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An experimental study on a cylindrical microperforated panel sound absorber with core

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ABSTRACT

A microperforated panel (MPP) is usually placed in front of a rigid back wall with an air-back cavity to form a Helmholtz resonator with the performation acting as necks and the air-back cavity acting as the entrapped air. However, the authors have so far proposed several kinds of MPP space sound absorbers which can work without a rigid back wall. Cylindrical MPP space absorber (CMSA) is one which has a cylindrical shape. CMSA has a resonance peak due to a Helmholtz resonator, and has additional low frequency absorption caused by its acoustic permeability. Although the absorption coefficient is not high, CMSA can be used as a space sound absorber in practical situations. In this study, as an approach to improve its sound absorptivity, the authors proposed CMSA with Core which has a cylindrical core inside a CMSA. Results from measurements conducted on sound absorption characteristics of the CMSA with Core are discussed. The resonance peak frequency becomes higher as the core diameter becomes larger. This means that the CMSA with Core can be used in various situations by adapting the core diameter to the target frequency. The result suggests that the CMSA with Core can be used as a space sound absorber in practical situations.

1. Introduction

A microperforated panel (MPP) is a kind of perforation panel made of thin panel (about 0.5 [mm] thick) which has small perforations (less than 1 [mm] in diameter) with perforation ratio less than 1 [%]. Due to the small perforations, a MPP has suitable acoustic impedance and it realizes better sound absorption performance than ordinary perforation panels. A MPP can be made from various materials such as acrylic or metal, and therefore, it has a good durability and recyclability and does not contaminate the surroundings with fibrous dusts. In this manner, MPP solves many ordinary sound absorbing problems and as such has, is one of the most promising alternatives among so-called "next-generation sound absorbing materials".

MPP was first proposed by Maa[1] in 1970s who developed its theory and validated its effectiveness [2,3]. Later, many researchers presented studies on its applications to various purposes [4-6].

MPP is usually used with a rigid back wall with an air-back cavity in between to form Helmholtz resonators. However, the authors of this paper have proposed several kinds of space sound absorbers using MPP which do not require the backing structures, such as "double-leaf MPP space sound absorber (DLMPP)", "triple-leaf MPP space sound absorbers (TLMPP)", or structures with a permeable membrane and have shown their effectiveness [7-9]. These panel-like structures can be used for a sound absorbing panel or partition. However, their usage is restricted in some actual rooms due to its panel-like shape.

Therefore, the authors proposed a light-weight three-dimensional space absorber which can more easily hang from the ceiling or be free-standing on a floor ~~more~~. As a first step, the authors of this paper proposed cylindrical MPP space absorbers (CMSA) which are made by forming a MPP into a cylindrical shape and considered its sound absorption characteristics from an experimental measurement [10,11]. As a result, a CMSA showed a resonance peak in the absorption and additional low frequency absorption which are similar to the absorption characteristics of DLMPP, and considered to be useful in practical situations.

In this study, as an approach to improve CMSA's sound absorptivity, and as a proposal for alternative usage of a CMSA, the authors proposed CMSA with Core which has a rigid cylindrical core inside a CMSA. Different absorption characteristics, (i.e., more significant peak absorption) are expected by inserting the core. Also, if it is found that CMSA can be used effectively with the core inside, it means that it can be used in more various design situations. In this paper, its sound absorption characteristics are measured and the results are discussed.

2. Experiments

The measurement of the random incidence sound absorption coefficient in a reverberation chamber was carried in compliance with JIS A 1409 (ISO 354 compatible). The measurement of the reverberation time is an average for two sound source positions at five microphone positions. An omnidirectional condenser microphone was used in the measurement and a stationary-interrupted one-third octave noise was used to drive an omnidirectional loudspeaker. Reverberation time was obtained by T_{30} with a linear regression fitting between -5 and -35 dB. The reverberation chamber used in the experiment is of volume 513 [m^3] and surface area 382 [m^2]. For obtaining the absorption coefficient, Eqn. (1), based on the Sabine's formula,was used.

$$\alpha_s = 55.3 \frac{V}{cS} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) , \qquad (1)$$

where α_s is the absorption coefficient of the specimen, V the volume and S the surface area of the reverberation chamber, c the sound speed, T_2 the reverberation time with specimen and T_1 without specimen.

