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In-situ sound absorption measurement method of materials using ensemble averaging - Comparison of proposed method with tube method or reverberation room method -

Noriko OKAMOTO(1), Toru OTSURU(2), Reiji TOMIKU(3), Kaho ITO(4)

(1)The University of Kitakyushu, Japan, n-okamoto@kitakyu-u.ac.jp
(2)Oita University, Japan, otsuru@kobe-u.ac.jp
(3)Oita University, Japan, tomiku-reiji@oita-u.ac.jp
(4)Graduate School of Environmental Engineering, The University of Kitakyushu, Japan

Abstract

The sound absorption characteristics of building materials are generally measured by the reverberation room method and the impedance tube method, however, measurement values by these methods are known to have uncertainties due to the diffuseness of sound fields and the installation condition of materials to the tube, respectively. On the other hands, the authors have recently proposed the sound absorption measurement method using ensemble averaging technique, i.e., EA method. The method yields a simple and efficient in-situ measurement of surface normal impedance of materials at random-incidence. The purpose of this study is to show the relationship between the EA method and conventional methods: the reverberation room method and the impedance tube method. In this paper, the sound absorption characteristics of four materials: rook-wool board, gypsum board, carpet tile and needle felt are measured by the three method, and the sound absorption coefficient of EA method is compared with those of the reverberation room method and the impedance tube method.

Keywords: In-situ measurement method, Reverberation room method, Impedance tube methode method

1 INTRODUCTION

To predict and control the indoor sound field, it is important to understand sound absorption characteristics of building materials. The characteristics are generally measured by the reverberation room method[1, 2] and the impedance tube method[3, 4]. It is known that the methods face some problems as for accuracy: the former shows large deviations of measured sound absorption coefficients due to the diffuseness of sound fields and the latter causes difference in measured values depending on installation condition of materials to the tube. In additions, it is difficult to measure those of building materials installed in practical rooms by the methods.

On the other hands, the authors have recently proposed the in-situ measurement method using ensemble averaging technique, i.e., EA method[5, 6]. 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[5, 7, 8]. However, few studies have focused on the relationship between value measured by the EA method and those of the conventional methods.

In this paper, in order to clarify the relationship, the sound absorption coefficient by EA-Noise method is compared with those of the impedance tube method and the reverberation room method for four kinds of materials.

2 THE OUTLINE OF EA METHOD

As previously stated, the EA method is a simple and efficient method of measuring surface normal impedance of materials at random-incidence. Figure 1 illustrates the basic setup of EA method using two microphones (pp-sensor) and a pressure-velocity sensor (pu-sensor), respectively. In actual measurement, the random-incidence condition is realized by using the ambient noise exists around a material and by use of moving some portable loudspeakers radiating broadband noise. The impedance measured by the method can be regarded as a kind of ensemble-averaged quantity for multiple sound incidences at/around a point. Since the use of random-incidence sound sources decreases the interference effect caused mainly by the specimen's edge[6], this method can also use even reflection sounds from room boundaries as the sound sources.

In this study, the method using pu-sensor is employed as shown in Fig. 1 (b). It is not easy to locate the pu-sensor on a material surface because of its physical size: 1/2 inch diameter. Therefore, we located the pu-sensor at the position where d, which is distance from the material surface, equals 10 mm. When the pu-sensor is used in EA method, normalized surface impedance of a material: Z_{EA}, is simply defined as:

$$Z_{\mathrm{EA}} = < Z > = < \frac{p}{u_n} > . \tag{1}$$

Where $< - >$, Z, p and u_n denote the ensemble average, normal surface impedance, sound pressure and particle velocity with respect to the normal direction at the material surface, respectively. Assuming that the system has ergodicity, Z_{EA} is expressed in the following equation.

$$Z_{\mathrm{EA}} = < Z > = \frac{< p >}{< u_n >}. \tag{2}$$

To check and evaluate the results, the "corresponding sound absorption coefficient" is defined as follows:

$$\alpha_{\mathrm{EA}} = 1 - \left| \frac{Z_{\mathrm{EA}} - \rho c}{Z_{\mathrm{EA}} + \rho c} \right|^2 . \tag{3}$$

Where ρ and c represent air density and speed of sound, respectively.

