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Application of an in-situ measurement method using ensemble averaging technique to material development

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ABSTRACT

An in-situ measurement method using ensemble averaging technique, i.e., EA method, is applied to evaluation for absorption characteristics of multi-functional interior materials using porous mortar in the research and development phase. First, absorption characteristics of small specimens are measured by the EA method in a reverberation room, and the repeatability of the measurement result is confirmed. Next, absorption characteristics of eight kinds of the porous mortars with different fine aggregate and target voids are measured by the method, and their absorption characteristics are compared with each other. Finally, the effect of finishing materials on absorption characteristics of the porous mortar is examined.

Keywords: Building materials, Absorption characteristics, In-situ measurement I-INCE Classification of Subjects Number(s): 72.7

1. INTRODUCTION

In recent years, studies on the next generation high-functional materials have been carried out from a viewpoint of environment as well as strength, workability and design. In the indoor environment, it is also expected to develop materials that simultaneously achieve a combination of good water absorption/desorption performance, thermal performance and sound insulation/absorption performance.

In the design process of material development like this, when sound absorption characteristics of materials are investigated, measurement methods standardized by ISO such as the tube method (1) or the reverberation room method (2) are generally applied. However, depending on materials to develop, it may be difficult to set the material into the acoustic tube and to prepare the material with the size of 10 m^2. This situation would interfere the material development.

On the other hand, the authors have proposed an in-situ acoustic impedance measurement method using ensemble averaging technique, namely EA method (3, 4). Since the method has fewer restriction with respect to size and geometry of materials than conventional methods, it can be expected to carry out an easy measurement for materials that have difficulty for the measurement by conventional method.

In this study, the EA method is applied to evaluation for absorption characteristics of multi-functional interior materials using the porous mortar (POM) with relatively small size (0.04 m^2) in the research and development phase. First, absorption characteristics of small specimens are measured by the EA method in a reverberation room, and the repeatability of the measurement result is confirmed. Next, absorption characteristics of eight kinds of porous mortars with different the fine aggregate and target voids are measured by the method, and their absorption characteristics are compared with each other. Finally, the effect of finishing material on absorption characteristics of the POM is examined.

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2. METHODOLOGY

2.1 EA method

The EA method is a simple and efficient in-situ measurement method of surface normal impedance of materials at random incidence. The basic repeatability and applicability of the method in several practical environments have been presented in Refs(3, 5). The advantage of the method is that the use of random incidence sound source decreases the interference effect caused mainly by the specimen's edge. Also, as the sound sources, this method can even use reflection sounds from room boundaries. In actual measurement, the random incidence condition is realized by using the ambient noise exists around a material or moving sound sources.

Figure 1 illustrates the basic setup of EA method using two microphones (pp-sensor) and a pressure-velocity sensor (pu-sensor), respectively. Because the purpose of this study is to use the EA method at development phase of new materials, the simpler method using pp-sensor, i.e., pp method, is employed as shown in Figure 1 (a). In the pp method, two microphones of which the distance is set to l=0.013 m are placed close to the material's surface at the distance d=0.01 m. The normal surface impedance of material, $Z_{n,\mathrm{EA}}$, is calculated with the transfer function, H_{AB}, between the sound pressures of two microphones at different positions, p_a and p_b, as

$$Z_{n,\mathrm{EA}}(\omega) = \rho c \frac{H_{\mathrm{AB}}(\omega)(1-\mathrm{e}^{2jk(l+d)}) - \mathrm{e}^{jkl}(1-\mathrm{e}^{2jkd})}{H_{\mathrm{AB}}(\omega)(1+\mathrm{e}^{2jk(l+d)}) - \mathrm{e}^{jkl}(1+\mathrm{e}^{2jkd})}. \tag{1}$$

Where ρ, c, k and j represent air density, speed of sound, wave number and the imaginary unit, respectively. The absorption coefficient, $\alpha_{n,\mathrm{EA}}$, is calculated as

$$\alpha_{n,\mathrm{EA}} = 1 - \left| \frac{Z_{n,\mathrm{EA}} - \rho c}{Z_{n,\mathrm{EA}} + \rho c} \right|^2. \tag{2}$$