The MPP used in the experiment had an 0.5 [mm] hole diameter, 0.5 [mm] thickness, 0.785 [%] perforation ratio and 0.6 [kg/m^2] surface density, and made of a transparent polycarbonate. At first, a 1m × 1m MPP was formed into a cylindrical shape and a CMSA (1/π [m] diameter, 1[m] high, 1[m^2] surface area), and then a cylindrical core has been inserted in the center of a CMSA as shown in Figure 1. The core is made of acrylic or polyvinyl chloride. An example of specimen is shown in Figure 2.

In the experiment, to observe the difference of absorption characteristics by changing the diameter of core, the measurements were conducted by changing the core diameter to 50 [mm], 100 [mm], 165 [mm], and 215 [mm]. The list of specimens used in the experiments is shown in Table 1. Twelve specimens were set and its absorption coefficients were measured in reverberation chamber as shown in Figure 3.

Also, to observe the difference due to the end condition of the top end, absorbers with an open end and absorbers with a closed end were measured in each core diameter case.

Note that the measured results should be expressed as "absorption power of a unit surface area for a single specimen" instead of "absorption coefficient" when we discuss this types of space sound absorbers. However, in this paper, we treat "absorption power of a unit surface area for a single specimen" as "absorption coefficient" for convenience, since the surface area is of each specimen is 1 [m^2] and the measurements per specimen do not change even if the number of specimens set in the reverberation chamber is changed as shown in the preliminary measurements.

3. Experimental results and discussions

3.1 Discussion of measured results

The measured absorption coefficients of the CMSA and the CMSA with Core are shown in Figure 4. From the graph, the following facts can be observed:

(a) Case 1: core diameter 50mm

The absorption characteristics of the CMSA with Core are similar to those of the CMSA. Both absorption characteristics have a resonance peak at about 400Hz and there are no significant differences at the other frequencies. It is found that absorption characteristics do not show remarkable changes withthe core inside the CMSA in the case of core diameter 50mm.

(b) Case 2: core diameter 100mm

In Case 2, the absorption characteristics show an insignificant resonance peak between 400Hz and 800Hz, and become more constant than absorption characteristics of the CMSA. However, no significant difference was found at the other frequencies.

(c) Case 3: core diameter 150mm

The CMSA with Core has a resonance peak at 800Hz in contrast to the CMSA which showed a peaka in the absorption at 400Hz. It means that the resonance frequency has changed by inserting a core. In addition, the absorption coefficient became lower than that of CMSA at low frequencies. According to this result, it can be stated that the absorption characteristics have changed by inserting the core when the core diameter is 150mm.

(d) Case 4: core diameter 200mm

Aresonance peak appears between 800Hz and 1000Hz, which means the peak moves to higher a frequency than the case of core diameter 150mm. Also, the absorption coefficient becomes lower than the case of core diameter 150mm at low frequencies. According to this result, it can be also stated that the absorption characteristics have changed in the case of core diameter 200mm.

From the above results, it is found that the core will not produce any remarkable differences in absorption characteristics in the cases of core diameter 50mm and 100mm. However, with core diameter between 100mm and 200mm, the absorption characteristics gradually change as the core diameter becomes larger.

3.2 Discussion on absorption mechanism

From the discussion in 3.1, it is found that the absorption characteristics change as the core diameter becomes larger. Hereupon, the characteristics of CMSA with Core are compared with those of CMSA and the typical single-leaf MPP with a rigid back wall, and discussions of the absorption mechanism shift are made.

