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An experimental study on a cylindrical microperforated panel space sound absorber

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A microperforated panel (MPP), which is widely known as one of the most promising alternatives of the next-generation sound absorbers, is typically used with a rigid-back wall with an air-cavity. However, a multiple-leaf MPP space absorber, which does not have any backing structure, double-leaf MPP space absorber (DLMPP) and triple-leaf MPP space absorber (TLMPP) is proposed. However, these are panel-like structure which are limited to where they can be used. In order to develop an MPP space absorber that can be used in more various situations, a trial production of a cylindrical MPP space sound absorber (CMSA) is made with an MPP shaped into a cylindrical. The sound absorption characteristics of a CMSA are measured in a reverberation chamber. As a result, although the absorption coefficient is not very high, a CMSA shows sound absorption characteristics similar to a DLMPP and TLMPP: a resonance peak by a Helmholtz resonator and an additional low frequency absorption by its acoustic permeability appear. The results suggest that a CMSA can be used as a space sound absorber in practical situations.

Primary subject classification: 35.1; Secondary subject classification: 34.3

1 INTRODUCTION

A microperforated panel (MPP) is one of the most promising alternatives of the next-generation of the sound absorbing materials, which solves various problems and shortcomings of typical porous sound absorbing materials. It has recently been attracting a great deal of acousticians' attention. An MPP is a very thin (usually less than 1 mm thick) panel or film with submillimetre holes of perforation ratio less than 1%. This is, in principle, similar to the traditional perforation panels with larger thickness and perforation parameters which have been used for long time in many buildings. However, in MPPs, using a very thin panel and small perforations, the optimal acoustic resistance and reactance for sound absorbers are realized. Therefore, one of its significant acoustical features is that it can produce a higher absorption peak and wider absorption frequency range than the traditional perforated panel absorbers. An MPP was first proposed by Maa[1] in 1970's, and later Maa himself developed its predicting theories, validated them and proposed efficient design methods[2–4]. Furthermore, other researchers have attempted to apply MPPs for various purposes and reported the results[5–8].

The typical usage of an MPP is to put an MPP against a rigid-back wall with an air-cavity in between. Helmholtz resonators are formed by each perforation and the air-cavity behind the perforation, which causes a resonance-type peak in the sound absorption. The authors have proposed a space sound absorber composed of two MPPs put in parallel to each other without any backing structure, which is called a double-leaf MPP space sound absorber (DLMPP)[9,10]. Also proposed is a similar construction composed of three MPP leaves, which is called a triple-leaf MPP space sound absorber (TLMPP)[11]. The authors also examined the possibility of substituting one of the MPP leaves in these multiple-leaf absorbers with a permeable membrane[12]. Thus, the authors proposed those MPP space sound absorbers without a backing structure, and studied their sound absorption characteristics. The

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Table 1—Parameters of the MPP used for the CMSA specimens used in the experiments.

	Hole diameter (mm)	Thickness (mm)	Perforation ratio (%)	Surface density (kg/m^2)
No.1	0.5	0.5	0.785	0.6
No.2	0.5	1.0	0.785	1.2

potential of those absorbers has been shown in the above cited authors' previous publications.

The above multiple-leaf space sound absorbers are all in panel-like flat shape. Therefore, they are mainly considered to be used as a sound absorbing panel or partition, and the method of their placement can be somewhat limited because panel-like absorbers basically can be put either on the floor with a stand or hang from the ceiling. If a space sound absorber made of MPPs can be placed more freely anywhere, it would be situated in more places and would be more beneficial.

Therefore, in this paper, a space sound absorber with three-dimensional shape made of an MPP is proposed, and its potential as a sound absorber is studied experimentally. To shape an MPP into three-dimensional object, it can be curved into cylinder or configured into a parallelepiped. In this study, as the easiest way to construct such a three-dimensional shape which can be considered to maintain the general feature of a three-dimensional shaped MPP space sound absorber, a cylindrical shape is chosen. This is an MPP shaped into a cylinder (void inside) and will be called cylindrical MPP space sound absorber (CMSA) hereafter. In this study, the sound absorption characteristics of a CMSA are measured in a reverberation chamber in various cases, and the experimental results discussed.

2 EXPERIMENTAL DETAILS

2.1 Measurement Method and Specimens

The measurements of diffuse-field sound absorption coefficients were conducted in accordance with JIS A 1409 (compatible to ISO 354) except for the method of the placement of specimens. The measurements of the reverberation time were made twice in each of five receiving positions by changing the position of the sound source. The reverberation chamber has a volume of 513 m^3, and a surface area of 382 m^2.

