PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Measurement of Diffuse-Field Sound Absorption Coefficient of Materials Using the Two Microphones Method

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ABSTRACT

Projects in room acoustics usually demand values of sound absorption coefficients of materials measured in diffuse field. The most widely used method for diffuse field measurement is the reverberant chamber method described by ISO 354. Diffuse field coefficients can also be estimated by integration of absorption values obtained from measurements for discrete sound incidence angles in free field. Furthermore, some alternative methods use sound intensity sensors for the measurement of absorption coefficients in reverberation rooms. This work presents a case of absorption coefficient measurement in a reverberation room using the two microphones method. The concept of a single normal incident plane wave, as occurs in the Kundt's tube, was extend for the incidence of multiple plane waves from the various propagation paths in the room. Absorption coefficients of glass wool panels were obtained experimentally for samples laid down at the room floor, by using an omnidirectional loudspeaker at three points of the room and two microphone positions close to the sample surface. Transfer functions from the source to the microphone were measured using swept sine excitation, and the coefficient calculation was performed afterwards. Assessment of measurement results shows how sample size and microphone positioning can affect results and measurement accuracy.

Keywords: Diffuse field, absorption coefficient, two microphone method

1. INTRODUCTION

Projects in room acoustics usually demand values of sound absorption coefficients of materials measured in diffuse field. The most widely used method for diffuse field measurement is the reverberant chamber method described by ISO 354 (1). However, researches on the method have still been published in the literature for improvement of the results reprodutility between different test rooms. New subjects include reference materials (2), corrections for samples size and corrections for test rooms (3). On the other hand, diffuse field coefficients can also be estimated by integration of absorption values obtained from measurements at discrete sound incidence angles in free field. Furthermore, some alternative methods use sound intensity sensors for the measurement of absorption coefficients in reverberation rooms (4).

This work presents a case of absorption coefficient measurement in a reverberation room using the two microphones method. The investigation aims to simplify the measurement by applying impulse responses from a dodecahedron source, which can be positioned in some places of the room. It will be used small size flat samples laid on the room floor and a small diameter single microphone located close the sample surface. Between the measurements, the microphone position is sequentially changed for the calculation of the reflection (or absorption) coefficients by the two-microphone method. Figure 1 summarizes the basic elements involved in the measurement procedure proposed.

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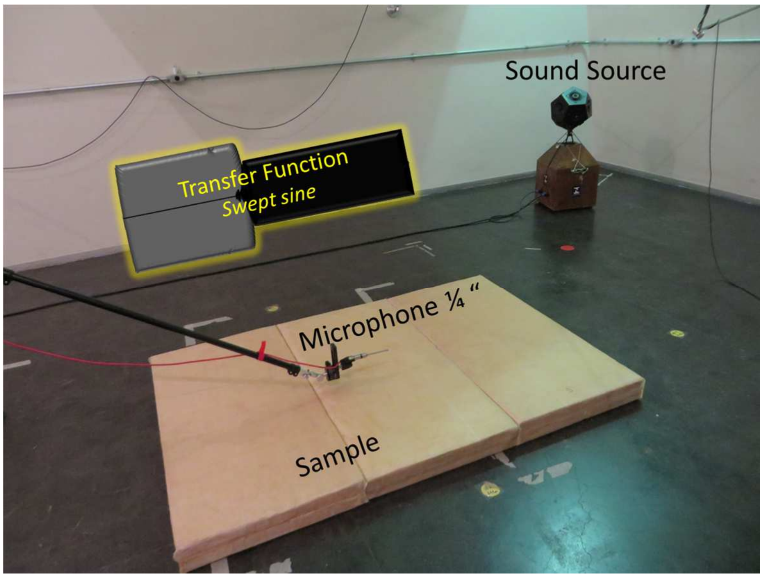

Figure 1 – Measurement setup inside the reverberation room

2. TWO MICROPHONE METHOD

The method of the two microphones, or transfer function method, for measurement of sound reflection coefficient R was initially developed for use in tubes (5). By this method, R is calculated by the following equation:

$$R = \frac{H_{12} - e^{iks}}{e^{-iks} - H_{12}} e^{-2ikl} \tag{1}$$

where s and l represent respectively the distance between the two microphones and the distance from the farthest microphone to the sample surface, as in Figure 2, k is the wave number and H_{12} the transfer function between the sound pressure spectra in points 1 and 2..