A typical MPP sound absorber with a rigid back wall has a sharp peak in the absorption due to a resonator comprised of MPP and air-back cavity [2]. On the other hand, a CMSA has a peak in the absorption (which is not so sharp as a typical MPP sound absorber with a rigid back wall) and an additional low-frequency absorption coefficient about 0.3 [10]. Comparing these two absorption characteristics, CMSA with Core seems to have the absorption characteristics similar to a CMSA when a small core diameter, and is similar to a typical MPP sound absorber with a rigid back wall when the core diameter is large. According to this comparison, it can be stated that the absorption mechanism of the CMSA with Core shifts from the similar mechanism of the CMSA to the similar mechanism of the typical MPP sound absorber with a rigid back wall, as the core diameter becomes larger.

The inference above will be confirmed by comparing the measured results in each case of the CMSA with Core to the measured results of the CMSA and the calculated results of the typical MPP sound absorber with a rigid back wall. An absorption coefficient of the typical MPP sound absorber was calculated by using electro-acoustical equivalent circuit analysis. The specific acoustic impedance of the MPP, $Z = r - i\omega m$, is derived by the following formula which are proposed by Maa [2].

$$r = \frac{32\eta t}{p\,\rho_0 c_0 d^2}\left(\sqrt{1+\frac{k^2}{32}}+\frac{\sqrt{2}}{8}k\frac{d}{t}\right) \tag{1}$$

$$\omega m = \frac{\omega t}{p\,c_0}\left(1+\frac{1}{\sqrt{9+\frac{k^2}{2}}}+0.85\frac{d}{t}\right) \tag{2}$$

where

$$k = d\sqrt{\frac{\omega\rho_0}{4\eta}} \tag{3}$$

and, ρ_0 is the air density, c_0 is the sound speed in air, ω is the angular frequency, η is the viscosity of the air (1.789×10^{-5}[Pa s]), t is the thickness, d is the hole diameter, p is the perforation ratio of the MPP. The depth of the air-back cavity used in the calculation corresponds to the thickness of air layer for each case (shown in Table 1).

Figure 5 shows the comparison between measured results of the CMSA with Core and the CMSA, and calculated results of the typical MPP sound absorber with a rigid back wall. From Figure 5, the following observations may be made.

(a) Case 1: core diameter 50mm (air-back cavity 134mm)

The resonance peak appears at about 400Hz, and additional low frequency absorption is shown, which means the absorption characteristics are almost same as the CMSA. Therefore, it is stated that the absorption mechanisms of the CMSA with Core are the same as those of the CMSA in the case of core diameter 50mm.

(b) Case 2: core diameter 100mm (air-back cavity 109mm)

The measurement shows more constant absorption characteristics with frequency than that of the CMSA between 400Hz and 800Hz. However, no differences have occurred at the other frequencies. Thus, we can also say that the absorption mechanisms are still similar to that of the CMSA in case of core diameter 100mm.

(c) Case 3: core diameter 150mm (air-back cavity 76.7mm)

The absorption characteristics of the CMSA with Core with a diameter of 150mm differ from either CMSA or typical MPP sound absorber with a rigid back wall. The CMSA with Core shows a low-frequency absorption which is particular to the CMSA where the resonance peak appears at

800Hz which is identical to the resonance frequency of the typical MPP sound absorber with a rigid back wall. It cannot be concluded which types of the mechanisms are dominant, and should be considered as both mechanisms are produced in this case.

(d) Case 4: core diameter 200mm (air-back cavity 51.5mm)

The resonant peaks in the absorption appears at around 800Hz and 1000Hz and shows absorption characteristics similar to the typical MPP sound absorber with a rigid back wall. Thus, it can be stated that the absorption mechanisms of a typical MPP sound absorber are dominant in this case. However, it should be noted that the absorption coefficients in low frequency ranges are higher than those of typical MPP sound absorber with a rigid back wall, which means that this feature of the CMSA still remains at low frequencies.