The MPPs used for making a specimen of CMSA in the experiments were squares of dimensions (1 by 1) m. They are made of polycarbonate. Two types of MPP were used for making CMSA specimens in the experiments: the parameters of each are shown in Table 1.

The specimens of CMSA, as shown in Fig. 1, were formed by shaping the above 1 m^2 square MPP into a cylindrical shape (height 1 m, surface area 1 m^2, diameter $1/\pi$ m, and void inside). In order to study the effect of the surface area and the height, other specimens of the same diameter but twice as high (two 1-m specimens (Fig. 1) are stacked), and those of the same height but larger diameter (two 1 m by 1 m square MPPs are used to make a larger cylinder with the diameter twice as large) were prepared and measured in the experiments.

2.2 Measurement Conditions

In the measurements, in order to determine the area effect, along with the effect of the arrangement and the mode of placement in the reverberation chamber, various experiments (including preliminary experiments) were conducted. The conditions of the experiments are summarized below:

(A) Number of specimens: (1) 6 specimens, (2) 12 specimens.

(B) Specimen arrangement: (1) 12 specimens were placed with regular intervals as in Fig. 2, (2) 6

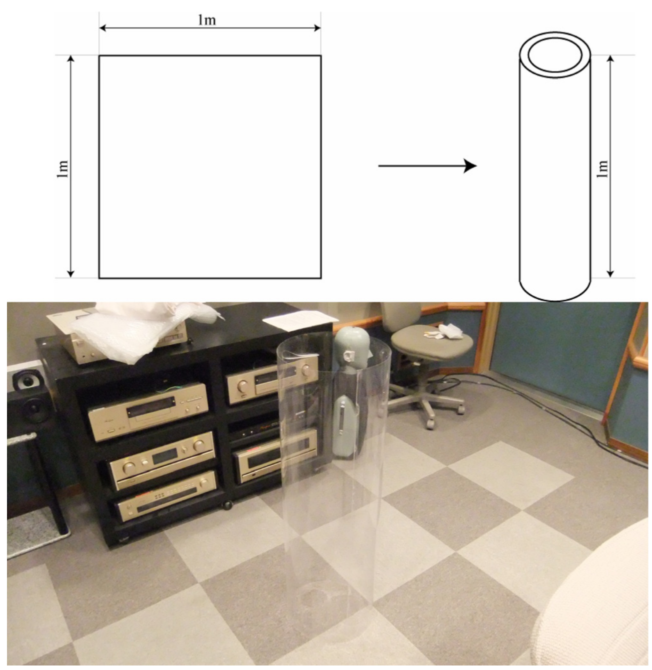

Fig. 1—Schematic representation of the procedure to make a CMSA from a square MPP (top) and a photograph of a CMSA specimen (bottom).

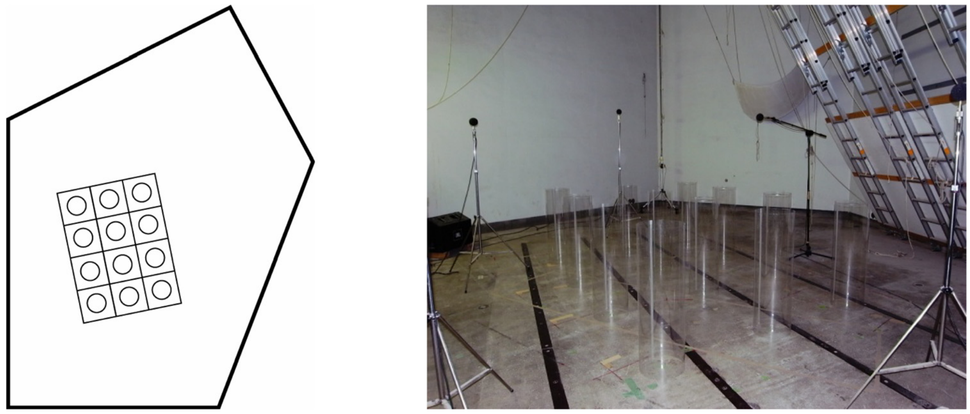

Fig. 2—An example of the setting of the experimental specimens in a reverberation chamber. In this example twelve specimens are placed as the sketch on the left. The photograph of the setting is shown on the right.

specimens were placed in the half of the area indicated by the grid in Fig. 2.