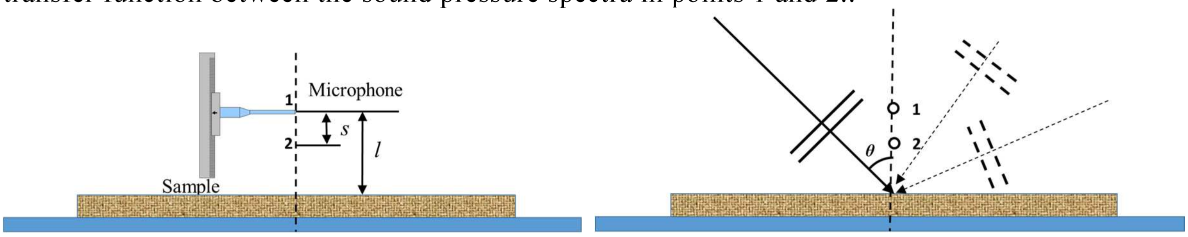

Figure 2 – Microphone distances from a sample and plane waves incidence

2.1 Wave Front Interpretation

The method can be described in terms of wave fronts, after replacing the ratio $H_{12}=P_2/P_1$ in Equation (1), where P_1 and P_2 are the sound pressure spectra measured at the points 1 and 2 (6-8).

$$R = \frac{P_2 - P_1 e^{iks}}{P_1 e^{-iks} - P_2} e^{-2ikl} \tag{2}$$

Considering impulsive excitation, Figure 3 shows a graphical representation in time domain of the incident and reflected wave front pulses. The arrival times of the incident and reflected waves at the points 1 and 2 differs according the distances s and l. Equation (2) features similar subtractions between the sound pressure spectra at the two points after phase corrections, represented by the term e^{iks} or e^{-iks}, on the numerator and denominator in the frequency domain. The result of the subtractions are a pair of reflected pulses in the numerator and pair of incident pulses in the denominator. Finally, the term e^{-2ikl} synchronizes the numerator and the denominator pulses before the division. Figure 4 shows the described procedure step by step. In the end, the result can be given in terms of the incident spectra, P_i, and the reflected spectra, P_r, as in Equation (3).

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$$R = \frac{P_r - P_r e^{i2ks}}{P_i - P_i e^{i2ks}} = \frac{P_r\left(1 - e^{i2ks}\right)}{P_i\left(1 - e^{i2ks}\right)} \tag{3}$$

From Equation (3), the reflection coefficient is the ratio between reflected and incident pressure combined with a comb filter function. At frequency where´s e^{-i2ks}=1 the ratio became undetermined and the choice of distance s defines the frequency span range of the measurements.