From the above comparisons, it can be stated that CMSA with Core has the absorption mechanism similar to that of CMSA when the core diameter is small (as in Cases 1 and 2 with core diameters of 50mm and 100mm), and has the absorption mechanism similar to that of typical MPP sound absorber with a rigid back wall when the core diameter is large (as in Case 4, core diameter of 200mm). However, when the core diameter is not definitely large or small (as in Case 3, core diameter of 150mm), it seems that the both mechanisms of CMSA and typical MPP sound absorber with a rigid back wall are participant since both characteristics appear.

Therefore, the frequency where a peak in the absorption appears can be predicted by using the predicting theory of the typical MPP sound absorber only when the core diameter is large. It is difficult to predict the frequency where a peak in the absorption appears when the core is small, and any quantitative predictions cannot be made at this stage. Establishing the predicting will be the subject of future research.

3.3 Variation in the absorption characteristics by the core diameter

Now the amount of change in absorption coefficient between each case will be compared. As shown in Table 2, the amount of change between core diameter 100mm and 150mm is larger than the amount of change between core diameter 50mm and 100mm. And the amount of change between core diameter 150mm and 200mm is larger than the amount of change between core diameter 100mm and 150mm. This means that the absorption characteristic will change acceleratingly as the core diameter becomes larger.

To consider this cause, the comparison between the volume of the whole specimen and the volume of the core are made. The ratio by the volume of the core and the whole specimen is expressed as $(D_2/D_1)^2$, by using the diameter of the whole specimen D_1 and the diameter of the core D_2. D_1 is constant at $1/\pi$ [m], which means the ratio will increase as D_2 becomes larger, just like the absorption characteristic change. From this consideration, it might be inferred that the characteristic shift depends on the volume occupied by the core.

3.4 The effect of an end condition of absorber

It is confirmed in the previous study [10] that covering the top end of aCMSA can improve its absorption performance at resonant frequency. It is because the cover prevents the sound wave from escaping which produces increases the resonancenear the end. The same effect can be expected with a CMSA with Core and its measurement results are shown in Figure 6.

From Figure 6, it can be observed that the absorption coefficient has increased by covering the end of an absorber. However, the difference becomes smaller as the core diameter becomes larger. This is because the depth of the air-back cavity is small so that the resonance becomes more defined also in the case of the open end condition when a core diameter is large.

4. Concluding remarks

In this study, a three-dimensional MPP sound absorber, which is called as a CMSA with Core is proposed, as an approach to improve the sound absorptivity of CMSA and as a proposal for another CMSA usage. The CMSA with Core is fabricated by inserting a cylindrical core inside the CMSA and absorption coefficients measured in a reverberation chamber.

In the measurements, the diameter of the core was changed and measurements were conducted for each case. Accordingly, it is found that the absorption characteristics of CMSA with Core shift from that of a CMSA to that of a typical MPP sound absorber with a rigid back wall, as the core diameter becomes larger.

The above discussion implies that CMSA with Core can be used effectively by adapting the core diameter to absorb the target frequency. Iit also implies the possibilities of using CMSA with some small stuff (ex. Light bulb, electric wiring, etc.) inside. It is concluded that CMSA with Core can be used in practical situations.

Acknowledgement

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Caption of the Table

Table 1: The list of specimens used in the experiment.

Table 2: The amount of absorption coefficient changes between each case.

Captions of the Figures

Figure 1: Schematic representation of making a CMSA with Core specimen.

Figure 2: A photograph of the CMSA with Core specimen (Case 1: core diameter 50mm).

Figure 3: (Left) A layout plan. (Right) A photograph of specimens set in the reverberation chamber.

Figure 4: Measured results of CMSA and CMSA with Core. (●) CMSA, (×) Case 1: core diameter 50mm, (○) Case 2: core diameter 100mm, (□) Case 3: core diameter 150mm, and (△) Case 4: core diameter 200mm.