(C) Specimen height: (1) 1 m (2) 2 m.

(D) Specimen placement: (1) placed on the floor, (2) set apart from the floor.

As well as the above, in order to know the effect of the diameter of cylinder and the surface density of the MPP leaf, the two conditions below were also considered.

(E) The diameter of the cylinder: (1) $1/\pi$ m (made of one sheet of 1 m^2), (2) $2/\pi$ m made of two sheets of 1 m^2. The diameter and the surface area are twice larger).

(F) The surface density of the MPP used for a CMSA specimen: (1) MPP No. 1 in Table 1 (0.5 mm thick, 0.6 kg m^{-2}), (2) MPP No. 2 in Table 1 (1.0 mm thick, 1.2 kg m^{-2}).

Both ends of the CMSA specimens prepared for the experiments were open. When they are put on the floor, the bottom side is closed by the floor, but the top side is open. When they are set apart from the floor, the both sides are open. In order to know the effect of closing the open end by a cover, in each of the above conditions both cases with a cover and without it were measured.

The results of the above experimental consideration, regarding the number of the specimens (A), both 12 specimens and 6 specimens give the same results for the absorption power of one specimen. (The absorption coefficient, which is normalized to the total surface area of specimens, agrees with the absorption power of one specimen. Therefore, in the following all the absorption coefficients are normalized by the total surface area of the specimens.) Thus, it is not necessary to take into account the area effect, and only six specimens are good enough for appropriate measurement. Regarding to the arrangement of the specimens (B), no significant difference was observed as long as the number of the specimens was the same. Therefore, it is not necessary to consider the arrangement of the specimens.

Therefore, in the following the discussions will be made for the other measurements than (A) and (B), and the absorption characteristics of a CMSA are discussed through the results.

3 RESULTS AND DISCUSSIONS

3.1 Typical Examples of the Measured Results: CMSA with and without a Cover at the Open End

Figure 3 shows a typical measured results of the diffuse-field absorption coefficient of a CMSA (made with the MPP No. 1 in Table 1; height 1 m and diameter of $1/\pi$ m). These results were measured with 12 CMSAs placed directly on the floor. The black curves are the results for the case that the top ends of the CMSA specimens are open, and the grey curves are for the case that the top ends are closed with covers. The bottom ends of the CMSA specimens are closed by the floor. As shown in the figure, the absorption coefficient shows a resonance peak at around 400 Hz, which is similar to a typical wall-backed single MPP absorber and multiple-leaf MPP space absorbers (i.e., DLMPP). This fact suggests that a CMSA also causes a Helmholtz-type resonance sound absorption.

At frequencies lower than the frequency of the peak absorption, the absorption coefficient shows a nearly constant value around 0.3. This is similar to multiple-leaf MPP space sound absorbers, e.g., DLMPP, and also similar to other acoustically permeable sound absorbing structures such as a permeable membrane. Thus, it is inferred that, at lower frequencies, a CMSA causes a

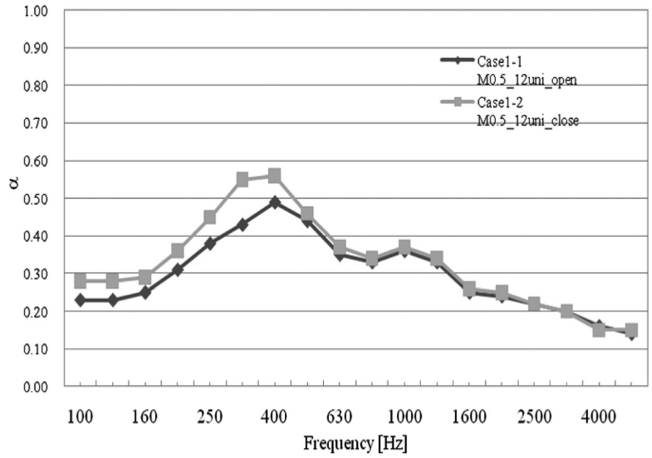

Fig. 3—Typical examples of the experimental measured results. Twelve specimens of 1 m high made of MPP No.1 in Table 1 were placed as to stand directly on the floor. Black curve: open end; Grey curve: closed end.

moderate additional absorption due to the acoustical resistance of the permeable leaves. A CMSA shows typical features of a multiple-leaf MPP space sound absorber, and moderate sound absorptivity in somewhat a wider frequency range, which can be used as a wide-band sound absorbing system. The authors tried to interpret this tendency by comparing this result with a theoretical result for a DLMPP with an equivalent air-layer thickness. It is difficult to predict the absorption characteristics of a CMSA by the DLMPP theory, however the comparison of them explained to a certain degree the absorption mechanism of a CMSA and its similarity to a DLMPP[13].

