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Advanced investigation using the EApu method on the effect of quantitation and particle size of charcoal in clay bricks on sound absorption coefficient

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ABSTRACT

Due to rapid urbanization, noise pollution becomes the environmental problems in Asia and their harmful effects on people's health are undeniable. Reducing noise by absorption material is a good alternative. Bricks are one of the most common construction supplies in Asia because of the cost. Therefore, this study aims to apply for the authors' EApu method (sound absorption characteristics measurement method using ensemble averaging technique and a pressure-velocity sensor) to clay bricks to clarify the relationship between the sound absorption coefficient and the amount and size of an additive. The measurement was conducted in a reverberation room following the procedure presented in our previous papers. Measured bricks have four types of porous that were designed by selecting from different sizes of charcoal that was added into the specimens in the amounts of 0-30%wt. Next, samples were fired at 1100℃ and tested for sound absorption coefficient. Lastly, the microstructure analysis was conducted. The results indicated that the larger size and higher percentage of charcoal added in fired clay bricks presented the excellent absorption coefficient. Such a detailed investigation can be performed by the EApu method, and the EApu method helps material designing process become more accessible to control sound absorption.

Keywords: Quantitation, Particle size, Clay bricks, Sound absorption coefficient, and EApu method.

1. INTRODUCTION

Noise pollution is one of the most severe pollutions found in the world. Reducing noise by using absorption materials are a good option and have many research guarantee as well as an economic viewpoint on the manufactures in an around South East Asian countries that leads us to start investigating the sound absorption characteristics of clay bricks.

Porous sound absorption bricks are composed of channels, cracks, or cavities, which allow the sound waves to enter the materials. Sound energy is dissipated by thermal loss caused by the friction of air molecules within the pore walls, and viscous loss brought the viscously of airflow within the materials. These energy consumption principles endow porous materials with broad frequency band for sound absorption (1, 2).

Two techniques commonly used to perform as measurements sound absorption coefficients are a reverberation room method (ISO 354:2006) (3) and an Impedance tube method (10534-2:1998) (4). These methods are not suitable for materials under development. The reverberation room method determined the dimensions of samples should be the minimum and maximum sample size as $10m^2$ – $12m^2$ respectively, while impedance tube determines are tightly fixed to one end of the tube during the measurement. It found that the size and shape of samples are very problematic to form clay brick. Thus, the EApu method was adapted to this measurement.

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Firstly, Takahashi et al. (5) proposed "EA method" as to measure materials' sound absorption characteristics, surface normal impedance and absorption coefficient, in-situ using a two-microphone utilizing environmental ambient noise. Next, Otsuru et al. (6) resumed the method using a pressure-velocity sensor, pu-sensor, and showed that the ensemble averaging technique serves to obtain stable sound absorption characteristics eliminating the material's edge-effect. Then, our recent paper (7) presented an improved calibration method of pu-sensor using acoustical tube taking account of relative humidity change. From the calibration by using the EA method and using a pu-sensor, it was found the EApu method have excellent reproducibility.

Herein, EApu method is applied onto clay bricks and clarify the relationship of this material, sound absorption coefficient, and physical properties. Meanwhile, an adequate averaging number for the material is discussed because individual differences between bricks as well as positions are inevitable for standard economic clay bricks.

2. MATERIALS AND METHODS

2.1 Raw Materials, Forming and Sintering Process

The local clay used as raw material was obtained from Ko Kha district in Lampang province, northern of Thailand. Then, the local clay was grounded for 8 hours in a ball mill and passed a sieve with 230 mesh in order to determine the extent of the pore-forming effected by using charcoal. The charcoal was a dry sieve and separated into four different sizes; large (L): 2 mm, medium (M): 1.5 mm, small (S): 0.5 mm, and (F) fineness: less than 0.05 mm. Next, the prepared charcoal powder was added into the local clay brick with seven different percentages: 0, 5, 10, 15, 20, 25 and 30 percent of the total weight (%wt). After that, the specimens were formed by pressing. Each group of green specimens was fired at 1100 degree Celsius with two hours soaking time in the electric kiln furnace. The specimens were natural cool down to room temperature in the furnace. Finally, the specimens were tested physical properties, sound absorption coefficient, and microstructure analysis to find a correlation between properties.