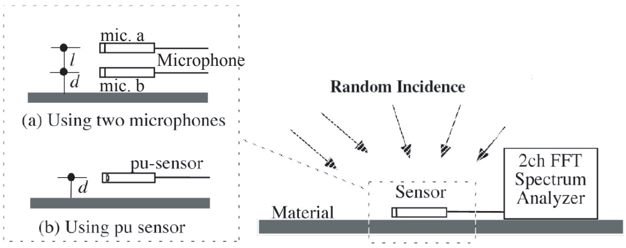
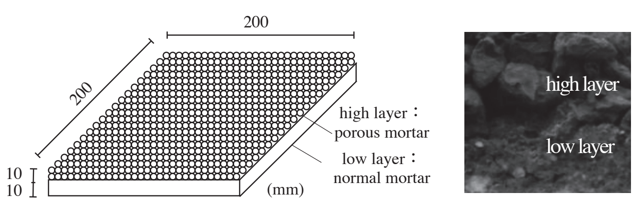


Figure 1 – Block diagram of the measurement setup in EA method.

2.2 Outline of materials

Figure 2 shows POM having double-layered structure, which means 10 mm thick porous mortar is constructed on 10 mm thick normal mortar, with the size of 200 mm x 200 mm x 20 mm. Table 1 lists fine aggregate used for the POM and target voids. Five kinds of fine aggregates, namely, crushed stone, natural zeolite, particle silica black, particle activated charcoal and perlite are used with the basic target void of 15 %. Also, crushed stone, natural zeolite and particle silica black with the target void of 30 % is further prepared.

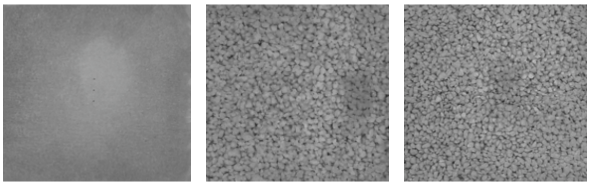


(a) Dimension of material (b) Photo of section of POM

Figure 2 – Schematic of POM to be measured.

Table 1 – Fine aggregate used for POM and target voids.

Fine aggregate (high layer materials)	Target voids[%]
Normal mortar (NM)	0
Crushed stone (CS)	15, 30
Natural zeolite (ZL)	15, 30
Particle silica black (SB)	15, 30
Particle activated charcoal (AC)	15
Perlite (PL)	15



(a) Normal mortar (Target void 0 %) (b) Crushed stone (Target void 15 %) (c) Crushed stone (Target void 30 %)

Figure 3 – Photos of surface of POM using crushed store.

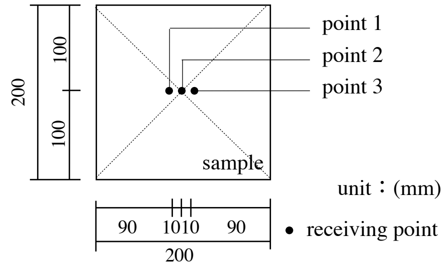
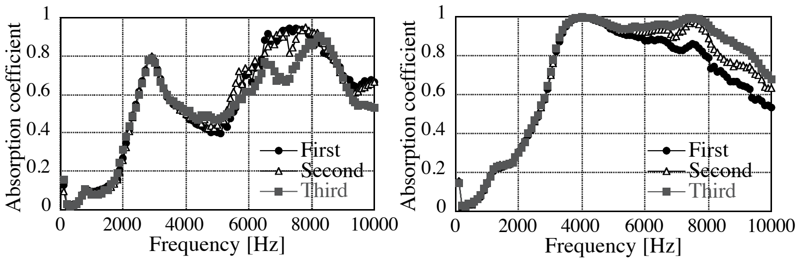


Figure 4 – Location of receiving points.



(a) Particle silica black (b) Particle activated charcoal

Figure 5 – Comparison among absorption coefficients on three times measurements at point 2.

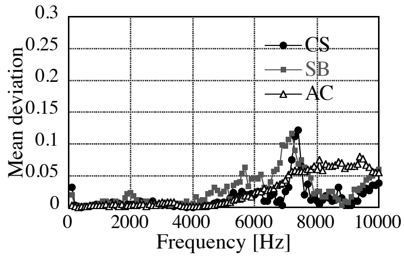


Figure 6 – Comparison among mean deviations on measurements at same receiving point.