Comparing those two cases (with and without the cover on the top end) it is found that the resonance absorption peak is more significant when the top end is closed by the cover. When the top end is open the sound wave can be incident from the open end, which can disturb the sound field inside the CMSA and eventually the resonator formed by holes and the cavity in the CMSA becomes less efficient, because the system becomes less airtight. Therefore, in practical situations, the end of the CMSA should be closed to obtain higher absorptivity.

3.2 Effect of the Height of CMSA

In order to clarify the effect of the height of a CMSA, specimens of 2 m high are made of the MPP No.1 in Table 1, and were measured to compare with those of 1 m high. The method of the placement and arrangement of the specimens were the same as in the preceding section. The measurements were made for the cases with and without a cover on the top ends of CMSA specimens. In this comparison, the number of the specimens is 12 for 1 m high specimens and 6 for 2-m specimens, as the effect of the number of specimens had been found to be negligible. The results are shown in Fig. 4 (a: top ends open, b: top ends close).

Regardless to the condition of the end (open or close), the results for 1 m high and those for 2 m high are in good agreement in most frequency ranges. However, at low frequencies (especially 100 – 125 Hz), there is slight discrepancies: the CMSA of 2 m high shows somewhat lower absorption coefficient. The reason for this fact might be the characteristics of the absorber itself or the effect of the difference in the height from the floor, but it is difficult to find a reasonable

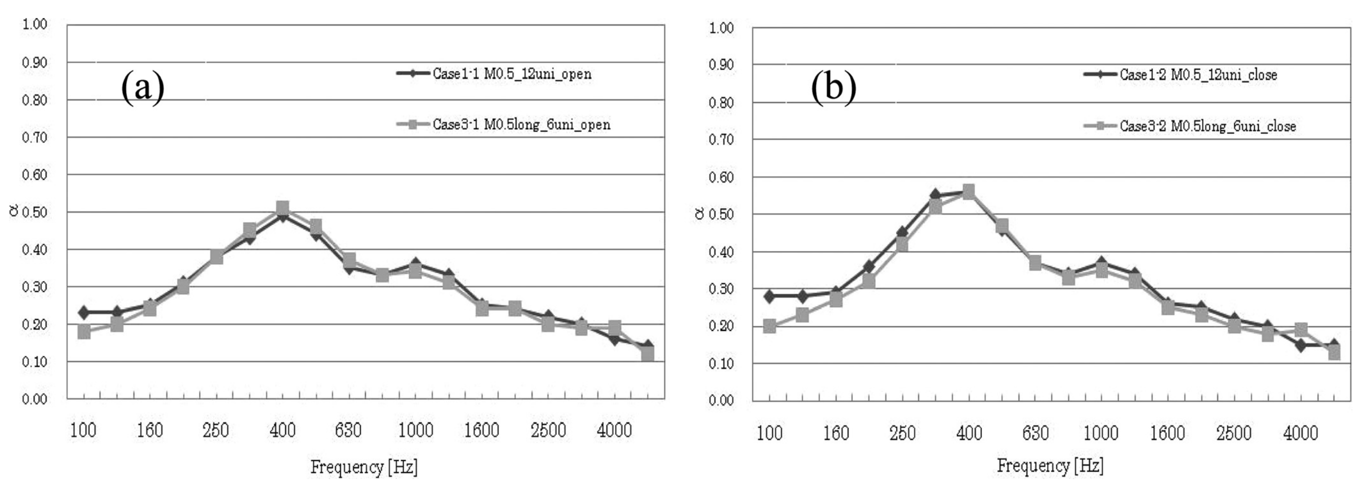

Fig. 4—Effect of the height of a CMSA. Black curve: CMSA made of MPP No.1 (Table 1) 1 m high (measured with twelve specimens): Grey curve: CMSA made of MPP No. 1 (Table 1) 2 m high (measured with six specimens). All specimens were placed on the floor standing. (a) the top ends were open, (b) the top ends were closed.

explanation. (Note: in these experiments, when the absorption coefficient is calculated, the surface area, in the case of 1 m high CMSA the surface area of one absorber, is 1 m^2, and in the case of 2-m high CMSA it is 2 m^2. Therefore, considering the absorption power for "one" absorber, it is stated that the CMSA of 2 m has twice as much absorption power.)