2.2 Test and Specimens Description

Table 1 – Description testing method and specimens dimension which explain in results and discussion

Result and discussion	Test	Specimens Dimensions
3.1	EApu Method	100×100×10 mm
3.2	EApu and Tube Methods	ø10×5 mm

2.3 Microstructure Analysis, Physical Properties Testing and Multivariate Linear Model

The Microstructure Analysis was done by using optical microscopy. The Physical properties test method was carried out under the standard of Thai Industrial Standard (TISI 77-2545) to determine the water absorption (8) while the method based on ASTM C373-88 was used to determine the bulk density, and apparent porosity (9).

The physical properties data were analyzed to find the relationship between physical properties and absorption coefficient from the EApu method in term of noise reduction coefficient (NRC). Statistics, commonly known as simple linear regression (SLR) and multiple linear regression (MLR) was calculated for this research.

2.4 EApu Measurement Setup

The EApu method configuration has followed in our previous papers (7,11,12): a pu-sensor (Microflown; PR-900782) was placed 1 cm above the material's surface and is plugged into a 2ch-FFT instrument (B&K; 3160-A-042). All measurements were conducted in the reverberation room having a volume of 168m3 at Oita University. The incoherent filtered white noises of 100–3,150 Hz emitted from four loudspeakers (Fostex; FE-103E) mounted in a wooden box and a sub-woofer (JVC; SX-DW77). All loudspeakers and a subwoofer were distributed on the floor close to the walls of the reverberation room.

In a measurement following the EApu method, the 2ch-FFT instrument calculates a material's ensemble averaged surface normal impedance Z_{EA} as the transfer function between particle velocity v and sound pressure p. Then, the corresponding sound absorption coefficient α_{EA} was calculated by using the following equation:

$$\propto_{EA} = 1 - \left|\frac{Z_{EA} - \rho c}{Z_{EA} + \rho c}\right|^2 \tag{1}$$

Where, ρc is air density, and speed of sound, respectively.

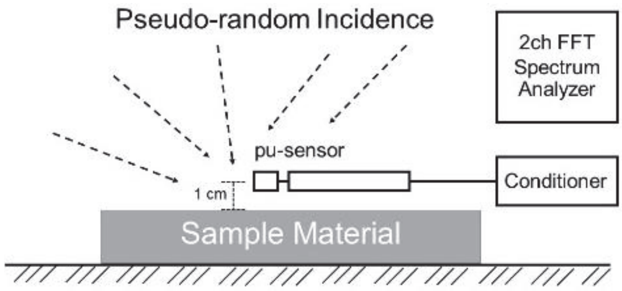

Figure 1 – the sound absorption coefficient method measurement setup.

3. RESULTS AND DISCUSSION

3.1 The Microstructure Analysis and Physical Properties

Figure 2 showed the surface of the clay bricks that charcoal size contents increased with the same magnification; the position on these optical microscopy images was the spot of pu-sensor measurement. The fired samples presented the different porous sizes on the surface after being fired at 1100 degree Celsius. The specimens with large charcoal size also showed great visible pores about 1.5-0.8 mm, and when the size decreased, the pores were being smaller to 0.7-0.3 mm and 0.3-0.08 mm respectively. Fineness size and none charcoal added could not appreciate the porous because sintering behavior made the clay particle closer.

