Comparison of sound absorption characteristics measured by impedance tube method and ensemble averaging technique on porous clay bricks

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1. Introduction

Porous clay brick (PCB) is one of the alternative materials used to solve heat and noise pollutions due to its inexpensiveness [1]. However, PCBs’ acoustic properties have only been the focus of a few studies because the measurement techniques are challenging.

The impedance tube method or tube method [2] is one of the techniques commonly used to measure the sound absorption coefficient of materials, but the sample preparation and mounting are challenging [3]. The tube method requires that the sample have a size and shape that fit the tube rim to prohibit air leakage.

Regarding sample preparation and mounting, creating a PCB with the correct size and sharp edges is nearly impossible after firing because the random additive destinations make shrinkage unpredictable. Moreover, cutting or resizing a PCB is still problematic because the clay particles will chip.

The authors tried to apply the ensemble averaging (EA) method to overcome this difficulty, and they obtained satisfactory results [4]. However, they also wanted to compare the results with standard methods to confirm how sound absorption characteristics have similarities or differences. Thus, this study compares the sound absorption characteristics between the tube and EA methods on PCBs.

2. Materials and method

2.1. Raw materials, formation, and sintering process

The production started with the addition of 2 mm dryly sieved charcoal into powdered raw clay in 30 wt.% ratios. The sample was then mixed with 7% water until it was formable and formed by hydraulic pressing into different shapes and dimensions (Table 1). Subsequently, the PCBs were fired at 1,100°C in a gas furnace for 12 h and left to naturally cool to room temperature.

2.2. Physical property testing and sample description

Four PCBs with a cylindrical shape (S01–S04) were resized for the tube method using a grinding machine (Fig. 1).

2.3. Measurement setup

(1) Impedance tube method setup

The tube method was applied on four PCBs using an impedance tube (Nihon Onkyo Eng.) measuring \(\phi 9.9\) cm. After grinding, the samples measured \(\phi 9.9 \times 4.0\) cm\(^3\) \(\pm 0.3\) cm. The measurable frequency range was from 100 to 1,600 Hz. The PCB diameter was slightly smaller than the tube diameter; thus, vibrations are likely to occur at certain resonance frequencies. The authors used a two-face tape to make the sample unmoved and reduce the vibration effect. Figure 2 depicts the measurement setup.

(2) EA method setup

The cylindrical PCBs used in the tube method were combined with the PCB cases (Fig. 3). Gaps of approximately 0.3 cm existed between the cylindrical PCB and the PCB cases. Subsequently, the cylindrical PCBs were joined with eight rectangular PCBs. The dimensions after the assembly were 57 \(\times\) 84 \(\times\) 4 cm\(^3\) (Fig. 3).

The absorption coefficient values were measured using the EA method described in the literature [6,7]. A pu-sensor (PR-900782, Micro flown) was positioned 1 cm \(\pm 3\) mm at the receiving point (rp\textsubscript{1, 2, and 3}) and plugged into the 2-ch Fast Fourier Transform. Incoherent filtered white noises within 100–1,600 Hz were emitted from six portable loudspeakers (Micro Wireless, JBL). Three people held the portable speakers and randomly moved at a speed of approximately 0.8–1.0 m s\(^{-1}\) on an ideal sphere with a radius of approximately 1.5 m from the center of the sample’s receiving point [8].

3. Results and discussions

The tube method measurement was repeated nine times for each sample, while the EA method measurement was repeated thrice at three receiving points (i.e., equals nine times).
Figure 4 presents the mean values of the sound absorption coefficient measured by both methods and compared for individual samples. Overall, both methods’ measured values had similar tendencies in their frequency characteristics, regardless of the sample difference. All samples measured by the tube method always had a higher value than those measured by the EA method because they might have included the air gap effect [9,10]. However, both methods showed good agreements between 100 and 400 Hz. The agreement became moderate as the frequency increased. The

| Shapes    | Dimensions      | Amount of samples tested |
|-----------|-----------------|--------------------------|
| Cylindrical | $d9.9 \times 4 \text{ cm}^3$ | 4                        |
| Rectangular | $19 \times 28 \times 4 \text{ cm}^3$ | 8                        |
| Case      | $19 \times 14 \times 4 \text{ cm}^3$ | 2                        |

| Table 1  Sample dimensions for testing. |
|----------|-------------------|-----------------|-----------------|
| Shapes   | Dimensions        | Amount of samples tested |
|----------|-------------------|--------------------------|
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Figure 1 Cylindrical PCBs after resizing and setting in a tube.

Table 2 Physical properties of cylindrical PCBs.

| Sample | AP (%) | BD (g cm$^{-3}$) | WT (%) |
|--------|--------|------------------|--------|
| S01    | 42.00  | 0.90             | 41.69  |
| S02    | 39.04  | 0.90             | 38.87  |
| S03    | 40.91  | 0.95             | 37.81  |
| S04    | 39.51  | 0.91             | 39.17  |

Figure 2 PCB setup and the receiving points of the tube method measurements.

Figure 3 PCB setup and the receiving points of the EA method measurements.

Figure 4 Sound absorption coefficient of S01–S04 measured using the tube and EA methods.
largest discrepancies were observed at approximately 800–1,000 Hz for all the samples.

The standard deviations of the PCBs from all measurements were presented on an error bar. At 100–800 Hz, the standard deviation values of both methods were less than 0.02; however, above 1,000 Hz, the values slightly increased to 0.03. All values were not over 0.04, even though the standard deviation values increased [11].

Figure 5 illustrates the mean values of the surface impedance. The values measured by the EA method below 200 Hz showed certain deviations, as was discussed in our earlier paper [8]. In the higher-frequency region from 200 to 1,600 Hz, the impedance values demonstrated almost stable behaviors. Similar values of both real and imaginary parts were obtained on all PCBs.

The values measured by the tube method showed fair agreements to those of the EA method in the frequency region from 200 to 600 Hz. At the real part of surface impedance, the tube method is always lower than the EA method because it directly affects acoustical leakage in the tube method by air gap [12,13]. In some PCBs, the tube method’s imaginary parts crossed the zero line and became positive at around 800 Hz. A resonance exists in the position where the imaginary parts are equal to zero [14]. However, the phenomenon is not found in the EA method, indicating that the EA method reduces the interference effect caused by the sample’s edges and surface normal impedance [15].

4. Conclusions
This study compared the sound absorption characteristics obtained from the impedance tube and EA methods using porous clay bricks. The results summarized that both methods provide almost similar upward tendencies and low standard deviations. In the frequency region between 100 and 400 Hz, considerably good agreements can be found in both methods’ sound absorption coefficient values. However, both become moderate at a frequency above 800 Hz. The tube method’s sound absorption coefficient is always higher than the EA method because the former’s values might include air gap and resonate effect.

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