AN EXPERIMENTAL STUDY ON THE SOUND ABSORPTION OF THREE-DIMENSIONAL MPP SPACE SOUND ABSORBERS: RECTANGULAR MPP SPACE SOUND ABSORBER (RMSA)

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A microperforated panel (MPP) is usually placed with a rigid-back wall to form a Helmholtz resonator with its hole and the air-back cavity. However, the authors have so far proposed an MPP space sound absorber without any backing structure. In the previous studies, as a basic form of such an MPP space absorber, multiple-leaf MPP structures without a back wall were proposed, and were theoretically and experimentally examined. In order to provide more unrestricted usage and designs for an MPP space absorber, the authors have also proposed a three-dimensional MPP space absorber, called a cylindrical MPP space absorber (CMSA). The CMSA was shown to exhibit resonance peak absorption and additional low frequency absorption. In this paper, another alternative of a three-dimensional MPP space absorber, a rectangular MPP space absorber (RMSA) is proposed. Its sound absorption performance is discussed using experimentally measured results. The results show sound absorption characteristics similar to a CMSA, and an RMSA can be effectively used if properly designed.

INTRODUCTION

A microperforated panel (MPP) is one of the most promising alternatives among so-called "next-generation sound absorbing materials". The use of an MPP solves problems associated with porous absorbing materials such as low durability, hygiene and low recyclability. An MPP is usually made of a thin panel or film (less than 1 mm thick) with submillimetre perforations with perforation ratio of less than 1%. The acoustic resistance and reactance suitable for sound absorbing materials is realised, and hence an MPP offers better sound absorption performance than ordinary perforation panels with larger perforations. An MPP was first proposed by Maa [1] in the 1970s. Maa developed the theory and design principle of an MPP as well as validated its effectiveness [2-4]. Many researchers have since presented studies on its application for various purposes [5-8].

The basic usage of an MPP is to place it in front of a rigid-back wall with an air-back cavity in-between. Helmholtz resonators are then formed with the holes of the MPP and the air-back cavity. The authors proposed a double-leaf structure of MPPs with an air-cavity in-between without a rigid-back wall, which is called a double-leaf MPP space sound absorber (DLMPP) [9,10], as well as a similar structure with three MPPs which is a triple-leaf MPP space sound absorber (TLMPP) [11]. The authors also proposed a space sound absorber with an MPP and a permeable membrane without any backing structure [12]. The sound absorption characteristics and the effectiveness of these sound absorbing structures were examined.

The DLMPP, TLMPP and MPP-membrane space absorbers are all in the form of a panel-like structure, which can be used as a sound absorbing panel or partition. However, this restricts the usage of these space sound absorbing structures due to its flat panel-like shape in some cases in actual rooms or buildings. To overcome these limitations, the authors proposed a light-weight three-dimensional MPP space sound absorber, which can be easily hung from the ceiling or put more freely on the floor. A cylindrical MPP space sound absorber (CMSA) which is made of an MPP shaped in a cylindrical shape was examined. The acoustic performance of the CMSA was experimentally studied [14]. CMSAs demonstrated moderate sound absorption performance which is rather similar to a DLMPP, and are considered to be a useful alternative for a sound absorber in rooms and buildings. A CMSA is also a good consideration as a sound absorption treatment in architectural design because it can be made of a transparent material as well as can be coloured.

Three-dimensional MPP space absorbers are a good sound absorption treatment if they can be made in various shapes. In this study, an alternative design corresponding to a rectangular pole (box-like shape with an air cavity inside) is constructed with MPPs, which is called a rectangular MPP space sound absorber (RMSA). The sound absorption characteristics of RMSAs are experimentally measured and their acoustic performance is discussed.

EXPERIMENTAL PROCEDURE

The measurement of the random incidence sound absorption coefficient in a reverberation chamber was carried out based on JIS A 1409 (ISO 354 compatible). The measurements of the reverberation time were made for two sound source positions and at five microphone positions. The reverberation chamber used is of volume 513 m^3 and surface area 382 m^2. To obtain the absorption coefficient, the following equation based on the Sabine's formula is used:

$$\alpha = 55.3 \frac{V}{cS}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \quad (1)$$

where α is the absorption coefficient of the specimen, c is the speed of sound, V is the volume, S is the surface area of the reverberation chamber, and T_1, T_2 correspond to the reverberation times without and with the specimens, respectively.

The test specimens are two types: number 1 is with square cross section of 0.25 m. Number 2 is with square cross section of 0.5 m. Both are void (with air cavity) inside and of 1 m high: They are constructed with MPP leaves of 0.25 m x 1.0 m for number 1, and 0.5 m x 1.0 m for number 2. The MPPs are attached to a wooden frame of square pole to form a parallelepiped shape. The MPP used is of 0.5 mm hole diameter, 0.5 mm thickness, 0.785% perforation ratio and 0.6 kg/m^2 surface density, and made of transparent polycarbonate. A photograph of specimen number 1 is shown in Figure 1. The specimens set in the reverberation chamber are shown in Figure 2. In the both cases (numbers 1 and 2), the measurement was made with the top open ends either kept open or closed by removable covers.

