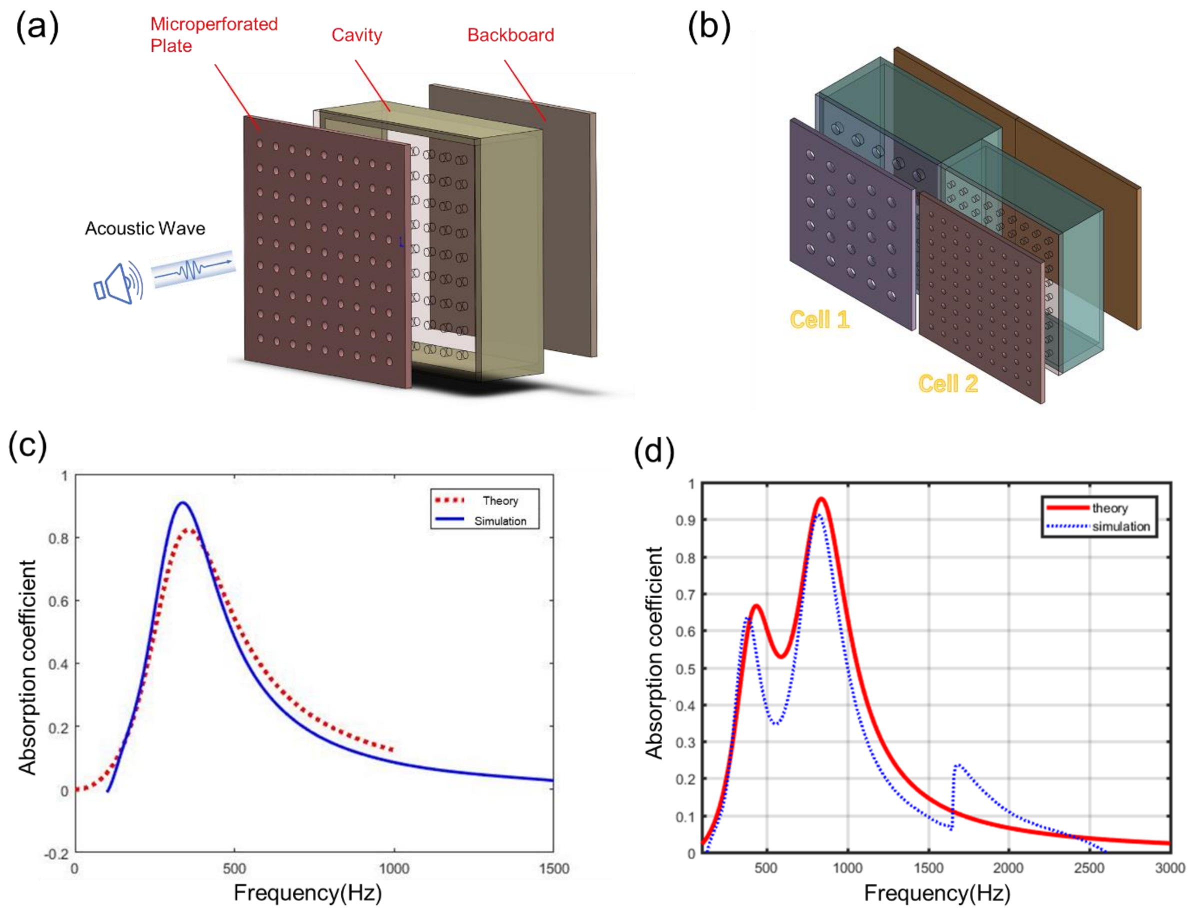

Figure 1: (a) Single-layer perforated plate structure. (b) Two single-layer perforated plates combined in parallel. (c) Sound absorption spectrum of single-layer perforated panel. (d) Sound absorption spectrum of two single-layer perforated plates coupled in parallel.

Fig.1 presents the absorptance spectra of one of the single cells. The numerical simulation approach is adopted by COMSOL Multiphysics. The Pressure Acoustic module is applied to simulate the incident acoustic field, and the Thermoviscous Acoustic module is set at the proposed metamaterial to take the thermal and viscous losses into account. Theoretical and numerical consequences coincide well with each other, thus the correctness of the proposed analytical model is verified [2].

2.2 Double-layer microperforated plate with a folding cavity

The traditional perforated plate structure has shown outstanding performance in the field of noise control, while the proposed double-layer perforated plate brings new ideas for the broadening of the absorption band. Compared to a single perforated plate, the structure has an additional perforated plate and a cavity. Single-layer perforated plate can produce only one absorption peak in the low frequency range, while the double-layer perforated plates can generate two absorption peaks. It presents the possibility of broadening the sound absorption band, which provides a theoretical basis for subsequent research.

