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Letter

Sound absorption characteristic of micro-helix metamaterial by 3D printing

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HIGHLIGHTS

- We present the design of micro-helix metamaterial supporting high sound absorption characteristic by 3D printing.
- The grating on TBCs is heated at the temperature ranging from 300 to 1000 for examining the oxidation resistibility to high temperature.
- Experiment measurement results show that different geometrical dimensions of helix vestibuleand cavity depth have a great effect on sound absorption coefficient
- Physical mechanism depends on the friction and viscosity between the air and the helix vestibule.

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ABSTRACT

We present the design of micro-helix metamaterial supporting high sound absorption characteristic by 3D printing. The sample structure which is fabricated out of polylactide (PLA) material, many micro-helix are arranged by periodic arrays on *XY* plane. Experiment measurement results show that different geometrical dimensions of helix vestibule and cavity depth have a great effect on sound absorption coefficient. Physical mechanism depends on the friction and viscosity between the air and the helix vestibule. This work shows great potential of micro-structure metamaterial in noise control applications require light weight and large rigid of sound absorption.

Acoustic metamaterial is artificial materials with purposely fabricated micro-structures that can achieve exotic sound physical phenomena in the last ten years, such as negative effective refraction index [1-4], negative effective density [5-7], negative effective modulus [8-10], omnidirectional sound absorption [11-13]. Corresponding studies have been the focus of the research hotspot. Great undertaking with respect to these excellent structures pointed out new concepts for the attenuation of low and medium frequency sound, challenging the sound absorption characteristic of traditional structures such as those using glass fibrous [14], mineral wool [15], porous foams [16], and micro-perforated panels [17]. In recent works, novel structures include membrane-type acoustic metamaterial [18-20] have been shown to absorb sound in the low frequency range experimentally. Peak transmission loss frequency was tuned to specific values by varying the membrane properties and mass. But the stiffness of membrane is difficult to control and the assemble of central mass lump need to be precise, that prohibit the membrane type acoustic metamaterial application. Ren et al. [21] proposed the ultra-thin multi-slit metamaterial consisting of meso-slits in sub-millimeter scale and micro-slits in dozens of micrometers scale. The theoretical predictions agree with the numerical simulations, prove that ultra-thin multi-slit metamaterial has a superior absorption over a wide frequency range. But the absorption peak frequency exceeds 1500 Hz, corresponding noise reduction was not solved. Starkey et al. [22] presented a thin acoustic metamaterial absorber comprised of only rigid metal and air, results show that the strong absorption in this system is attributed to the thermo-viscous losses arising from a sound wave guided between the plate and the wall. Experiment results show that this kind of structure can only be effective in high frequency

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range, and a thickness of air layer is too small to processing. By additive manufacturing, Liu et al. [23] made a porous polycarbonate material. The study found that by adjusting the perforation angle and the airgap behind the sample, the significant absorption can be achieved at low frequency. Inspired by this idea, we designed and prepared a micro-helix metamaterial (MHM) in this paper. Compared with the straight hole and thin seam structure, micro-helix structure is more complicated and related factors of sound absorption are more. This paper study the sound absorption characteristic experimentally. Results and mechanism analysis are as follows.

Matrix structure in this paper is single polylactide (PLA) material by 3-dimensional (3D) printed fabrication technique, "Maker Bot Replicator 2" equipment we used in this process can support minimum dimensional precision 0.1 mm. Micro-structure dimension diagram of MHM structure is shown in Fig. 1(a). Blue region is the hollow helix vestibule portion, and the faint yellow region is the micro-helix portion on the space. Distance s between neighboring unit is 5 mm, screw pitch a is 2 mm, diameter of circular helix vestibule D is 0.8 mm, and the external diameter of helix structure b is 4.5 mm. Helix hollow structures are arranged by quartet linear array at the XY plane. Number of piles is 5, shown in Fig. 1(b). The diameter of sample-1 is 99 mm, the white teflon tape was used for deterring sound leakage. Figure 2(a) is the measurement setup in the lab and Fig. 2(b) is two-microphone impedance method schematic, corresponding method adopt ASTM E1050-12 standard [24]. In this method, the complex sound reflection coefficient R of a test sample is calculated from total acoustic field transfer function H_{12}. According to Chung and Blaser's [25] results, the complex sound reflection coefficient is $R = \mathrm{e}^{-2\mathrm{j}k_0(l+s)}(H_{12} - H_i)/(H_r - H_{12})$, where the wave number $k_0 = 2\pi f/c$, l is the distance between Mic 2 (Fig. 2) and test sample, s is the distance between the two Mics, $H_i = \mathrm{e}^{-\mathrm{j}k_0 s}$ and $H_r = \mathrm{e}^{\mathrm{j}k_0 s}$ Normal incidence sound absorption coefficient α_n is obtained by $\alpha_n = 1 - |R|^2$ [24-26], where ρ and c are the density and speed of sound in the air, respectively. Normal incidence sound absorption measurements for MHM structures were conducted using an impedance tube (Brüel and Kjær 4206), two microphone (Brüel and Kjær 4187) and data input acquisition module (Brüel and Kjær 3560C). The sound absorption coefficient of the MHM structure was calculated using a transfer function method (PULSE software, Brüel and Kjær). In order to investigate the effects of helix structure dimension and cavity (behind the samples) depth variation on the sound characteristics, we designed and made different samples, test experiment results and discussions are as follows.