In previous studies on a cylindrical MPP space sound absorber (CMSA), preliminary experiments were made to check the effect of area. In the present study, preliminary measurements were also made with 2, 4 and 6 specimens (which are separated to each other by 1 m distance, placed on the central area of the floor of the chamber) to observe if the absorption power per one specimen changes with the number of specimens. However, as in the case of a CMSA, the absorption power per one specimen did not change when the number of specimens was changed. As in the CMSA cases, the sound absorption power obtained in the experiment is normalised by the total of the surface area of the specimens so that the value equivalent to the sound absorption coefficient is obtained. All measured data in this work are with six specimens. The absorption coefficient corresponds to the sound absorption power per unit surface area of the specimen by normalising the measured results with the total surface area of the six specimens. Hence in the case of number 1, the specimen surface area is 1 m^2 and the sound absorption power per one specimen is equivalent to the sound absorption coefficient. In the case of number 2, the specimen surface area is 2 m^2 and the measured value normalised by 2 is equivalent to the sound absorption coefficient.

Figure 1. A photograph of the specimen of RMSA used in the experiment (number 1 with a removable cover on the top end)

Figure 2. The specimens of rectangular MPP space sound absorbers (RMSA) set in a reverberation chamber. In this photo the top ends of the specimens are closed with removable covers

EXPERIMENTAL RESULTS

Case number 1

The measurement results for number 1 are shown in Figure 3. In the graph both the open end and closed end cases are shown for comparison. As a general feature, the RMSA shows a resonance absorption peak (in this case at around 500 Hz). At low frequencies around 200 Hz the absorption coefficient still keeps a constant value around 0.2, which is similar to CMSA, DLMPP and other space absorbers with permeable materials. This is caused by the acoustic resistance of the MPP and particularly for permeable structures, as inferred in the study on CMSA [14]. The effect of the cover appears around the resonance peak: the peak is more significant when the top end is closed by a cover. This is also a similar feature to a CMSA. Therefore, the sound absorption mechanism of the RMSA is considered to be similar to that of a CMSA.

Case number 2

The measurement results for number 2 are shown in Figure 4. In the graph both the open end and closed end cases are shown for comparison. On the contrary, in this case a significant peak does not appear. This is attributed to the fact that the cavity inside becomes too large to cause a resonance: the resonance peak does not significantly appear even in the case of a typical single-leaf MPP with a rigid-back wall [13]. This phenomenon has also been discussed in the case of a CMSA with larger dimensions [14]. When the top end is closed by a cover the absorption coefficient becomes somewhat higher, and a broad peak-like feature appears. This is also similar to CMSA cases. The RMSA does not show a significant resonance peak when the size becomes too large, which is similar to a CMSA. Therefore, the size of the RMSA is critical in the design of a three-dimensional MPP space sound absorber, that is, the size should not be too large.

Other considerations

In this section, further discussion on a rectangular MPP space sound absorber (RMSA) is given in what follows. Firstly, it is useful to discuss the difference between the RMSA and the common MPP sound absorber with a rigid-back wall. Although the RMSA shows a resonance peak absorption which is similar to the common MPP absorber with a back wall, the peak is lower. This feature also occurs in the case of a cylindrical MPP space sound absorber (CMSA) and is attributed to the fact that the boundaries that form the cavity are not rigid. On the other hand, the additional low frequency absorption, which is not produced in the common MPP absorber, occurs in both a RMSA and a CMSA. Therefore, although the peak for a RMSA and a CMSA is lower than that for the common MPP, these absorbers can cover a wider frequency range.

The rectangular and cylindrical MPP space sound absorbers show very similar sound absorption characteristics as described previously. Both absorbers have lower resonance peak absorption as well as additional low frequency absorption. However, the peak value tends to be higher in the CMSA case compared to the RMSA case. The reason why the RMSA peak is lower than CMSA is subject to discussion in the future study, although one possible reason is because of the difference in the angle of incidence to the sound absorber. In the cylindrical case (CMSA), even though the sound is incident randomly, the absorber can be regarded to behave as though the sound has normal incidence. However in the rectangular case (RMSA), the incident wave has a certain angle to the surface. Since the MPP shows the most efficient absorption in the normal incidence case, this fact makes the peak for the RMSA lower than for the CMSA.