For a comparison purpose, the normal mortar with the target void of 0 % is also measured. Figure 3 shows a photo of surface of POM using the crushed stone as an example of measured materials. See the reference (6) for further details on POM.

2.3 Measurement setup

To keep ambient noise sufficiently, measurements were conducted in a reverberation room (room volume: 168 m^3; surface are: 179 m^2) with non-parallel walls. The materials to be measured were located in the center of the reverberation room. To create the random incidence condition, five speakers (JBL MICROWIRELESS$\times$4; Fostex FE-103$\times$1) radiating incoherent pink noises were moved manually.

In the measurement, two 1/2-inch microphones (B&K Type 4190) as a sensor were used, and the transfer function were measured by FFT analyzer (B&K PULSE Type 3160). The resolution of FFT was set to 1.5625 Hz and the frequency range was 0 to 10 kHz. Linear averaging in frequency domain was performed N = 200 times. The $\alpha_{n,\mathrm{EA}}$ by the equation (2) was calculated, and the values were averaged in the frequency domain and compared at 100 Hz steps.

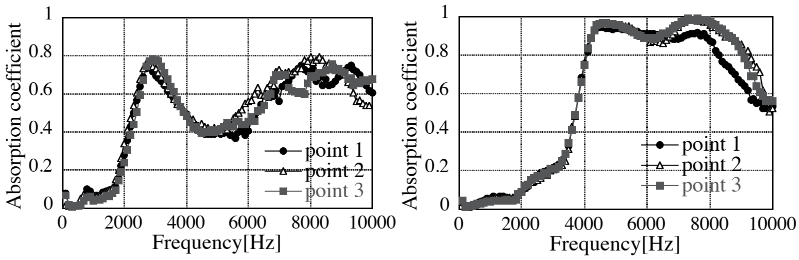
Because the POM has irregular surfaces as described above, there is a possibility that measured values change depending on a receiving point according to the EA method which estimates absorption characteristics at an arbitrary point. Therefore, as shown in Figure 4, three receiving points were placed near the center of the material for each material.

3. RESULTS AND DISCUSSION

3.1 Measurement reproducibility

To confirm the measurement reproducibility for the small samples, continuous measurements of three times were conducted at the point 2 as shown in Figure 4. In each measurement, the microphones and the material were removed and placed once again. The measured materials were the POMs using crushed stone, particle activated charcoal and particle silica black (target void 15 %).

Figure 5 (a) and (b) show the absorption coefficient, $\alpha_{n,\mathrm{EA}}$, of POMs using particle silica black and particle activated charcoal, respectively. Regardless of fine aggregate, three measurement values have a good agreement at below 5 kHz while the difference among those values can be seen at over 5 kHz. Figure 6 shows mean deviations of absorption coefficients obtained by three times measurements on three kinds of POMs. Although the values of the mean deviation are less than 0.05 at below 5 kHz, the values becomes large at over 5 kHz, regardless of fine aggregate.



(a) Particle silica black (b) Particle activated charcoal

Figure 7 – Comparison among absorption coefficients on measurements at different receiving point.

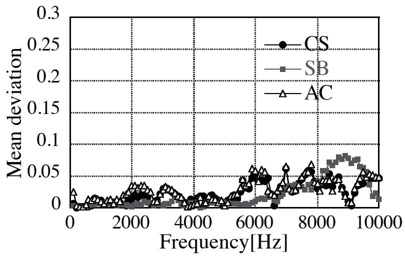
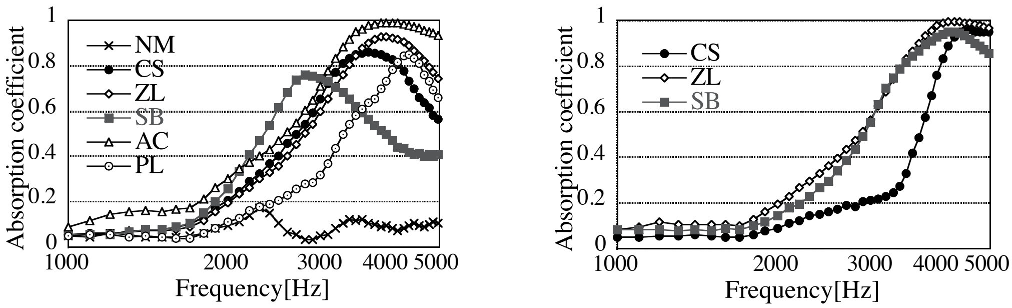


Figure 8 – Comparison among mean deviations on measurements at different receiving point.



