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Technical Note

Improvement of sound absorption characteristics under low frequency for micro-perforated panel absorbers using super-aligned carbon nanotube arrays

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ABSTRACT

Super-aligned carbon nanotube (SACNT) arrays are grown on the surface of micro perforated panel (MPP) in the hope of improving the acoustic performance of MPP absorbers by virtue of their unique properties. Scanning electron microscopy reveals that SACNT arrays did not block the perforations of MPPs or changed the perforation diameter due to their "super-aligned" nature, although MPPs are thickened. The absorption effect of SACNT arrays which are of the same and different lengths with different incident side on MPP absorbers are investigated, and standing wave tube method is used to determine the normal sound absorption coefficient. Results show that both of the lengths of SACNT arrays and the incident side have effects on the sound absorption performance of MPP absorbers. And generally SACNT arrays help to improve the sound absorption capacity of MPP absorbers in low-frequency regions only when the SACNT arrays surface is the incident side. SACNT arrays decrease absorption performance of MPP absorbers when the MPP surface is used as the incident side. Moreover, SACNT arrays are found to increase the acoustic ability of MPP absorbers with the same structure parameters monotonically at lengths up to 600 μm in the condition that the SACNT arrays surface is used as the incident side.

1. Introduction

Nowadays the noise pollution has become a serious problem, the demand for a better environment and more diversified life styles is increased. Thus thin, light weight and low-cost absorption constructions that will absorb sound in wide frequency range are strongly desired. Micro-perforated panel (MPP) absorbers have been widely used in noise control engineering since they were first proposed by Maa in 1975 [1]. MPP absorbers are friendly environment, low cost, simple structure and high safety. Based on the above advantages, MPP absorbers have been always regarded as promising as a basis for the next generation of sound absorbing constructions and the study on their absorption characteristics has become a hotspot research. However, compared with the traditional porous sound absorption materials, MPP absorbers have one very notable unpleasant property—its narrow sound absorption bandwidth, normally 1–2 octave, which restricts it becoming a general sound absorber. In order to achieve optimal enhancement in the sound absorption properties of MPP absorbers, a lot of improvement approaches have been proposed. Lin et al. [2] attempted to improve the sound absorption performance through adding porous sound-absorbing materials in the cavity. According to the position of the porous materials, the corresponding theoretical prediction models were built and experimental results agreed well with the prediction results. Sheng [3,4] obtained composite sound-absorbing constructions by covering a thin film in the front side or the back side of MPPs, and their sound absorption properties were theoretically and experimentally studied. Variable section of orifice was used to widen the absorption bandwidth of MPP absorbers by He et al. [5]. Sakagami et al. [6] and Randeberg [7] also focused on enhancing the absorption performance through orifice design. A new type of MPP absorber with holes of multiple sizes instead of uniform size was experimentally studied by Misasa et al. [8] aiming at obtaining a wide band sound absorber. A double-layer MPP absorber [1] was also proposed by Maa to broaden the absorption bandwidth, but at the cost of occupying more space. Moreover, a lot of other research efforts have been directed towards optimization design of the cavities to improve the acoustic

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performance of MPP absorbers, such as cellular cavities [9], irregular cavities [10], and subdivided cavities [11]. However, all the improvement approaches increase weight and the complexity of structure or occupy more space which will limit widespread use of MPP absorbers. According to Maa [12], a straightforward method to broaden the absorption bandwidth of MPP absorbers is to reduce the perforation diameter, namely, ultra-micro MPP absorbers [13], but experimental results show that such MPP absorbers are just good in high frequency region ranging from 2000 Hz to 6000 Hz.