It is also useful to consider the effect of the floor on the sound absorption by a RMSA. In the present work the measurements were only made with specimens placed on the floor. However, in the previous study on the CMSA, the measurements were conducted with specimens set apart from the floor [14]. According to Ref. [14], when a CMSA is set apart from the floor, though the difference is very small, the peak absorption becomes slightly higher, especially in the case when the ends are closed by the cover. The reason of this feature is not clarified, however, the same effect can be expected in the present RMSA cases.

Finally, it is of interest whether it is possible to use an alternative material to construct a similar sound absorbing

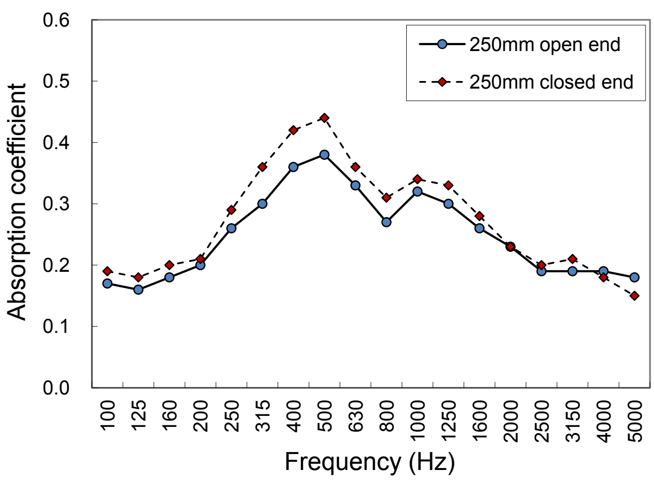

Figure 3. Measured results of the rectangular MPP space absorbers (RMSAs) of 250 mm x 250 mm square section. Solid line: open top ends; Dashed line: closed top ends with covers

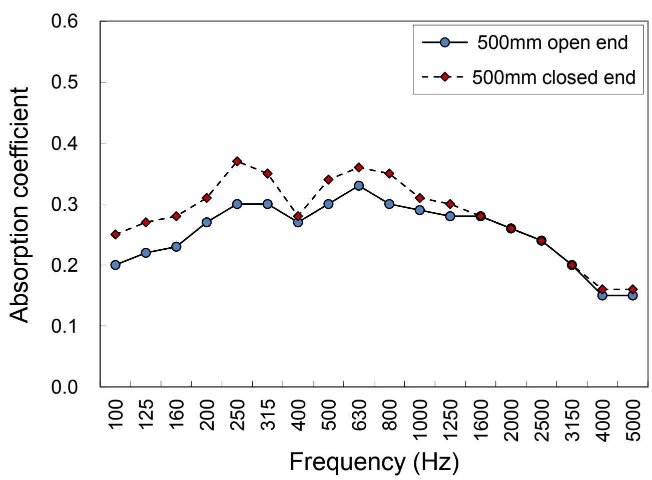

Figure 4. Measured results of the rectangular MPP space absorbers (RMSAs) of 500 mm x 500 mm square section. Solid line: open top ends; Dashed line: closed top ends with covers

system. According to previous studies on membrane-type space absorbers [15, 16], a permeable membrane can be used to produce a space absorber similar to a CMSA or RMSA: in that case no resonance peak will appear but almost flat sound absorption characteristics may be obtained due to its acoustic flow resistance. On the other hand, if an impermeable membrane is used, it is not expected to obtain sound absorptivity: a resonance peak of membrane-type absorption could be produced if the cavity depth is appropriate [17]. However, if the cavity is too large, the resonance will be very weak, and it is difficult to make an efficient sound absorber.

CONCLUDING REMARKS

To develop a more flexible design, easy-to-use space sound absorber with MPPs, a rectangular MPP space sound absorber (RMSA) is proposed as an alternative to a three-dimensional MPP space sound absorber. The sound absorption characteristics of the RMSA are measured experimentally in a reverberation chamber and the results are discussed.

The RMSA shows characteristics similar to a cylindrical MPP space sound absorber (CMSA) or a double-leaf MPP space sound absorber (DLMPP) and other space sound absorbers with MPPs: it exhibits a resonance absorption peak and additional low-frequency absorption due to the acoustic resistance. Although the sound absorption coefficient is not very high as it covers a wide frequency range, RMSAs are useful as an alternative sound absorption treatment to control the acoustic environment in rooms and buildings.

In order to effectively use RMSAs (as well as CMSAs), it should be noted that the size should not be too large. When the size is too large (0.5 m in this study), the resonance absorption peak does not appear and the absorber becomes less efficient. The absorber is more efficient when its ends are closed by covers.

In order to design and predict the sound absorption performance of an RMSA more efficiently, it is necessary to theoretically predict its acoustic performance. Furthermore, other three-dimensional shapes should be considered for wider variation of designs. These will be discussed in future work.

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