(a) Target void 15 % (b) Target void 30 %

Figure 9 – Comparisons of absorption coefficient obtained for different fine agreements.

3.2 Variability of measurement value

To investigate the variation of absorption characteristics by a receiving point, measurements were respectively conducted at three receiving points, which is point 1 - point 3, shown in Figure 4. The materials measured were the same as the former section.

Figure 7 (a) and (b) give an example of the measurement result ($\alpha_{n,\mathrm{EA}}$) of POMs using particle silica black and particle activated charcoal, respectively. Regardless of fine aggregate, measurement values agree well at below 5 kHz while the difference among those values can be seen at over 5 kHz. Figure 8 shows mean deviations of absorption coefficients obtained at the three different receiving points on three kinds of POMs. Although the mean deviations are less than 0.05 at below 5 kHz, the values becomes larger at over 5kHz in comparison with Figure 7.

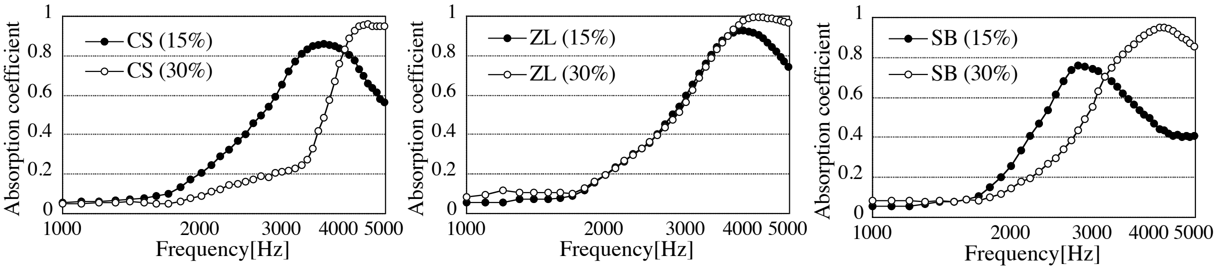
Thus, at below 5 kHz, the measurement by the EA method yields the reproducible results and the difference of measurement values by a receiving point is small even the material size is 0.04 m^2 in the case of materials used in this study. In the following investigations, the averaged value of measurement results obtained at point 1 to point 3 is used for evaluation.

3.3 Absorption characteristics of POM

On the basis of the results described above, in this section, we investigate the effect of the difference of both fine aggregate and target voids on the resulting absorption characteristics of POM.

Figure 9 (a) and (b) shows results of POM with the target void 15 % and the target void 30 %, respectively. In the Figure 9 (a), the result of normal mortar as the target void 0 % is also depicted. Regardless of fine aggregate and target voids, absorption coefficients of POM are apparently higher than those of normal mortar at the frequency range from 2 kHz to 5 kHz while absorption coefficients of POM differ little from those of normal mortar at below 1.5 kHz. In POMs with the target void 15 %, although POMs except for one using particle activated charcoal show similar absorption characteristics at below 1.8 kHz, frequency characteristics of absorption coefficient are varied at over 2 kHz depending on fine aggregate to be used.

In material measured, results show that the POM using particle silica black has high absorption coefficient at 2 kHz - 3kHz, and POM using particle activated charcoal has high absorption in other frequencies. In POMs with the target void 30 %, similar absorption characteristics are observed at below 1.8 kHz irrespective of fine aggregate, and the peak of the absorption coefficient is appeared at around 4.5 kHz. The absorption characteristics of the POM using natural zeolite and that of using particle silica black is similar at from 1 to



(a) Crushed stone (b) Natural zeolite (c) Particle silica black

Figure 10 – Relationship between absorption coefficient and the target void of POM.

(a) POM with wooden flame (b) Vinyl wallpaper (c) Hemp cloth

Figure 11 – Relationship between absorption coefficient and the target void of POM.