Furthermore, all the approaches mentioned above about improving sound absorption performance of MPP absorbers involve no nanomaterials which have been adopted widely in porous sound-absorbing materials for getting many desired properties. Verdejo et al. [14] found that low loading fraction of carbon nanotubes (CNT's) in flexible polyurethane foams have relatively high effect in sound absorption; even 0.1% CNT's can enhance the acoustic absorption dramatically, which leads the peak absorption coefficient to increase up to 90% from 70% for the pure polymer foam especially in the high frequency region. Gayathri et al. [15] showed that sound absorption coefficient of polyurethane foam modified with nanosilica, nanoclay and crumble rubber fillers were found to demonstrate an increase up to 80% from 52% for the pure foam in the frequency range of 100–200 Hz. Thus nanomaterials may have great potential to improve the absorption ability of sound-absorbing materials. But so far study on improving acoustic performance of MPP absorbers based on nanomaterials has not been reported yet. The purpose of this study is to examine the effects of surface modification on acoustic properties of MPP absorbers by nanomaterials. Ordinary nanomaterials may block the holes of MPP absorbers, and given that super-aligned carbon nanotube (SACNT) arrays are selected. It is generally known that compared to ordinary CNT, SACNT arrays are a kind of high-quality and ordered carbon nanotube arrays and in a SACNT array, CNTs possess a high density and very clean surface. SACNT arrays can be easily grown on the surface of silicon or glass substrate, as a matter of convenience, a non-template chemical vapor deposition (CVD) method was used to synthesize SACNT arrays on the surface of MPPs made out of silicon based on MEMS technology. Ferrocene was used as a catalyst, xylene as the carbon source. An obvious trait of the SACNT array is that it can produce an ordered array parallel to the drawing direction and the CNTs will not block the holes of MPPs because there is no catalyst in the position of holes. Moreover, SACNT arrays have high surface area; in this case, they are expected to offer proper impedance matching between air and MPP absorbers when the SACNT arrays surface is used as the incident side. At the same time the acoustic resistance of MPP absorbers will increase as a result of the increased panel thickness. By these considerations the possibility of achieving a wideband sound absorber with surface modification of MPP absorbers using SACNT arrays is discussed. Finally, the influence of the incident side on the sound absorption characteristics of the composite structure of MPP absorbers with SACNT arrays is also explored. The normal sound absorption coefficient of MPP absorbers are measured according to standard: ISO 10534 10534-2:1998 “Acoustics – determination of Sound Absorption Coefficients and Impedance Tubes-part 1: Method using standing wave ratio” [16].

2. Experimental results and discussion

2.1. Specimens

For the experimental investigation, MPPs were made out of silicon based on MEMS technology since the SACNT arrays were easily grown on silicon substrate. The MPPs were made with various hole sizes, various arrangements and various perforation ratio, but the same panel thickness and cavity depth. SACNT arrays with different lengths were grown on the surface of MPPs. The structure parameters of MPP absorbers are listed in Table 1. In Table 1, d is the diameter of the perforations, t is the panel thickness, b is the distance between centers of adjacent perforations, D is the depth of the cavity, σ is the perforation ratio (the ratio of surface area of the perforations to the total surface area of the panel), and l is the length of SACNT arrays. Each group of the structure parameters is non-optimized. Note that the MPP absorber with SACNT arrays 0 μm in length (specimen #4) means that there is no SACNT arrays on it. The surface micro structure was observed using Scanning Electron Microscope (SEM) for MPP absorbers before and after surface modification using SACNT arrays and pictures of some of the specimens are shown in Fig. 1. It is evident from Fig. 1 that the perforations have not been blocked by SACNT arrays but the total panel thickness is increased. To facilitate the understanding, the cross section schematics of silicon MPP with

Table 1
The material and structural parameters of MPP absorbers.

Specimen	d (μm)	t (μm)	b (μm)	D (mm)	σ (%)	l (μm)
1	45	200	106	20	14.14	600
2	66	200	216	20	7.33	600
3	84	200	277	20	7.21	600
4	54	200	156	20	9.41	0
5	54	200	156	20	9.41	100
6	54	200	156	20	9.41	300
7	54	200	156	20	9.41	600

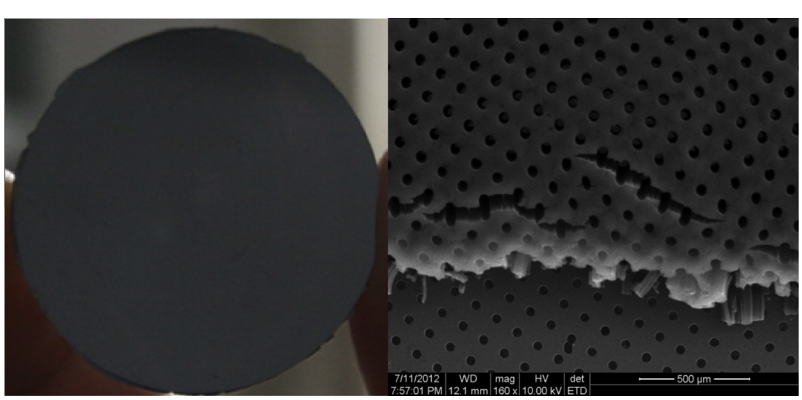

Fig. 1. Photograph and SEM micrograph of No. 4 MPP before and after surface modification with SACNT arrays.