Furthermore, comparing Figs. 4(a) and (b), one can understand that, in the case of 2 m high CMSA, to close the top ends of CMSA specimens is also effective in increasing the absorption coefficient as was observed in the 1-m case.

3.3 Effect of the Floor: Placed on the Floor and Set Apart from the Floor

In the above experiments, the CMSA specimens were placed directly on the floor of the reverberation chamber. However, considering the usage of a CMSA as a space sound absorber, it can be set up apart from the floor, e.g., they can be hung from the ceiling. Therefore, in this section, a comparison of the CMSA's absorption characteristics in the cases where they are placed on the floor and where they are set apart from the floor is made. In the both cases, the effect of the closing the end of CMSA is also discussed. Figure 5 shows the results (a: open end, b: closed end). In the both cases the bottom ends are closed by the floor or the cover, therefore 'open' means open top ends and 'close' means 'both ends closed'.

When the top ends are open, the case in which the specimens are set apart from the floor gives somewhat higher peak value. The peak frequency remains the same, and the characteristics are not very different elsewhere. When the both ends are closed, except for the values around the peak, the characteristics are almost the same regardless of the distance from the floor. However, at the frequencies lower than the peak (at around 125 Hz) a slight difference is observed in both cases (more significantly in the closed case): the absorption coefficient is somewhat higher when the specimens are placed on the floor. The reason for this is not clearly evident, but it can be suggested that the vibration of the CMSA can be somewhat restrained at the contact to the floor, which can result in apparently higher flow resistance giving higher absorptivity[14].

3.4 Effect of the Diameter of CMSA

Here the effect of the diameter of a CMSA is discussed. The CMSA specimens with a larger diameter (2 times a larger diameter, with the same height 1 m) made of two MPP leaves (Table 1, No. 1) for each are measured and compared with the CMSA specimens with a smaller diameter (used in the preceding sections). Figure 6 shows the results (a: open end, b: closed end).

The CMSA with the larger diameter does not show clear resonance peak absorption. Its absorptivity gradually increases with decreasing frequencies. This is because the air cavity is too large to show clear resonance. In the case of a wall-backed single MPP absorber, when the back cavity is too deep, the resonance peak becomes less significant[15]. These are considered to be a similar phenomenon. Consequently, the characteristics converge to those of acoustically permeable structure which absorbs sound energy with acoustic resistance. The effect of closed end also appears in this case: it shows higher absorptivity when the end is closed by a cover.

