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In situ measurements of absorption characteristics using two microphones and environmental "anonymous" noise

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1. Introduction

It is important to measure absorption characteristics of materials to predict and control acoustics in built environments. In particular, surface impedance of materials is indispensable for predicting sound fields in rooms with numerical methods. Therefore, numerous methods have been proposed to measure absorption characteristics of materials. Among conventional methods, reflection methods [1–8] are most suitable for *in situ* measurement implementation. Methods proposed by Allard *et al.* [1–4] or by Garai [5] have been popular and efficient among reflection methods up to now. However, some problems remain: *e.g.*, (i) low-frequency limitation, (ii) measurement of weakly absorbing materials, (iii) myriad and complicated equipment used *in situ*, (iv) positioning of a sound source - microphone - sample, *etc.*

A new, simple and efficient *in situ* measurement technique yielding both the impedance and absorption coefficients of materials is proposed in this paper. The technique can avoid influence of existing modes inside a room that cause measurement difficulties in conventional reflection methods.

2. Description of the technique

The technique proposed below is based on the measurement of the pressure transfer function between two microphones using a spectrum analyzer. As shown in Fig. 1, two 1/2-inch (1.27 cm) microphones are located at M_a and M_b. Distance d from the material surface is about 10 mm; the space l between two microphones is 13 mm. The transfer function $H_{ab}(\omega)$ between $p_a(\omega)$ and $p_b(\omega)$ at M_a and M_b is measured by means of FFT-analyzer.

With the plane wave assumption, the normal impedance ratio of material to air $z(\omega)$ is given as (here, time dependence $e^{i\omega t}$ is omitted):

$$z(\omega) = \frac{H_{ab}(\omega)(1 - e^{2ik(l+d)}) - e^{ikl}(1 - e^{2ikd})}{H_{ab}(\omega)(1 + e^{2ik(l+d)}) - e^{ikl}(1 + e^{2ikd})}. \quad (1)$$

In that equation, k is wavelength constant, and i is imaginary unit. The absorption coefficient α is calculated from impedance. When a pair of microphones with different sensitivities is used in measurement, the difference can be canceled by replacing each position alternately [9]. As for the FFT setup, resolution is set to 1 Hz and a Hamming window is employed. Measured data are averaged thirty times. The material to be measured is backed by a rigid wall.

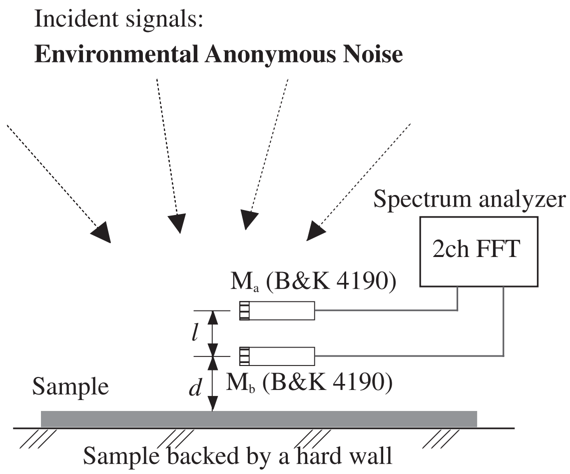

Fig. 1 A schematic diagram of measurement setup.

In this technique, a key distinguishing feature is that existing environmental noise in the sound field, so-called background noise, is employed as the sound source. Fundamentally, a loudspeaker is not required. The authors call such noise "Environmental Anonymous Noise," which indicates that the noise does not excite distinct modes. We confirmed that absorption measurements were difficult when a sound source was placed on a position in the sound field. On the other hand, we also confirmed that they were possible when many noncorrelated sound sources were placed around a material. From these results, it is considered that environmental anonymous noise is close to many noncorrelated sound source.

3. Universality of measurement

To verify measurement universality, measurements of absorption characteristics of glass wool are carried out in four

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Table 1 Outlines of the four sound fields with different volume, reverberation time and noise conditions.

Symbol	Sound field	Volume [m^3]	Reverberation time [s]	Noise conditions	
				L_{eq} [dB]	Variance [dB]
R-L	Experimental room	70	0.17	59.0	5.7
Cr	Corridor	177	1.57	56.0	1.7
Caf	Cafeteria	2,062	1.63	70.0	4.7
Tr	Terrace	(Outdoor)		57.9	0.5