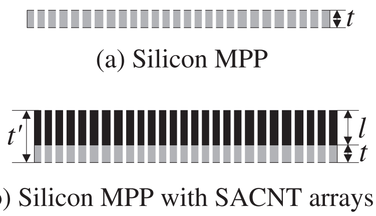

Fig. 2. Cross section schematics of MPPs with and without SACNT arrays.

and without SACNT arrays are indicated in Fig. 2. In Fig. 2, t' represents the total panel thickness of the composite structure and t' equals $t + l$. As you can see from Fig. 2, MPP absorbers before and after surface modification almost have the same structure parameters except for the panel thickness. And according to Maa's model [1], the sound absorption characteristics of MPP absorbers have nothing to do with the materials used. Therefore, when Maa's model is applied to calculate the sound absorption performance of MPP absorbers with SACNT arrays only the panel thickness is changed from t to t' relative to MPP absorbers without SACNT arrays. Note that to avoid SACNT arrays fall over and thus block the perforations of MPPs, the maximum length of SACNT arrays is 600 μm.

3. Results and discussion

For comparison, experimental normal absorption coefficients of MPP absorbers with and without SACNT arrays were obtained in impedance tube, as shown in Fig. 3. As previously mentioned, SACNT arrays are not only expected to increase the acoustic resistance but also offer good impedance matching. For this reason, the SACNT arrays surface is firstly used as the incident side. The testing frequency ranges from 1500 Hz to 6500 Hz, and the measured frequencies were the center frequencies of 1/3 octave. The theoretical predictions can be given according to Maa's model [1]. Note that in the calculation, the total panel thickness of the composite structures is t' instead of t, other structure parameters remain unchanged. Figs. 4 and 5 (SM represents surface modification), respectively show the experimental and theoretical results for the acoustic absorption coefficient of the samples, as a function of frequency. In Fig. 4, the MPP absorbers have a constant length of SACNT arrays, but their structure parameters are greatly different. It is clear from Fig. 4 that the absorption peaks of MPP absorbers with SACNT arrays are shifted to low frequency compared with the results of MPP absorbers without SACNT arrays. For example, before surface modification using SACNT arrays, absorption peaks of specimen #1, specimen #2 and specimen #3 are all at 3500 Hz, while after surface modification, the corresponding absorption peak frequencies become 2250 Hz, 2000 Hz and 2500 Hz, respectively. Obviously, SACNT arrays may help to improve the absorption capacity of MPP absorbers in low frequency

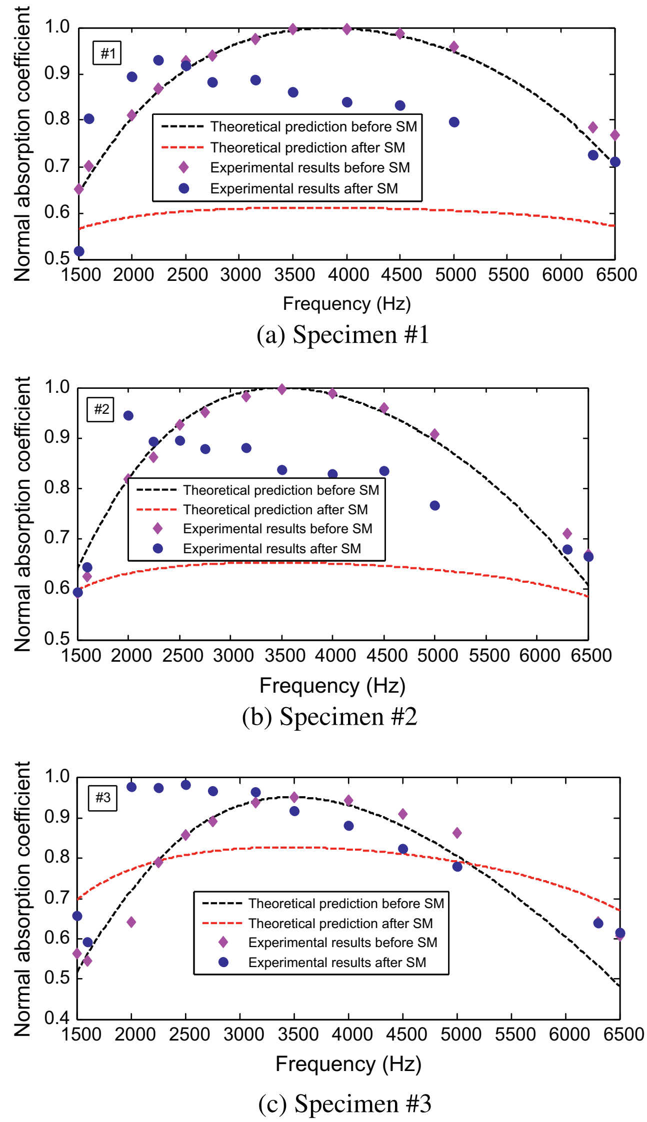

Fig. 4. The predicted and measured normal absorption coefficient of MPP absorbers before and after surface modification with SACNT arrays of a constant length.

range, but at the same time it will degrade the high frequency performance. What we can also learn from Fig. 4 is that the experimental results of normal absorption coefficient of MPP absorbers without SACNT arrays agree well with the theoretical prediction results based on Maa's model. But the difference between the experimental results and the theoretical results calculated by Maa's model of MPP absorbers with SACNT arrays is so large which

Fig. 3. Standing wave apparatus.