Figure 5: A comparison of the measured results of the CMSA with those of the CMSA with Core and the calculated result of the typical MPP sound absorber with a rigid back wall. (a) Case 1: core diameter 50mm, (b) Case 2: core diameter 100mm, (c) Case 3: core diameter 150mm, and (d) Case 4: core diameter 200mm.

Figure 6: A comparison of the measured results of the CMSA with Core in open end condition and closed end condition. (a) CMSA (b) Case 1: core diameter 50mm, (c) Case 2: core diameter 100mm, (d) Case 3: core diameter 150mm, and (e) Case 4: core diameter 200mm.

Table 1: The list of specimens used in the experiment.

Case No.	External diameter of core(mm)	Thickness of air layer (mm)
Case 1: core diameter 50mm	50	134.2
Case 2: core diameter 100mm	100	109.2
Case 3: core diameter 150mm	165	76.7
Case 4: core diameter 200mm	215	51.5

Table 2: The amount of absorption coefficient changes between each case.

Frequency	An amount of change between core diameter 0mm(CMSA) and 50mm	An amount of change between core diameter 50mm and 100mm	An amount of change between core diameter 100mm and 150mm	An amount of change between core diameter 150mm and 200mm
100Hz	0.01	0	0	0.05
125Hz	0.01	0.02	0.04	0.05
160Hz	0.01	0.02	0.04	0.05
200Hz	0.02	0.02	0.06	0.07
250Hz	0.01	0.01	0.09	0.09
315Hz	0.02	0.05	0.1	0.1
400Hz	0.01	0.04	0.12	0.11
500Hz	0.03	0.02	0.05	0.09
630Hz	0.01	0.02	0.01	0.06
800Hz	0.03	0.07	0.03	0.01
1000Hz	0.03	0.01	0.05	0.03
1250Hz	0.01	0.03	0.01	0.05
1600Hz	0	0.01	0.04	0.05
2000Hz	0.01	0.02	0.01	0.07
2500Hz	0.01	0.02	0.04	0.07
3150Hz	0.01	0.02	0	0
4000Hz	0.01	0.02	0.01	0.03
5000Hz	0.05	0.05	0.02	0.01
Total amount	0.29	0.45	0.72	0.99