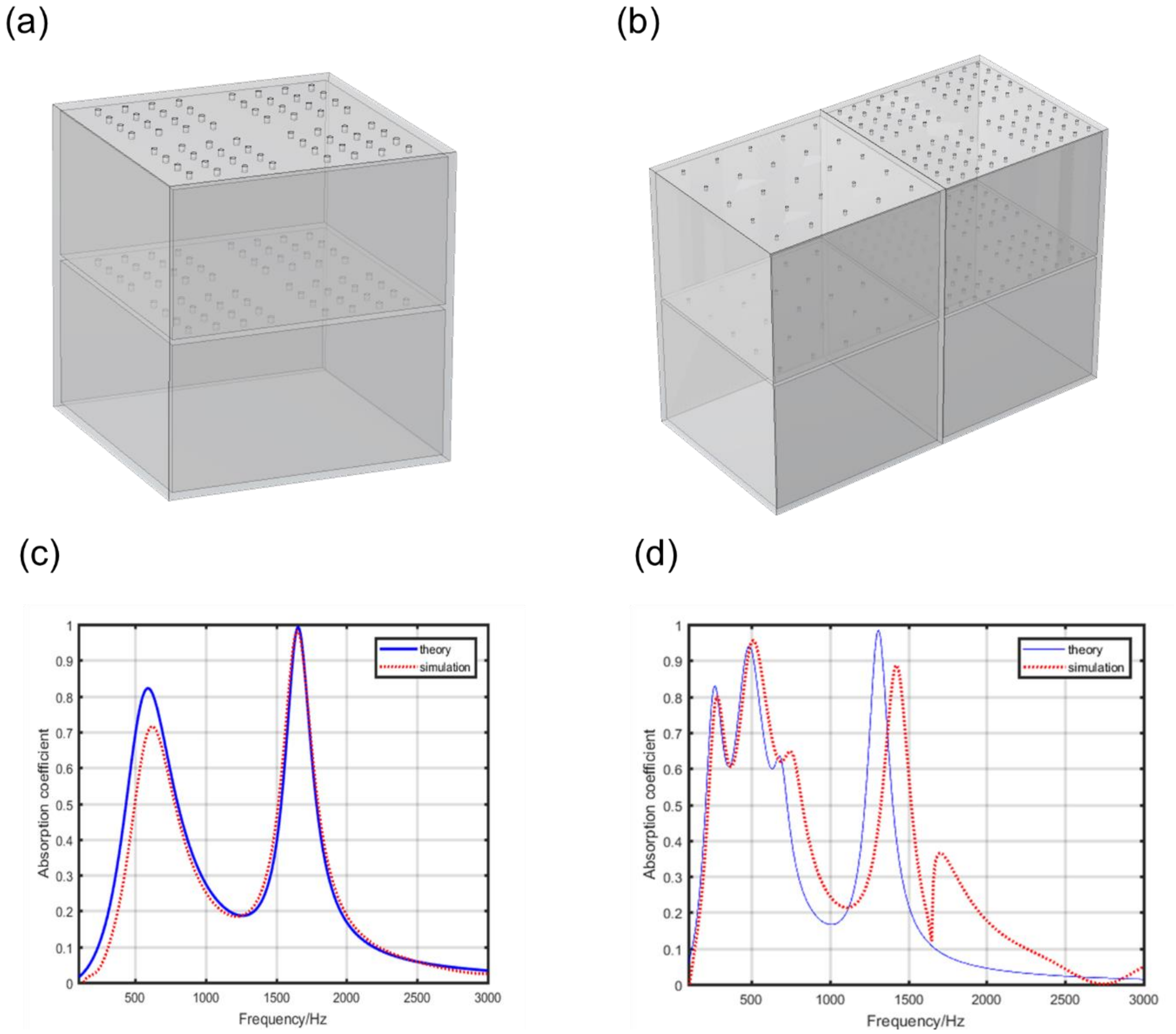

Figure 2: (a) Double-layer perforated plate structure (series combination). (b) Two double-layer perforated plates arranged in parallel. (c) Sound absorption spectrum of double-layer perforated plate. (d) Sound absorption spectrum of two double-layer perforated plates arranged in parallel.

To achieve sound absorption in the low frequency range, a longer back cavity is required. The double-layer perforated plate will increase the overall thickness of the structure, which is detrimental to the practical application. Therefore, we propose the double-layer perforated plate structure with the twisted back cavity. By twisting the back cavity, the thickness of the structure can be significantly reduced. And compared with the non-turned structure, it can still ensure its original sound absorption performance, which includes low-frequency, broadband and perfect sound absorption. Through the delicate design of structural parameters, it is possible to combine the twisted single cells into a whole with low frequency broadband sound absorption performance.