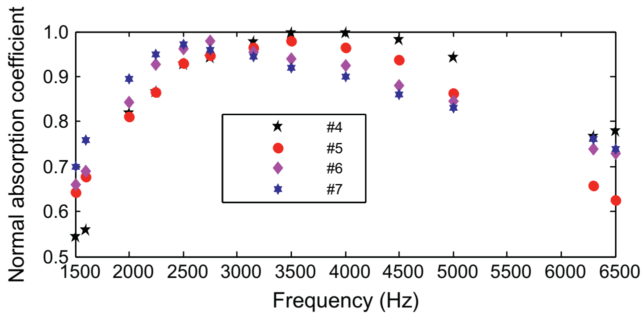

Fig. 5. The predicted and measured normal absorption coefficient of MPP absorbers with SACNT arrays of different length.

makes Maa's model does not apply. It might because SACNT arrays have many special properties such as high surface area which cause their unique sound absorption properties. As a result, although SACNT arrays greatly thicken the panel, the absorption performance of the composite structure has no significant degradation as Maa's model predicts. Moreover, in order to study the effects of different lengths of SACNT arrays on the sound absorption performance of MPP absorbers, SACNT arrays of different lengths are grown on the surface of MPPs with the same structure parameters. Their experimental normal absorption coefficients are shown in Fig. 5. It is seen from Fig. 5 that the absorption peaks are gradually shifted to low frequency as the lengths of SACNT arrays increase. Furthermore, Fig. 5 shows that the influence of SACNT arrays on MPP absorbers relates greatly to their length. For the MPP absorber with SACNT arrays 100 μm in length (specimen #5), the absorption performance in high frequency range has fallen, but the sound absorption properties in low frequency spectrum remain unchanged, therefore the overall absorption performance is reduced. For the MPP absorbers having SACNT arrays 300 μm (specimen #6) and 600 μm (specimen #7) in length, respectively, the acoustic properties are increased in low frequency and decreased in high frequency band but without degrading the overall performance. The analysis results suggest that only a certain length of SACNT arrays can improve the low frequency acoustic properties of MPP absorbers. But in most cases, SACNT arrays were found to increase the acoustic performance of MPP absorbers monotonically at length up to 600 μm in low frequency range. Whether there are optimized lengths for SACNT arrays which can improve the low frequency absorption performance of MPP absorbers without decreasing high frequency performance needs to be studied further.

Finally, in order to investigate that whether the incident side have influence on the sound absorption properties of the