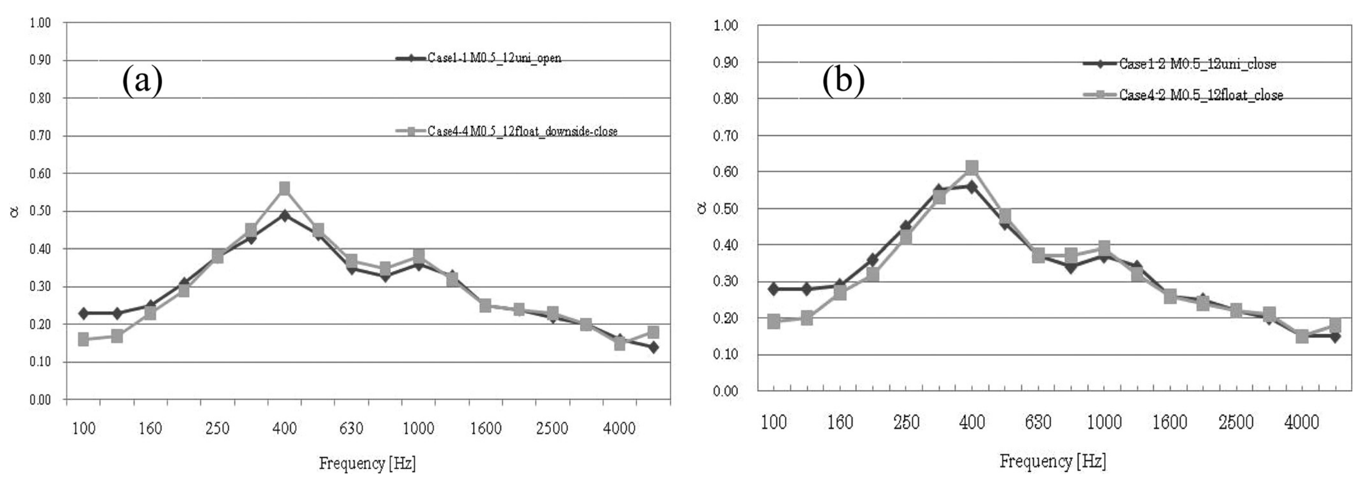

Fig. 5—Effect of the floor on the absorptivity of a CMSA. Black curve: CMSA made of MPP No.1 (Table 1) 1 m high on the floor: Grey curve: CMSA made of MPP No. 1 (Table 1) 1 m high off the floor (1.6 m high from the floor). Twelve specimens were used in all cases. (a) open top ends, (b) closed top ends. Note that the bottom ends are closed in all cases.

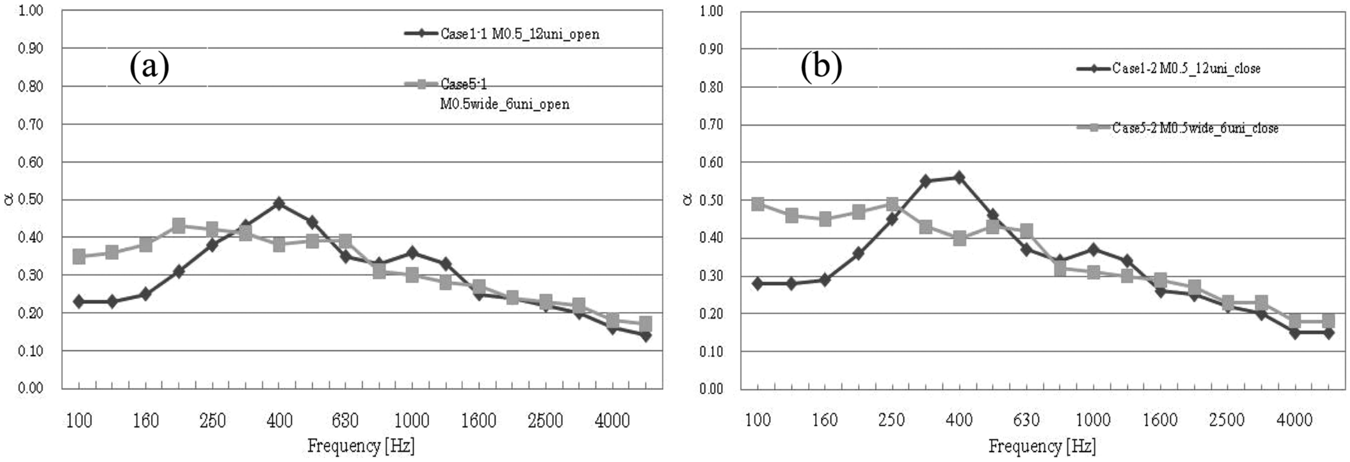

Fig. 6—Effect of the diameter of a CMSA. Black curve: diameter 1/π m (twelve specimens); Grey curve: diameter 2/π m (six specimens). All specimens were made of MPP No.1 in Table 1, and placed directly on the floor. (a) open ends, (b) closed ends.

3.5 Effect of the Thickness of MPP used in a CMSA

The CMSA with the larger diameter examined in the preceding section is now compared with a CMSA with the same diameter but made of thicker MPP (Table 1, No. 2. 1.0 mm thick). Figure 7 shows the results (a: made of 0.5 mm MPP, b: made of 1.0 mm MPP). In this case, the effect of open/close end was negligible, therefore only the results for the case with closed end are shown. As shown in the figure, the effect of the thickness of the MPP leaves used for CMSA does not appear. In this case, the diameter is too large to cause the resonance peak, and this can be why the difference is not observed. When the diameter is smaller and a significant resonance peak appears, some difference in the peak value and frequency can appear.