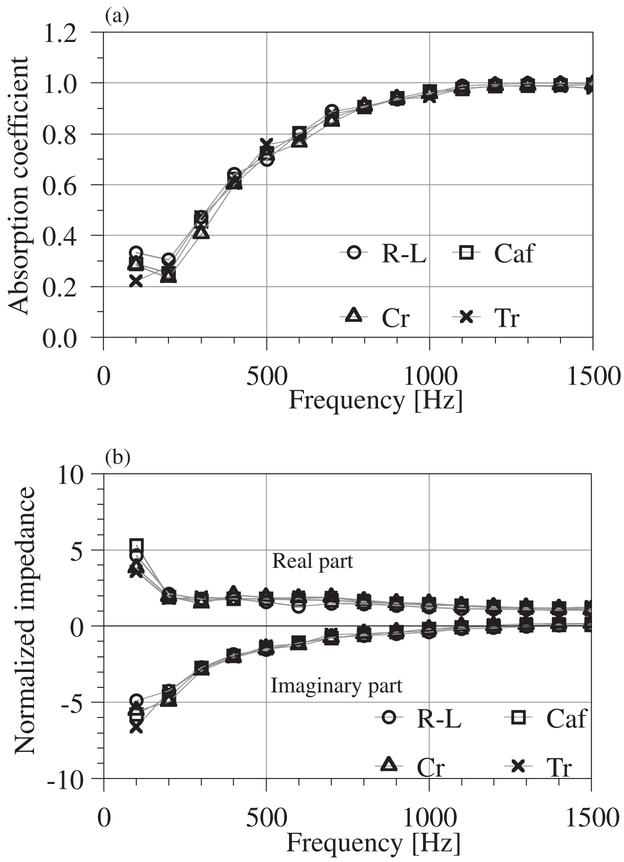

Fig. 2 Comparisons of absorption characteristics of glass wool obtained in four sound fields by the new technique. (a) absorption coefficient, (b) normalized impedance.

sound fields. The glass wool has dimensions $0.3 \times 0.6\,\text{m}^2$, and its thickness is 0.05 m. Outlines of the four sound fields with different volumes, reverberation times (500 Hz, 1 octave band) and noise conditions are shown in Table 1. Here, we assume that these sound fields has environmental anonymous noise, and incident condition in each sound field is almost same by averaging thirty times using FFT setup shown in the previous section.

Figures 2(a) and 2(b) show absorption coefficients and normal impedance values (normalized impedance $z(\omega)$) measured in each sound field. Measured values are averaged and plotted at 100 Hz steps to show difference distinctly. Averaged deviations of absorption coefficients are less than 0.025 at frequencies between 100 Hz and 1,500 Hz. For those impedances, values of the real part are less than 0.15 at frequencies above 200 Hz, while those of the imaginary part are about 0.28 at 200 Hz and less than 0.09 at frequencies above 300 Hz. It could be said that the tendencies of absorption coefficients and impedances obtained in the four sound fields agree well with each other at frequencies above 200 Hz.

They indicate that a kind of absorption characteristics of materials can be measured universally using the technique even if sound fields are different. It must be noted that the rooms reflect a state of ordinary daily usage; also, noise conditions listed in Table 1 are without peaks over 10 dB above the mean levels.

4. Measured absorption characteristics

4.1. Comparison with absorption characteristics at normal incidence

Impedances of porous materials can be estimated using the regression model derived by Miki [10] (Miki model). Here, a flow resistivity of glass wool $\sigma = 9,000$ MKS units is used. We confirmed that an absorption coefficient obtained by the Miki model with $\sigma = 9,000$ MKS units agree with that obtained by tube method. Comparisons of absorption characteristics obtained by the new technique and by the Miki model are shown in Fig. 3. Values obtained in Caf are chosen as representing values of absorption characteristics measured by the technique. As for the absorption coefficient, it can be found that these values do not agree with those obtained by the Miki model at the frequency range in measurement. Regarding impedances, imaginary part values are similar to those obtained by the Miki model, while those of the real part are not. These results are considered to be caused by a difference of incident conditions of signals.

4.2. Impedance at field incidence using Miki model

The authors assumed in measurements that the incident condition of signals set to be random since the sound source utilized here is a kind of ambient noise. In contrast, impedance obtained by the Miki model is regarded as impedance at normal incidence. In real situations, incident conditions in measurements are frequently assumed to be field incidence since incident sound energy is negligible at large angle of incidence. Therefore, a normal impedance at field incidence can be expected to be measured by the new technique.

To estimate the impedance at field incidence using the Miki model, an equation which can predict normal impedance of porous materials from the characteristic impedance and propagation constant of those [11] is refined here for use for field incidence here. Assuming that propagation distance of the incident and reflection signal inside the material at normal incidence is equal to material thickness t, as shown in Fig. 4, each distance at the refraction angle θ' becomes $t/\cos\theta'$. As this paper focus on possibility of simple *in situ* measurement