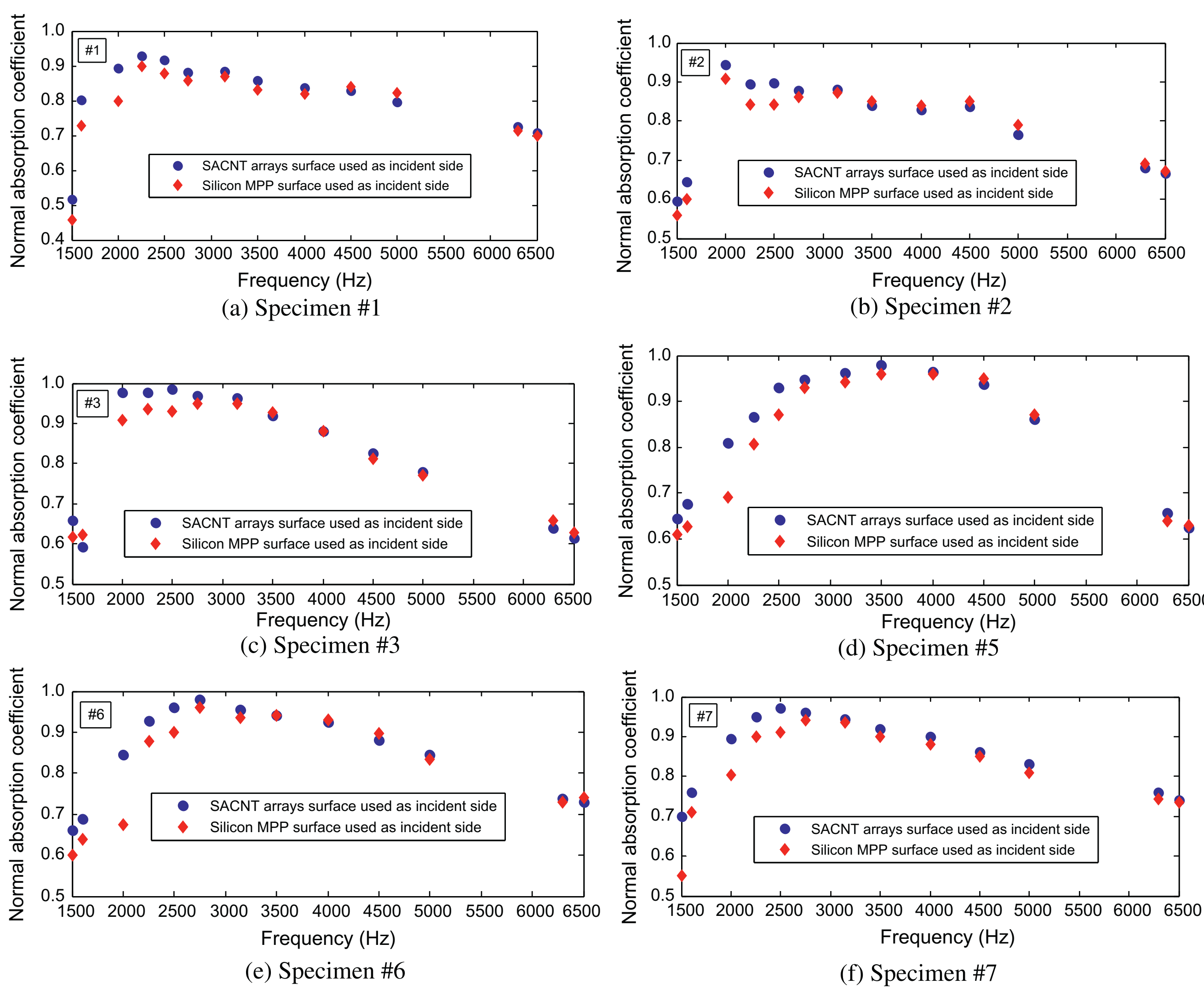

Fig. 6. Experimental normal absorption coefficient of the composite structures with different incident side.

composite structure, the measurement of their normal absorption coefficient was also carried out in impedance tube when the silicon MPP surface was used as the incident side. The experimental results are shown in Fig. 6. As can be seen from Fig. 6 that the absorption performance of the composite structures in high frequency range of 2750–6500 Hz has been less affected by the incident side, but the low frequency performance below 2750 Hz is reduced remarkably. In general, when the MPP surface is the incident side, the overall performance of MPP absorbers is weakened by SACNT arrays. Thus the conclusion is drawn that the SACNT arrays can be used to enhance the low frequency performance of MPP absorbers on condition that the SACNT arrays surface is used as the incident side.

4. Conclusions

In order to improve the sound absorption capacity of MPP absorbers, MPPs are surface modified by SACNT arrays and their sound absorption performance is experimentally studied in impedance tube in this paper. It is interesting to find that the absorption characteristics of the composite structure are affected greatly by the lengths of SACNT arrays and the incident side. SACNT arrays will bring performance enhancements for MPP absorbers only if the SACNT arrays surface is used as the incident side. Under such condition, the absorption peaks of the composite structures are shifted to low frequency compared with the experimental results of MPP absorbers before surface modification using SACNT arrays. And for MPP absorbers with the same structure parameters, the absorption peaks are gradually shifted to low frequency with the increase of the length of SACNT arrays. Thus, from the above studies one can conclude that SACNT arrays can help to increase the low frequency absorption performance of MPP absorbers providing that the SACNT arrays surface is the incident side. Furthermore, the results indicate that only the influence of a certain length of SACNT arrays is good, otherwise the overall absorption performance of MPP absorbers will be weakened. Further study are in progress to determine optimum length of SACNT arrays for the best sound absorption coefficient of MPP absorbers in the low frequency range and a new prediction approach should be developed to calculate the acoustic performance of MPP absorbers with SACNT arrays since it is found that Maa's model is not applicable for the composite structure possibly because of the unique absorption characteristics of SACNT arrays resulting from their special properties such as high surface area. The study results will provide a research approach to realize a low frequency absorber with broader absorption bandwidth.

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