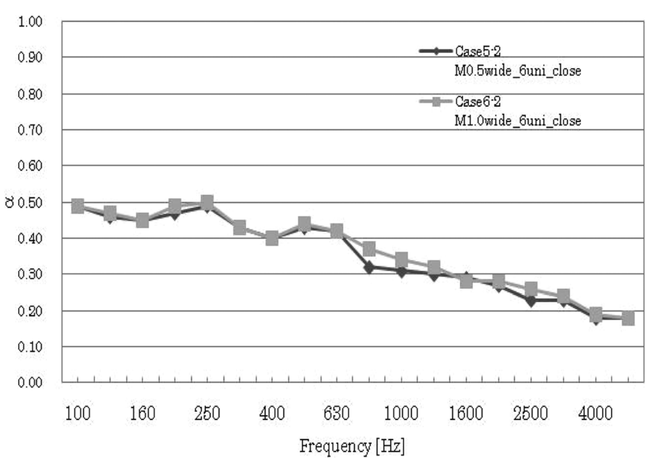

Fig. 7—Effect of the thickness of MPP on the absorptivity of a CMSA. Black curve: 0.5 mm; Grey curve: 1.0 mm. Other conditions are the same as Fig. 6 (cylinder diameter 2/π m and 6 specimens).

3.6 Double-Layered CMSA

Two CMSAs with different diameters are used to make a double-layer CMSA, and its sound absorption coefficient was measured. The CMSA with 1/π m diameter was put in the CMSA with 2/π m diameter (both were made of MPP No. 2 in Table 1). The results are shown in Fig. 8.

The results show that the characteristics are basically the same as a single-layer CMSA with larger

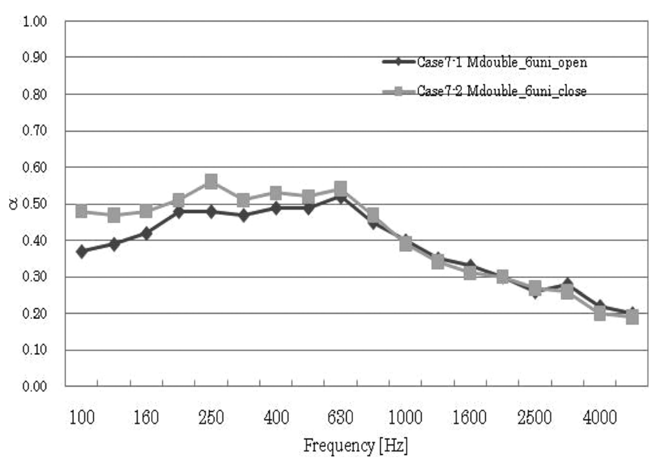

Fig. 8—Measured diffuse-field absorption coefficients of double CMSA. The double CMSA was realized by inserting a CMSA with diameter 1/π m in a CMSA with diameter 2/π m. Six specimens, all made of MPP No. 2 in Table 1, were placed on the floor. Black curve: open ends; Grey curve: closed ends.

diameter $2/\pi$ m. However, comparing this with Fig. 7, the absorptivity is somewhat increased at low frequencies than the single CMSA. This tendency is more significant as seen in the case when the top end is closed by a cover. But, in any case, the characteristics are basically those of a permeable absorption structure, and the resonance peak does not clearly appear. Therefore, though there is a small merit that low frequency absorption is somewhat increased, it cannot be concluded that the double-layered CMSA is better than the single CMSA from this result.

4 CONCLUDING REMARKS

In this paper, a Cylindrical MPP Space Sound Absorber (CMSA), which is an MPP shaped in a cylinder (void inside) was proposed. Its sound absorption characteristics were measured in a reverberation chamber, and the measured results discussed. As a result, a CMSA can show a Helmholtz-type resonance peak absorption, which is similar to a typical wall-backed MPP absorber and the other MPP space sound absorbers (DLMPP, TLMPP etc.). Also, an additional low frequency absorption caused by the acoustic resistance of the structure appears, which is also similar to DLMPP, TLMPP etc. Thus, although the absorption coefficient is not very high, it can cover a wider frequency range, which shows that the possibility of a CMSA to be used as a space sound absorber in practice.

When the height (length) of a CMSA becomes larger, the characteristics do not change significantly. However, when the diameter of a CMSA becomes larger (in this study $2/\pi$ m) the resonance peak does not appear. Only the low-frequency resistance absorption appears. Therefore, in a practical design it should be noted that the diameter of the cylinder can affect the performance. Regarding the parameters of MPP perforations, in the present study only two types of MPP (two different thicknesses) are used and no significant difference was found. Perhaps it may be needed to study the effect of all parameters of MPP perforations to gain a design principle, however almost all effect can be reasonably inferred from the previous studies on other type MPP absorbers.

5 ACKNOWLEDGEMENT

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