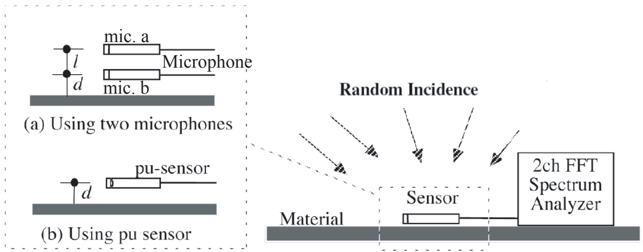


Figure 1. Block diagram of the measurement setup in EA method.

3 METHODS

3.1 Materials to be measured

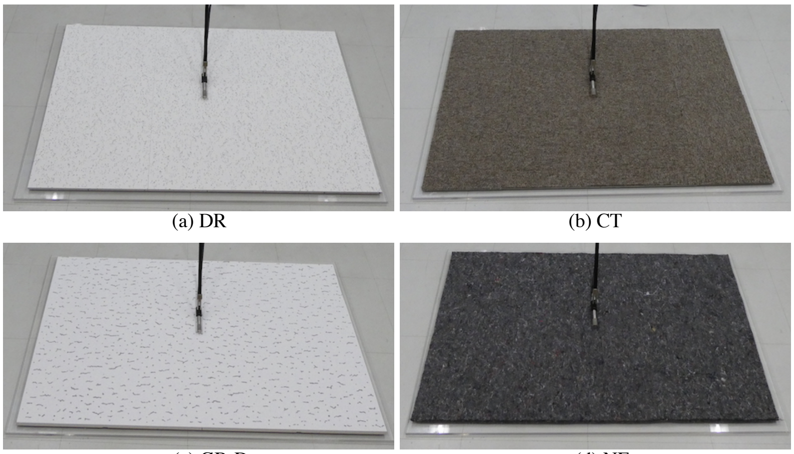
In this study, four kinds of materials: dressed rock-wool board (DR), carpet tile (CT), decorated gypsum board (GB-D) and needle felt (NF) shown in Table 1 and Fig. 2 are measured by EA method, impedance tube method and reverberation room method, respectively.

3.2 EA method

Measurements were conducted in a small office (room volume: 81 m^3). The test specimen to be measured was located at around the center of the room floor. The dimension of the specimen is 900 mm × 600 mm as shown in Table 1. To create the random-incidence condition, four portable loudspeakers radiating incoherent pink noises were moved manually. In the measurement, a pu-sensor (PU-Regular, Microflown Technologies)

Table 1. Materials to be measured. (Unit: [mm])

Symbol	Material	Thickness	Specimen's size		
			EA method	Tube method	Reverberation room method
DR	Dressed rockwool board	9	900×600	$99 \times \pi$	3600×3000
CT	Carpet tile	6.5	900×600	$99 \times \pi$	3500×3000
GB-D	Decorated gypsum board	9.5	900×600	$99 \times \pi$	3640×2730
NF	Needle felt	10	900×600	$99 \times \pi$	3640×2730



(a) DR (b) CT (c) GB-D (d) NF

Figure 2. Photo of materials to be measured by the EA method: (a) DR, (b) CT, (c) GB-D and (d) NF.

was used and located at the upside of the center of a material. Three measurement were made per sample at same receiving point. The pressure and particle velocity sensors were plugged into FFT analyzer and the transfer function was calculated. The frequency resolution of FFT was set to 3.125 Hz and linear averaging was performed 150 times using Hanning window. Calibration of pu-sensor was conducted in a standing-wave-tube with 95 mm × 95 mm × 735 mm. The α_{EA} by Eq. (3) was calculated at each frequency, and the values were averaged in the frequency domain of 1/3 octave band.

3.3 Impedance tube method

The normal surface impedance at normal-incidence was measured by the two-microphone method, in accordance with JIS 1405-2:2007. The cylindrical impedance tube having an inner diameter of 100 mm was used. A loudspeaker radiating incoherent pink noises was placed at the one side of the impedance tube. The sample was mounted at the other side of the tube. The samples ware cut using a circular cutter from the same sheets of material and the diameter is 99 mm. Three samples per a specimen are prepared. In the measurement, two 1/4-inch microphones as a sensor were used. The sound pressures at each microphone position were measured, and the transfer function between two positions were calculated. The frequency resolution of FFT was set to 3.125 Hz and linear averaging was performed 150 times using Hanning window. The normal surface impedance and absorption coefficient at normal-incidence were calculated using the transfer function. The average value of sound absorption coefficient for three samples is used for evaluation.