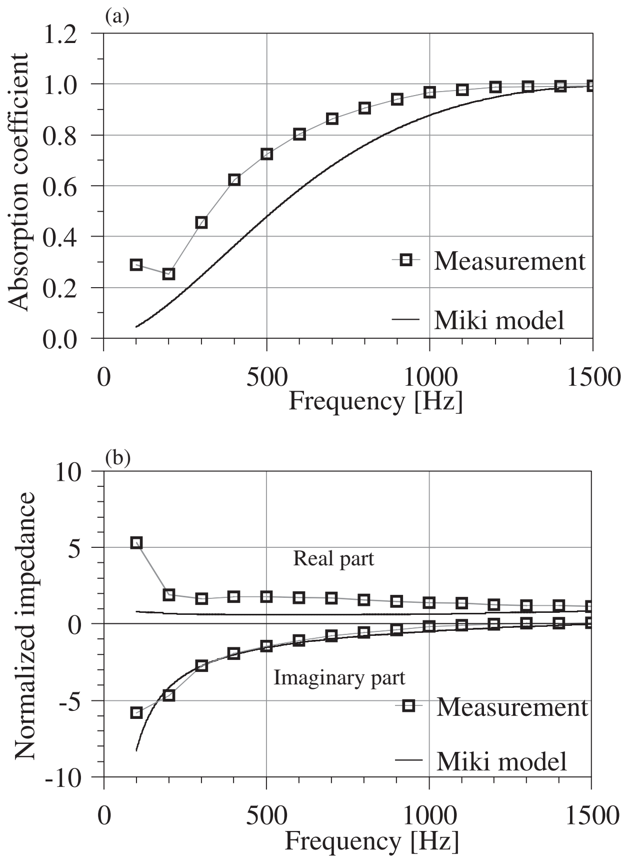

Fig. 3 Comparisons of absorption characteristics of glass wool obtained by the new technique in Caf and by the Miki model. (a) absorption coefficient, (b) normalized impedance.

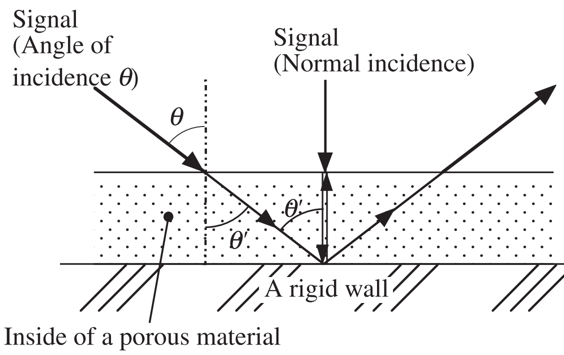

Fig. 4 Propagation of incident signals inside a porous material.

of absorption characteristics at low frequency as the first stage of this study, the authors simply assumed that $\theta' \approx \theta$ due to complexities of sound propagation in glass wool here. Therefore, normal impedance at oblique incidence $Z_\theta(\omega)$ can be expressed as:

$$Z_\theta(\omega) = Z_0(\omega)\coth\left\{\gamma(\omega)\frac{t}{\cos\theta}\right\}, \qquad (2)$$

where $Z_0(\omega)$ and $\gamma(\omega)$ are characteristic impedance and propagation constant obtained by the Miki model, respectively. Moreover, the impedance at field incidence can be calculated by averaging $Z_\theta(\omega)$ on the angle of incidence θ

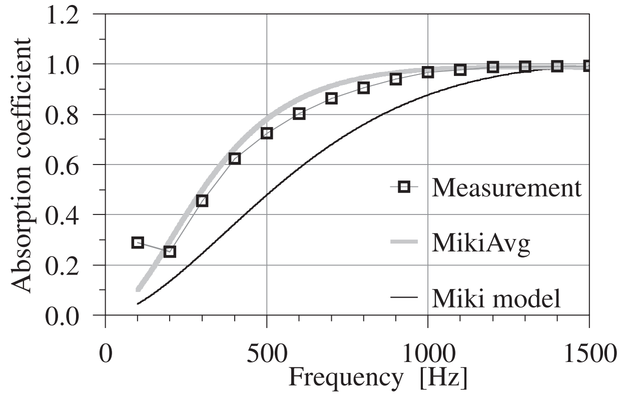

Fig. 5 Comparison of absorption coefficients of glass wool obtained by the new technique in Caf, by the Miki model and by Eqs. (2) and (3).

($\theta = 0^\circ \sim 78^\circ$) as follows:

$$Z_f(\omega) = \frac{\displaystyle\int_{0^\circ}^{78^\circ} Z_\theta(\omega)\sin\theta\cos\theta d\theta}{\displaystyle\int_{0^\circ}^{78^\circ} \sin\theta\cos\theta d\theta}. \qquad (3)$$

The value obtained by Eq. (3) is regarded as the impedance at field incidence; it is symbolized as "MikiAvg" in the following section.

4.3. Comparison with calculations

Figure 5 shows a comparison of absorption coefficients of glass wool obtained by the technique, by the Miki model and by Eqs. (2) and (3). Values measured in Caf are also used as representative values. Note that the measured absorption coefficient corresponds better to MikiAvg than that obtained by the Miki model at frequencies above 200 Hz. From these comparisons, the incident condition of the signals in the technique can be regarded as field incidence for porous material.

5. Conclusion

This paper presented a new, simple and efficient technique for measuring absorption characteristics of materials. The technique allows universal and efficient measurements at frequencies above 200 Hz that can provide stable impedance data in various sound fields, *i.e.*, *in situ*. Comparisons between the absorption coefficient obtained by the technique and MikiAvg revealed that the technique has the fundamental potential for application as a simple and efficient *in situ* measurement the technique to obtain the normal impedance at field incidence for materials for which the Miki model is applicable. Consequently, we infer that the problems (i), (iii) and (iv) described in the first part of this paper are eliminated using the new technique. Further investigations continue regarding its accuracy and detailed mechanisms, problem (ii), and so on.

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