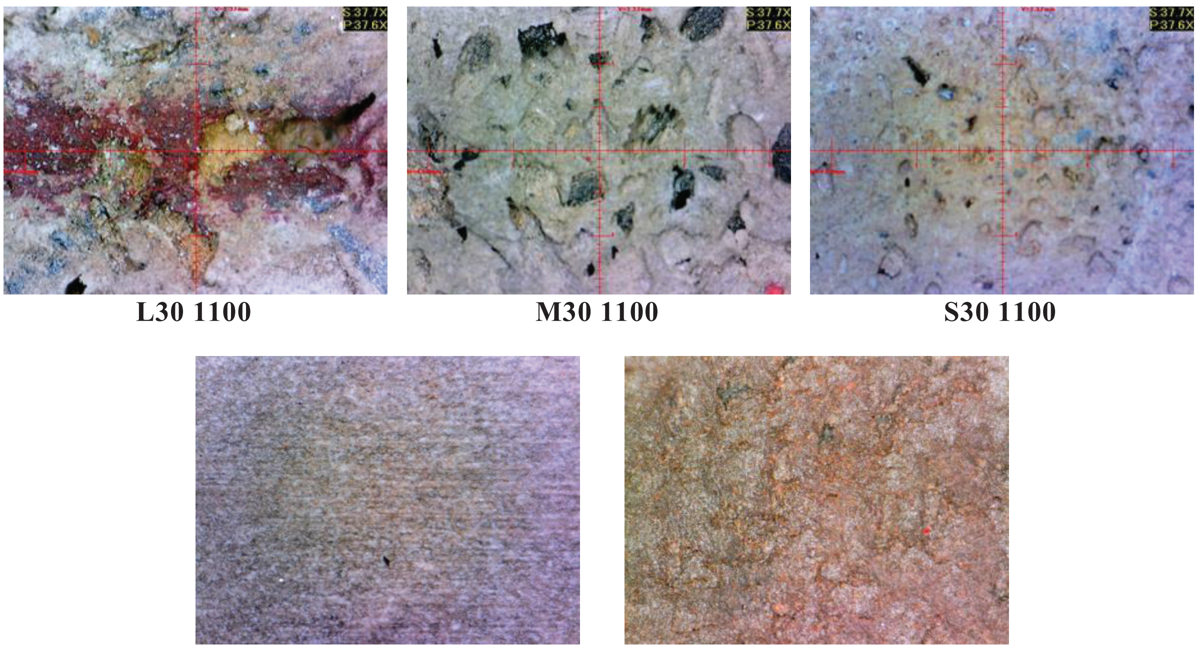

Figure 2 – microstructure analysis of clay brick

The data shown in Table 2 demonstrated the physical properties of clay, both none added and added charcoal 30% in the different sizes. The bulk density of specimens was decreased after increasing the amounts of charcoal from 0%wt to 30%wt, and it was decreased as charcoal size rose. The results show that bulk density in the ranges of 0.87–1.84 g/cm^3. The bulk density is not only related to apparent porosity but also related to the water absorption because of the porous inside of bricks.

Table 2 – Physical properties of clay brick both none added and added charcoal 30 %

Charcoal Size	Bulk density	Apparent porosity	Water absorption	Pore size
None	1.84 g/cm^3	10.24 %	6.37 %	-
F	1.44 g/cm^3	27.99 %	23.46 %	-
S	1.08 g/cm^3	35.99 %	26.27 %	0.3-0.08 mm
M	1.09 g/cm^3	38.37 %	35.33 %	0.7-0.3 mm
L	0.89 g/cm^3	42.13 %	35.40 %	1.5-0.8 mm

3.2 Effect of Quantitation and Particle Size of Charcoal on Sound Absorption Coefficient

The sound absorption coefficient was measured by the EApu method at three positions, and each measurement was repeated twice. Hereafter, mean values and standard deviations of the six times measurement were focused on the comparison. The mean values of the sound absorption coefficient compared among different sizes, and the amount showed in Figure 3 (a). The horizontal axis is a frequency, and the vertical axis is a sound absorption coefficient — the large size and high percentage of charcoal added and fired at 1100 degree Celsius demonstrate a good result, with approximate 0.30 while the second most numerous is the medium size the same as amount and temperature, approximate 0.15. As a result, the sound absorption coefficient corresponds to the sign of both size and amount. As we know well, the sound absorbability can be characterized by the available sound absorption coefficient. The main influencing factors are physical properties (apparent porosity, water absorption, and bulk density) (13). When sound waves impinge on porous material, they propagate into the interstices in which a part of the sound energy that was dissipated by frictional and viscous losses within the porous.