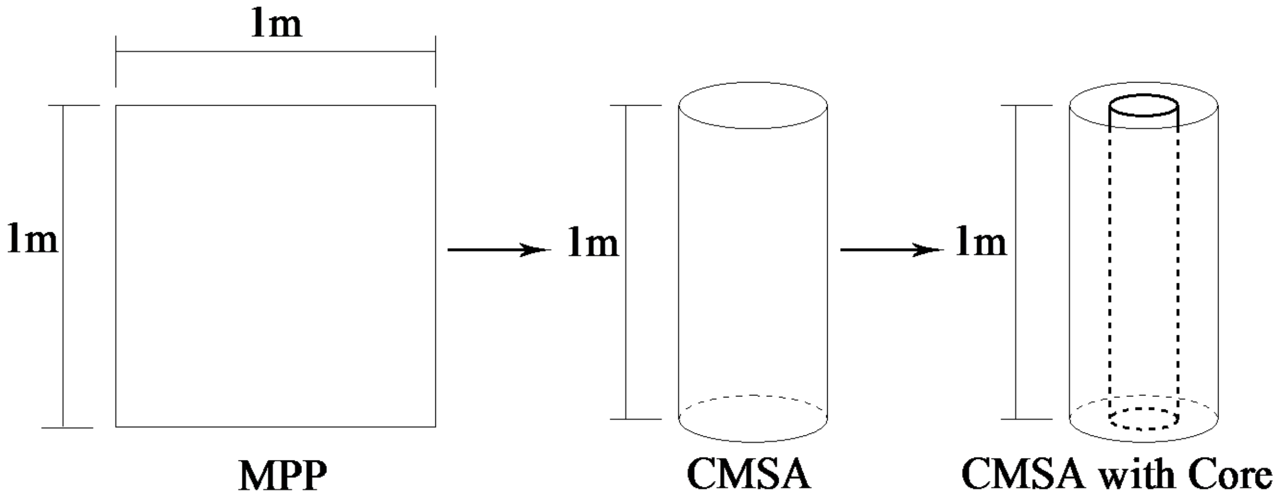
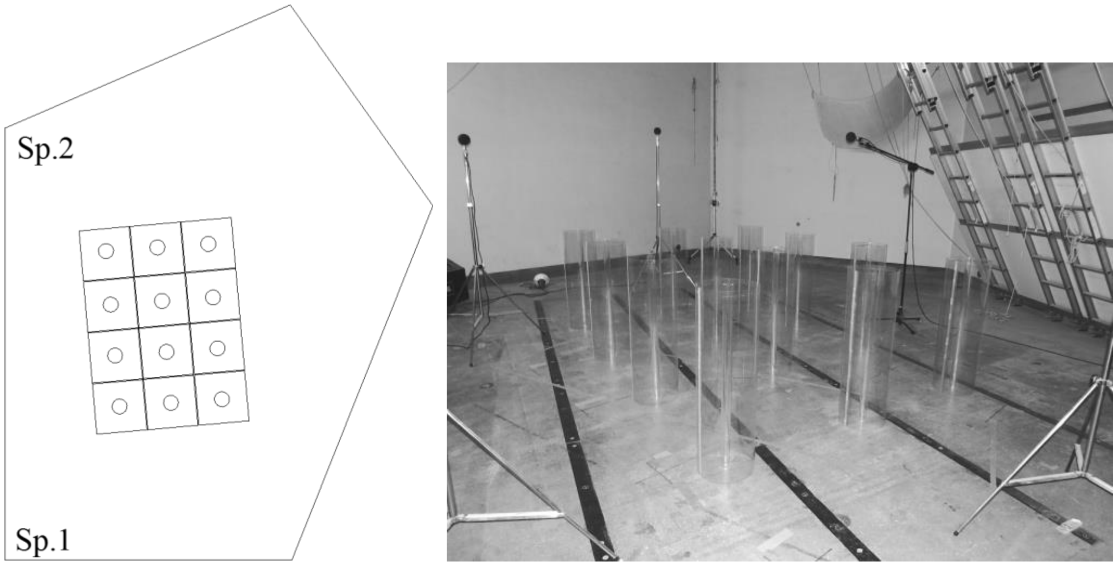


Figure 1: Schematic representation of making a CMSA with Core specimen.

Figure 2: A photograph of the CMSA with Core specimen (Case 1: core diameter 50mm).



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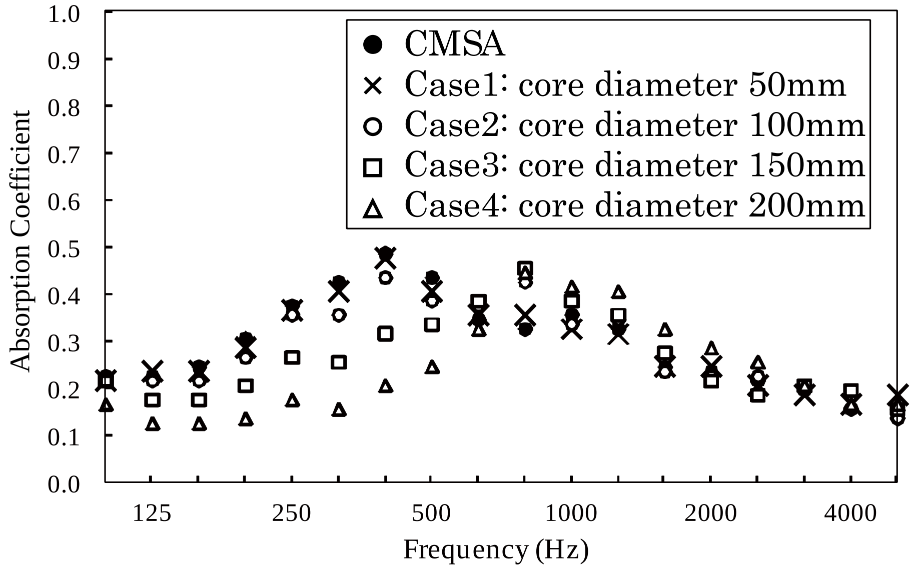