3.4 Reverberation room method

The reverberation absorption coefficient was measured in line with JIS A 1409, except for the position of the test specimen. The measurement was carried out in an irregularly-shaped reverberation room with diffusers (room volume: 165 m^3). An integrated impulse response method was applied to measure a reverberation time of sound field with/without a test specimen. The test material is rectangular shape, and the area is between 9.9 m^2 to 10.8 m^2 as shown in Table 1. The number of microphone position was six, and the number of source position is two: the number of microphone and loudspeaker positions is 12. Arithmetic averaging of 12 reverberation times at each band, which is 1/3 octave band, was performed per a test specimen.

4 RESULTS AND DISCUSSION

Comparisons of sound absorption coefficients obtained by the EA method (EA), the impedance tube method (Tube) and reverberation room method (Rev.) for each material are shown in Figure 3.

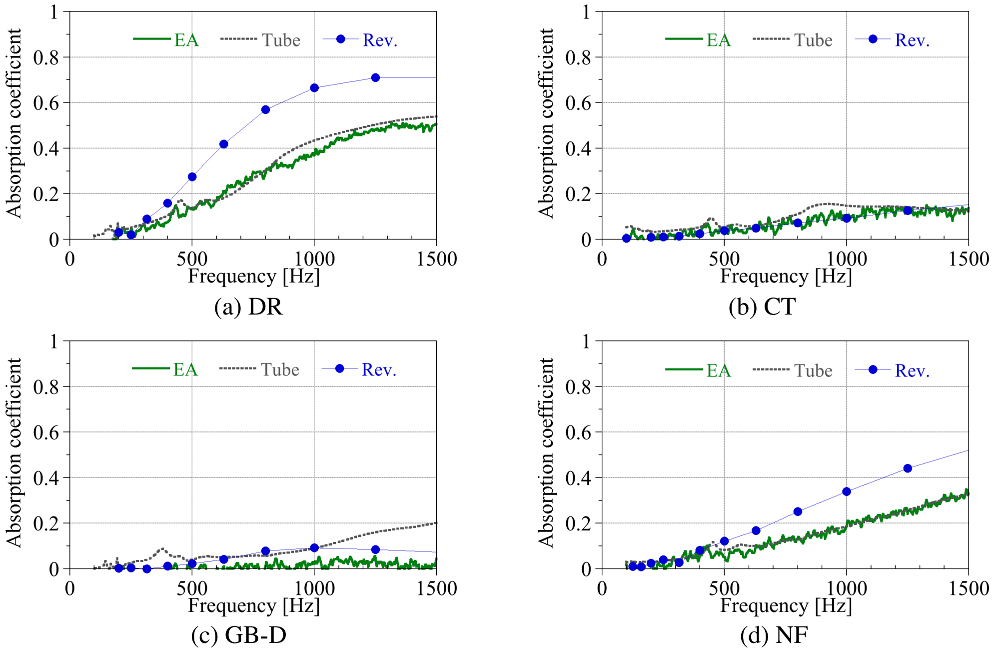


Figure 3. Comparison of sound absorption coefficient of material among the EA method, the impedance tube method and reverberation room method: (a) DR, (b) CT, (c) GB-D and (d) NF.

As for DR and NF, the higher the frequency becomes, the larger the measurement values becomes regardless of methods, and the frequency characteristics of sound absorption coefficient are similar among the three methods. The results of CT measured by the EA method is in good agreement with those of conventional methods. On the other hand, the absorption coefficient of GB-D measured by the impedance tube method is higher than those of other methods. Additionally, the result by the impedance tube method has a peak at around 400 Hz for all specimens. These values by the impedance tube method may contain the uncertainties where the sound absorption coefficient has a resonance and is low[9]. For future quantitative evaluation of relationship between EA method and conventional methods, the results obtained by the impedance tube method need to be discussed in more detail.

The results of this study reveal that the sound absorption coefficient of EA method is in good agreement with that of the impedance tube method at from 100 Hz to 1.5 kHz except for GB-D and is lower than that of the reverberation room method at from 500 Hz to 1.5 kHz except for CT. In addition, the relationships among the three methods differ depending on materials.

5 CONCLUSIONS

In this paper, the relationship between the EA method and conventional methods: the reverberation room method and the impedance tube method was investigated. The sound absorption characteristics of four materials were measured by the three method, and the result show that the relationships differ depending on materials, although the results obtained by the tube method need to be discussed in more detail. Further investigations for various kinds of material and for higher frequency range are required in order to practical use.

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