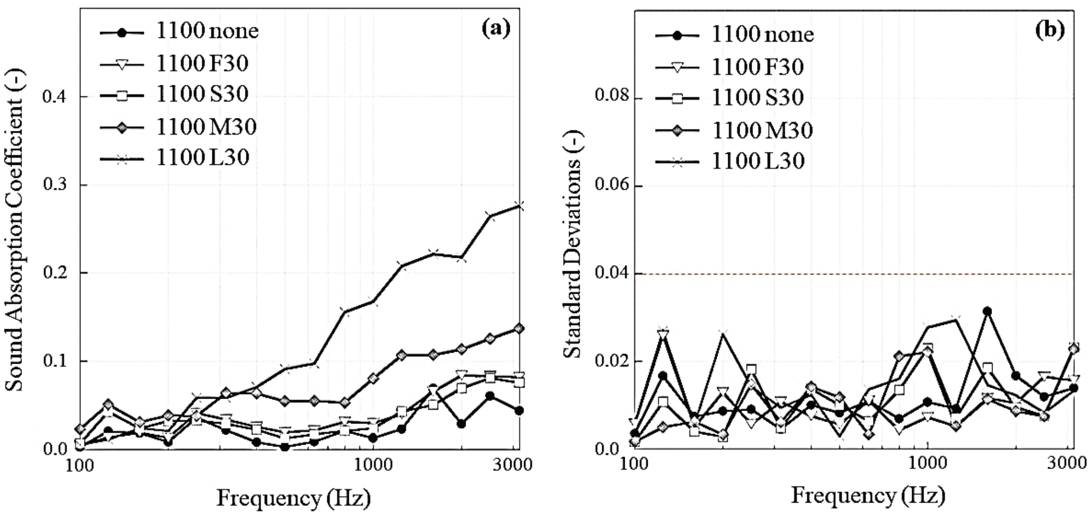

Figure 3 – (a) the mean values of sound absorption coefficient, and (b) the standard deviation

The standard deviation values of the clay bricks in the reverberation room are depicted in figure 3 (b). In this study, the standard deviations of specimens are tiny, from 0.01 to 0.03. i.e., all the uncertainty values stay less than 0.04 (14). It means that the specimens were not distinct in measuring the absorption materials by using the EApu method.

A comparison of the relationship between the sound absorption coefficient presented in term of noise reduction coefficient and the physical properties data collected from the samples with measured the bulk density and apparent porosity demonstrated in figure 4. A correlation of data between noise reduction coefficients and bulk density is evident, however when it compared with water absorption and apparent porosity, it is more spacious.

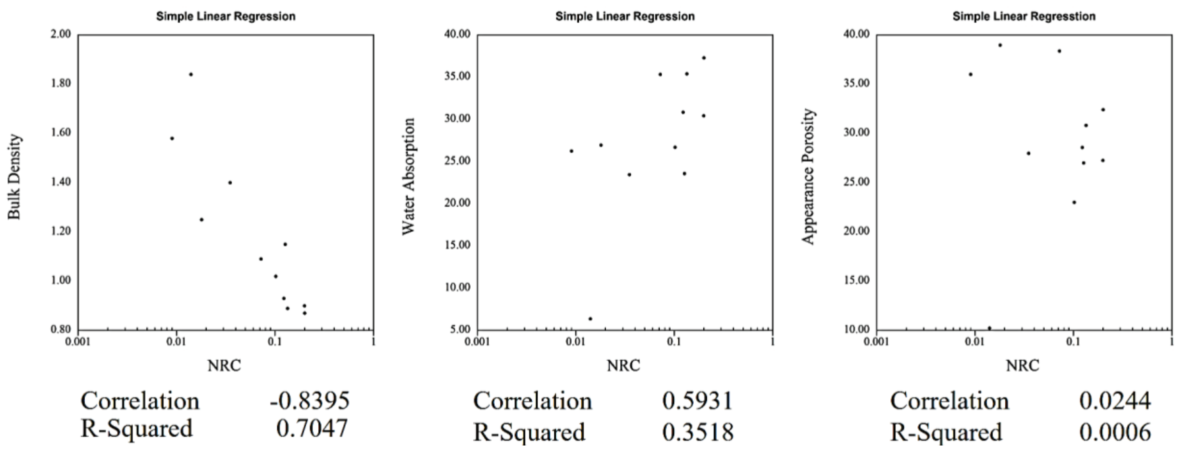

Figure 4 – the noise reduction coefficient versus physical properties.

Not surprisingly, the simple linear regression cannot be explained the complex relation because the physical properties have been more affected together and probably linked in a more sophisticated way to the microstructure. Table 3, the multiple linear regression was used to compare the relationship between the noise reduction coefficient and physical properties, bulk density, apparent porosity, and water absorption. The result showed a good correlation and R Square, 0.92 and 0.85, respectively.