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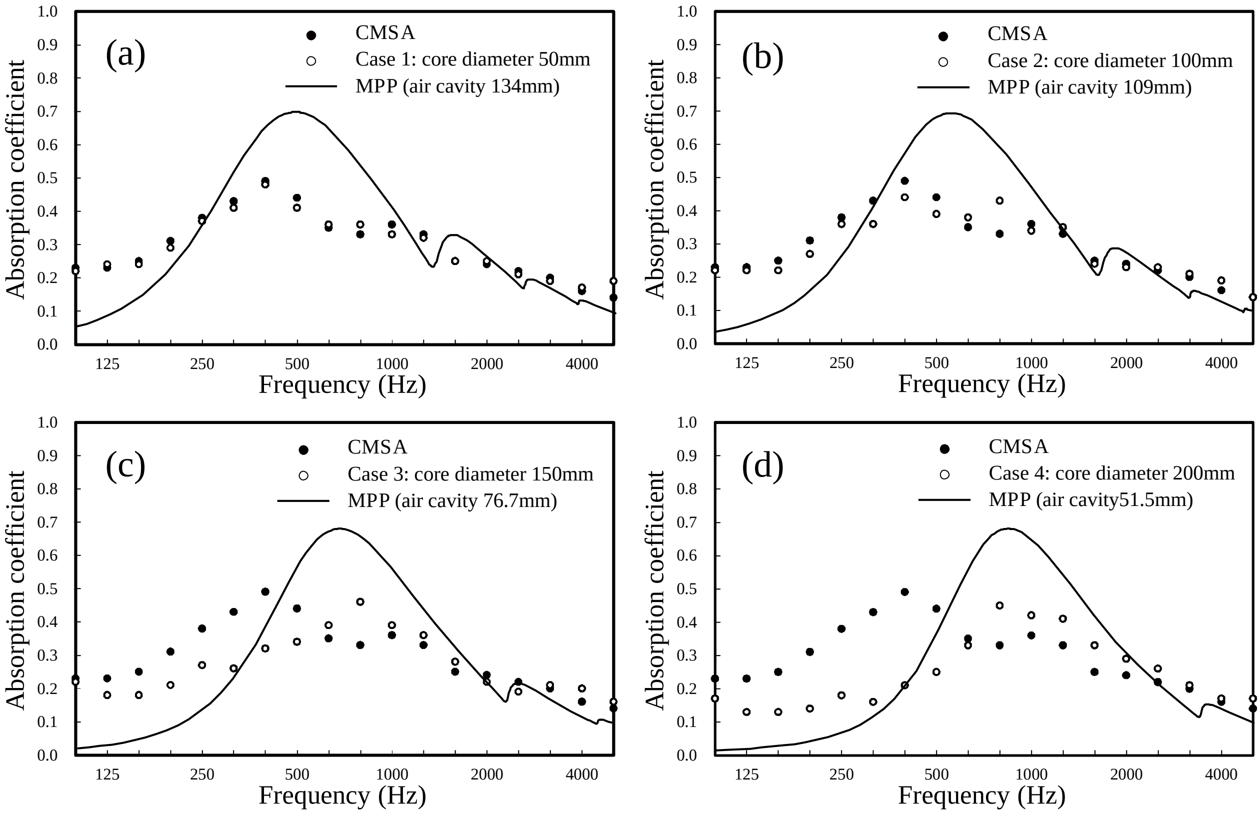