Figure 3 displays the effect results of different screw pitches on the sound absorption. Sample-1, sample-2, sample-3, and sample-4 correspond to the 4.0, 3.0, 2.5, and 2.0 mm respectively. As shown in the Fig. 3, different colors and line-types represent different sound absorption cavity depths. As the screw pitch decrease from 4 mm to 2 mm and the cavity depth is zero, the first sound absorption peak would move to the low frequency range slightly. When the screw pitch is 2.5 mm or 2.0 mm, the second sound absorption peak occurs in the range of 1300-1400 Hz. Introduction of cavity could improve the sound absorption coefficient greatly. When the cavity depths of the

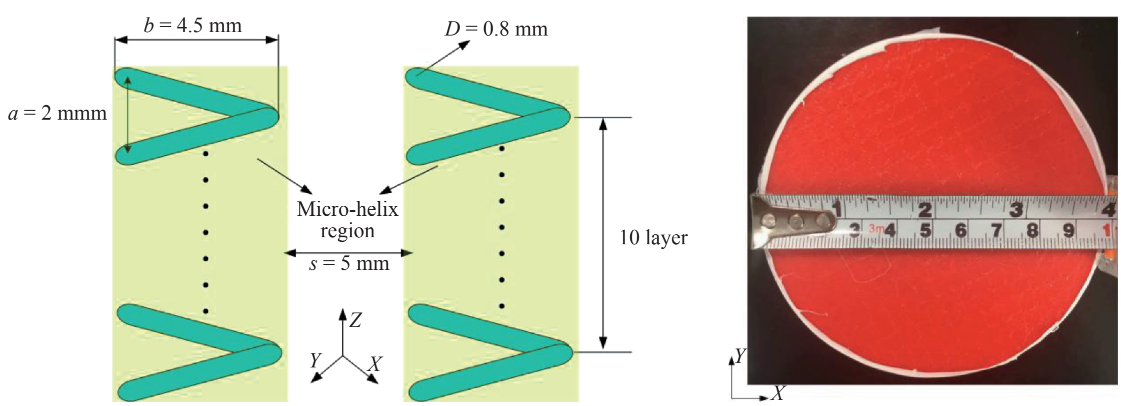

Fig. 1. a Micro-helix metamaterial structure diagram; **b** 3D printed test sample-1.

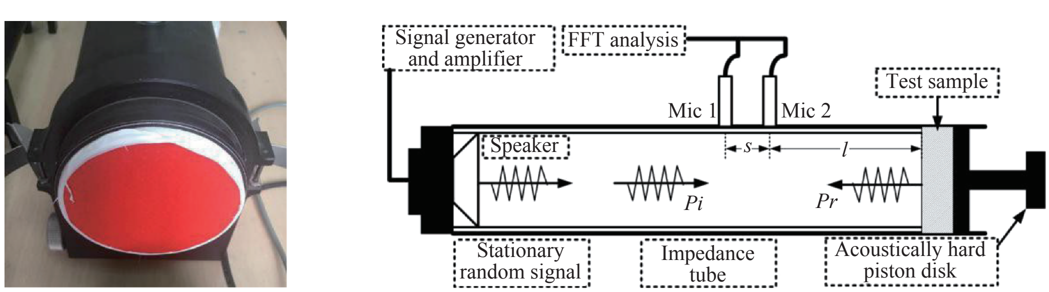

Fig. 2. a Sound absorption experiment; **b** schematic of two-microphone impedance method.