Table 3 – multiple linear regression of noise reduction coefficient and physical properties

Regression Statistics	
Correlation	0.921027
R Square	0.848291
Adjusted R Square	0.783273
Standard Error	0.039886

3.3 Comparison EApu and Tube Methods

In figure 5, the data showed sound absorption coefficients of the clay brick added charcoal 30 %wt, and they were fried at 1100 degree Celsius. The test pieces were circle sheets, diameter 100 mm, and thickness 5 mm. Different measurement methods tested them. In EApu method, the maximum accuracy was 3150 Hz, and the tube method was 1600 Hz. The behavior of sound absorption coefficients at 1600 Hz showed that the maximum of the tube method was double comparing with EApu method.

The difference in values between the EApu and those of the tube methods are also attributed to the fact that the first method utilizes the reverberant field where plane sound waves come from all directions, and the tube techniques utilize a sound source at normal incidence. However, both methods show similar tendencies.

It is worth mentioning that erroneous estimates of the absorption coefficients are acquired with the measurement method. For some sample types like clay brick, the sample size is limited. In figure 5 (a,b) as a result, the estimated average absorption and standard deviation having fair agreements based on the maximum dispersion being below 0.04. At this stage, it can be concluded that the reproducibility of the proposed method is satisfactory, and the method gives appropriate absorption coefficients despite the geometrical differences of the reverberation rooms.

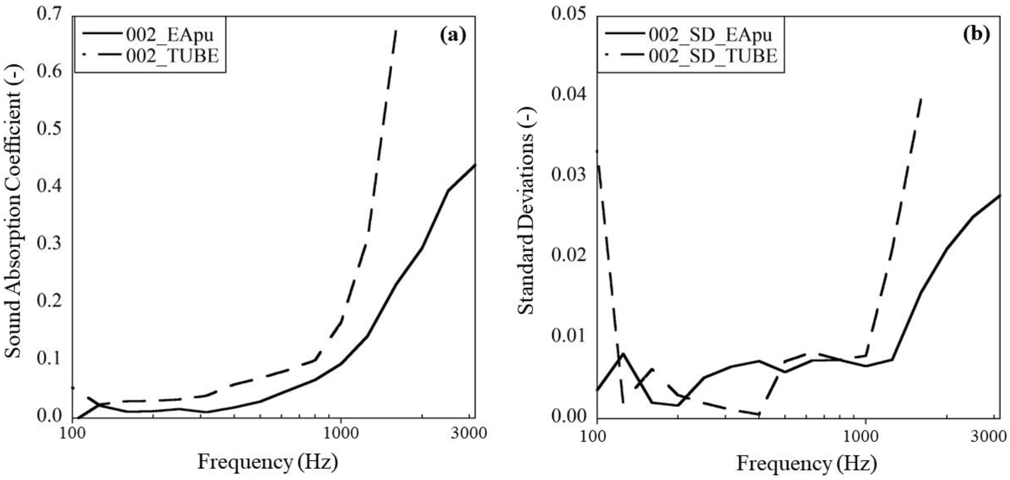

Figure 5 – (a) the average sound absorption coefficients of clay brick with different method, and (b) the standard deviation of measurement.

4. CONCLUSIONS

The objectives of this study which we tried to apply the ensemble-averaging technique using with clay bricks and concentrated on the amount and size of additive in clay bricks that affected on sound absorption coefficient. It can be concluded that

1. The ensemble-averaging technique can be used for measurement sound absorption coefficient in this clay bricks, and the standard deviation presents the satisfactory values.
2. There is a direct effect of the amount and size of additive on the sound absorption because the physical properties changed. The large size and high percentage of charcoal added to demonstrate the excellent result.
3. The methods of measurement affect data. According to this research, we found that the tube method was higher sound absorption coefficient than EApu methods. However, there are a similar tendency and low standard deviation of both data.

Future work

1. Produce the clay brick with different sizes and measured by comparing with three methods, tube, reverberation room, and EApu methods.
2. Clarify the influence of the sample size, physical properties, and microstructure with effect on sound absorption coefficient by using EApu method.

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