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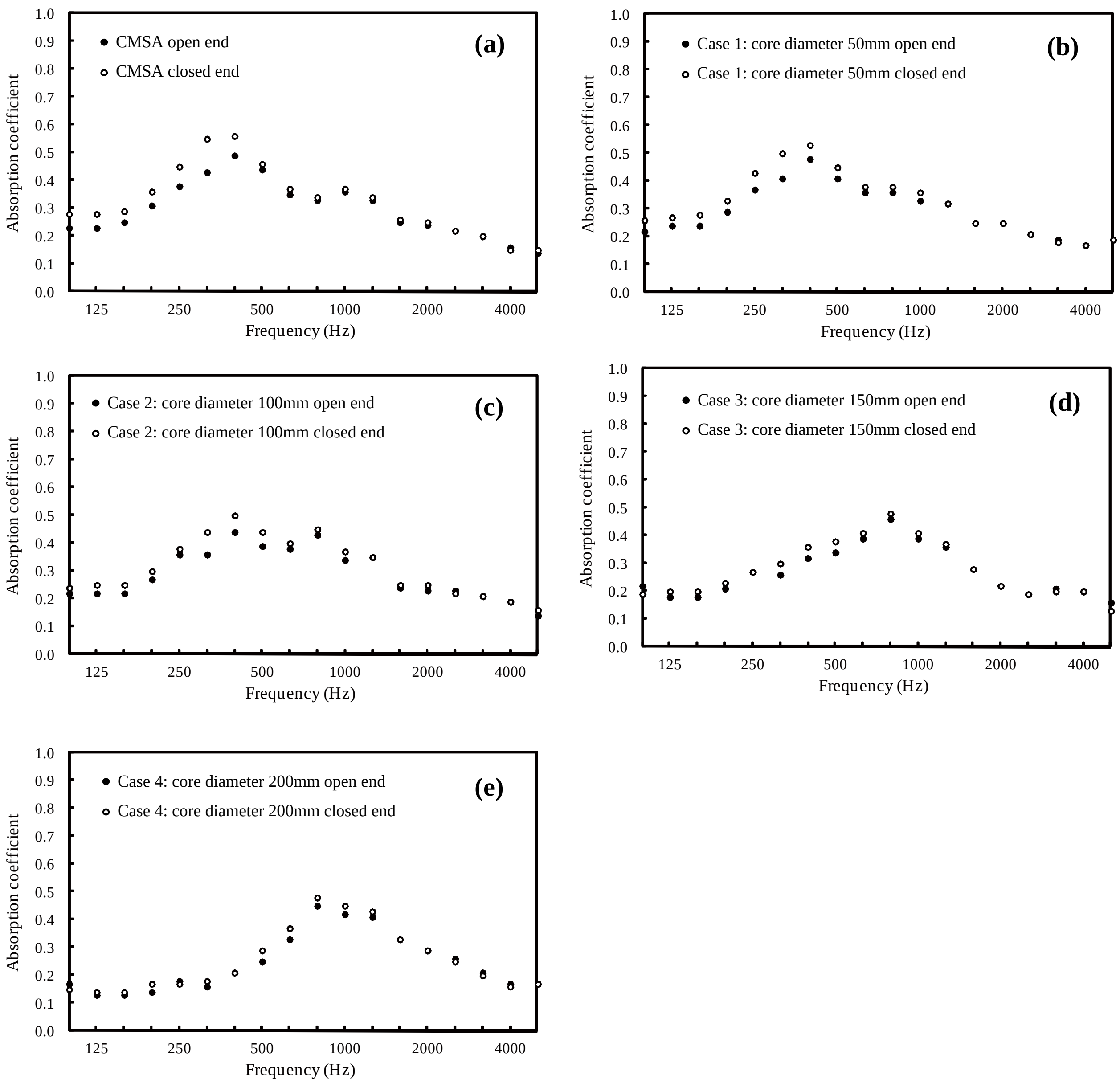

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