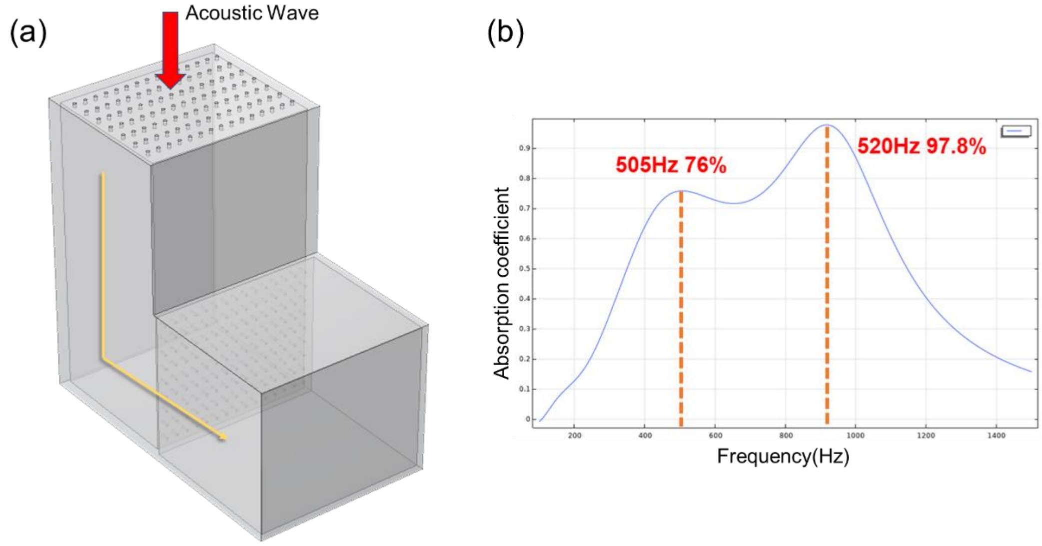

Figure 3: (a) Double-layer perforated plate with twisted cavity. (b) Sound absorption spectrum of double-layer perforated plate with twisted cavity.

2.3 Effect of coherent coupling

In order to obtain excellent results in broadband absorption, it is necessary to combine several single cells in parallel. In our research we found a phenomenon. The parallel combination of single cells with imperfect sound absorption can improve the overall sound absorption coefficient of the structure, and vice versa, it will reduce the general sound absorption effect [5]. This is known as the coherent coupling effect. By using coherent coupling as the design mechanism, it is possible to design acoustic metacomposites with ultra-broadband sound absorption performance. It is an essential instruction for the design of sound-absorbing metacomposite structures.

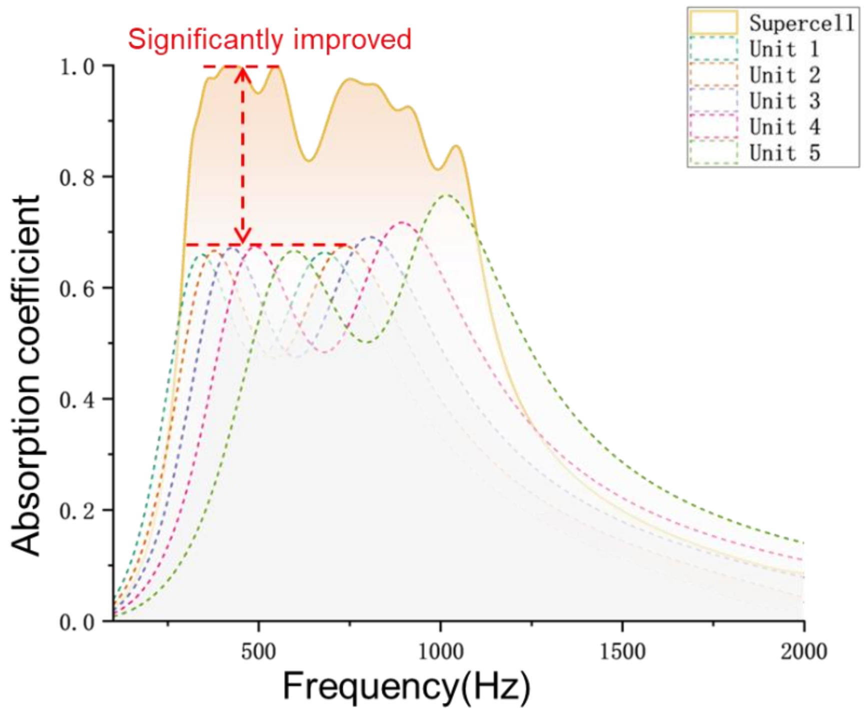

Figure 4: Absorption coefficient spectrum of 5 single cells arranged in parallel based on coherent coupling effect.