4kHz, and the absorption characteristics of the POM using natural zeolite and that of using crushed stone are also in agreement at over 4kHz.

Figure 10 shows comparisons of absorption coefficients between the target void 15% and the target void 30 % in the case of POM using crushed stone, natural zeolite and particle silica black. Regardless of fine aggregate, as the value of the target void becomes large, the peak of absorption coefficient is shifted to high frequency, and the value also increases.

From the results, it can be said that the EA method can capture the effect of the difference of fine aggregate and target voids on the resulting absorption characteristics with the relatively small samples.

3.4 Absorption characteristics of POM with surface-finishing materials.

Finally, effect of the surface-finishing materials on the resulting absorption characteristics of POM was investigated.

As surface-finishing materials, a vinyl wallpaper without air permeability and hemp cloth with air permeability was selected, and POM using crusted stone or particle silica black as the fine aggregate were used. As shown in Figure 11(a), the edge of POM was surrounded by wooden frame, and the surface-finishing materials were respectively constructed by double-faced tape attached to the wooden frame. The vinyl wallpaper and the hemp cloth constructed are shown in Figure 11 (a) and (b), respectively.

Figure 12 shows absorption coefficients of POM with the vinyl wallpaper as the surface finish. In the figure, absorption coefficients without surface-finishing materials are also depicted for comparison. In the case of POM without surface finish, the absorption coefficient peak of POM using crushed stone is appeared at around 3.8 kHz, and that of particle silica black is appeared at around 2.8 kHz. One the other hand, when the vinyl wallpaper is constructed, the absorption coefficient peaks of both of POMs are offered at around 1.8 kHz, and absorption characteristics of both of POMs show a similar tendency in other frequency range. Figure 13 shows absorption coefficients of POMs with the vinyl wallpapers, the hemp cloth and without surface-finishing materials. The absorption coefficients of POM with the hemp cloth show a similar frequency characteristic as that in POM without surface-finishing materials, and slightly higher absorption at around 4 kHz.

From those results, it is shown that the difference of absorption characteristics of POM with different surface-finishing materials can be observed by the EA method.

4. SUMMARY

An in-situ measurement method using ensemble averaging technique, i.e., EA method, is applied to evaluation for absorption characteristics of multi-functional interior materials using porous mortar in the research and development phase. The results of investigations lead to the following conclusions:

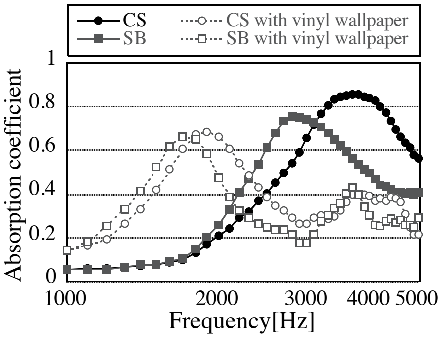


Figure 12 – Comparisons among absorption coefficients of POM in the case of constructing a vinyl wallpaper as the surface finish.

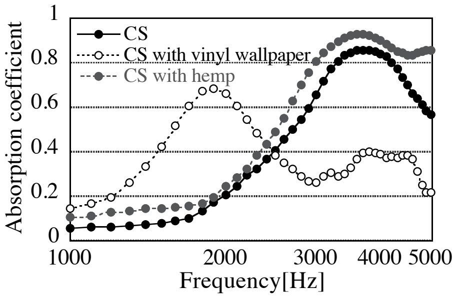


Figure 13 – Comparisons among absorption coefficients of POM in the case of constructing a vinyl wallpaper or hemp cloth as the surface finish.

- The mean deviations of absorption coefficient in repetitive measurement are less than 0.05 at below 5 kHz regardless of the fine aggregate.
- The mean deviations of absorption coefficient among different receiving points are less than 0.05 at below 5 kHz regardless of the fine aggregate.
- The absorption coefficients of POM is apparently higher than those of normal mortar at the frequency range from 2 kHz to 5 kHz, and as the value of target voids becomes large, the peak of absorption coefficient is shifted to high frequency, and the value also increases.
- The difference of absorption characteristics of POM with different surface-finishing materials can be captured by the EA method.

Further detailed investigations about the universality of the measurement value and the optimization design of materials including water absorption/desorption property and deodorization property and and so on are required.

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