Through meticulous design and calculations, six unit cells were finally determined. The individual sound absorption of each unit cell is not excellent. Based on the coherent coupling effect, the single cell is combined in parallel and forms a sound absorbing broadband. The final results show that the supercell has more than 80% sound absorption in the range of 380-1444Hz. And the theoretical and simulation results correspond well, thus verifying the rationality of the structural design.

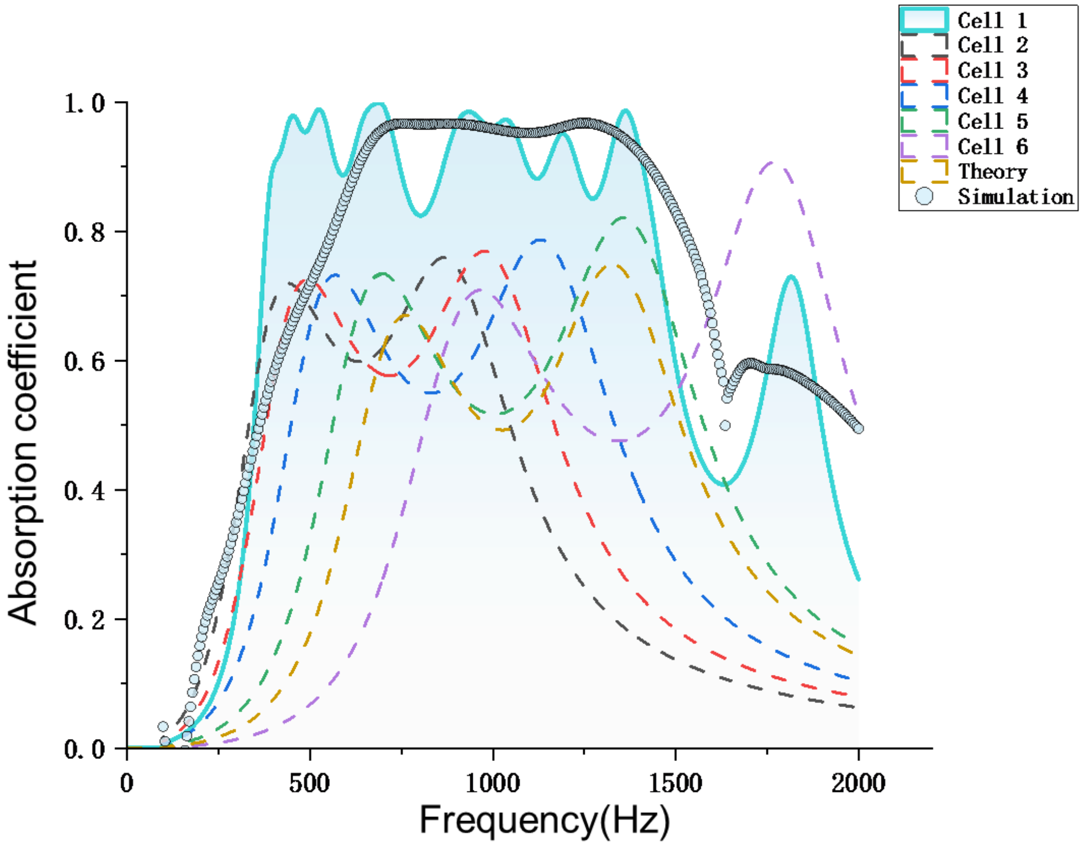

Figure 5: Sound absorption coefficient spectrum of supercell structure, theoretical results and simulation results match well.

4 CONCLUSIONS

In this paper, an acoustic metacomposite structure with low-frequency broadband sound absorption performance is proposed. Through theoretical calculations and simulations, the following conclusions can be obtained:

(1) Based on the theory of microperforated plate sound absorption, a double-layer microperforated plate structure is developed. It can generate additional absorption peaks in the target frequency band, which is for the design of broadband sound absorption.

(2) In order to reduce the thickness of the structure, we designed a sound-absorbing structure with a twisted back cavity. The dimensions of the structure are significantly reduced without compromising the sound absorption performance. The compact supercell can be composed by delicate design. It is promising for noise reduction and sound absorption in practical engineering applications.

(3) Different single cells are designed but do not possess the ability to absorb sound perfectly. Based on the coherent coupling effect, the unit cells were arranged and combined in parallel. The structures of acoustic metacomposite with broadband sound absorption capability we have designed are constituted. The structure achieves perfect sound absorption at 380-1444 Hz, and the theoretical results correspond well with the simulation results. It is a guidance for the design of future acoustic metamaterial structures.

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