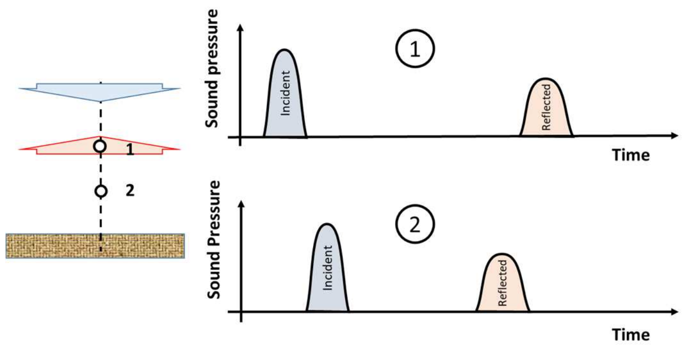


Figure 3 – Separation of single wave front pulses in time domain

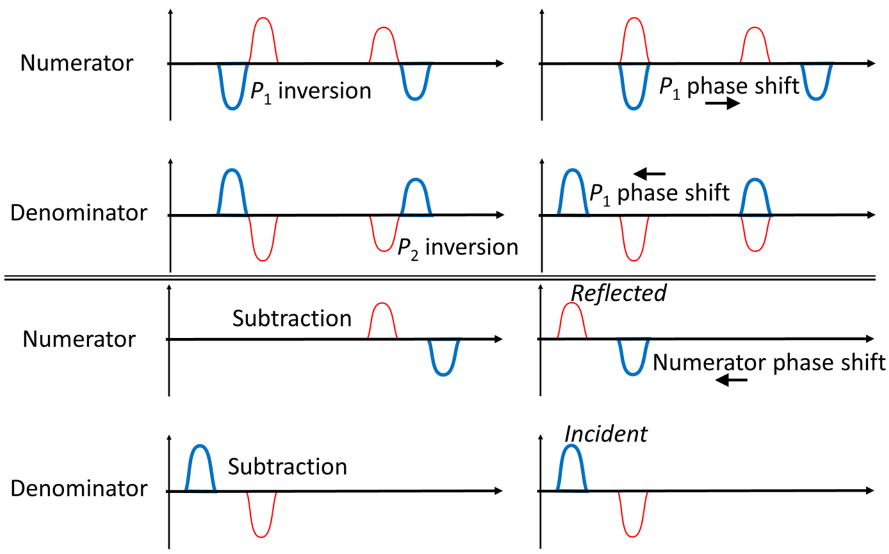


Figure 4 – Interpretation in the time domain of the separation of single wave front pulses, as in Equation (2)

Considering now a plane wave that reaches the sample with an angle of incidence θ, the reflection coefficient is calculated by:

$$R = \frac{P_2 - P_1 e^{iks\cos\theta}}{P_1 e^{-iks\cos\theta} - P_2} e^{-2ikl\cos\theta} \tag{4}$$

The point here is how to deal with the large quantity of incident waves that compose the diffuse field (Figure 2). A typical impulse response in a reverberation room is composed by the direct sound wave from the source, the first reflections and the reverberation tail. Each component reaches the sample in a different angle of incidence and in a different arrival time. Takahashi et al (9) have shown that choosing $\theta = 0°$ in Equation (4) leads to results comparable with the diffuse field coefficient calculated by integration of discrete angle in free field.

3. EXPERIMENTAL SETUP

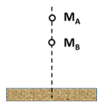
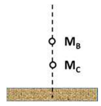
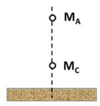
Transfer function measurements were carried out by using a swept sine (10) excitation signal for the input of a loudspeaker set, composed by a dodecahedron source fixed on a subwoofer unit. The software Monkey Forest was used for the generation of a dual channel swept sine, designed to feed the subwoofer and the dodecahedron, in order to improve the signal to noise ratio. The measured transfer functions correlate the input signal to the microphone response, which contains the loudspeaker, the microphone and the room responses. The source was positioned in three corners of the reverberation room, as can be seen at Figures 1 and 5. A ¼ inch diameter microphone was sequentially positioned at distances 2, 3 and 4 cm from the sample surface measured by a millimeter scale, corresponding to positions M_C, M_B and M_A, respectively. Table 1 presents the three setups of distances s and l used for the measurements. Figure 6.a) shows a comparison of the frequency ranges of the theoretical comb filter function for distances s = 1 cm and s = 2 cm. The acoustic panels tested consisted of glass wool panels of 1.2 × 0.6 × 0.1 m and 35 kg/m^3 density, wrapped by a fabric of glass fiber. Two sample sizes were tested (Figure 5), by laying only one panel on the floor or arranging three of them side by side. The procedure steps were basically: mounting the samples at the floor, placing the source in one of the corners, fixing the microphone in one of the three positions and measuring the transfer function. For each one of the source positions, six measurements were performed, resulting at the end in 18 transfer functions corresponding to a different impulse response inside the room in the time domain, including its reverberation tail.

From Equation (2), the calculation of the absorption coefficient α is done by the following expression:

$$\alpha = 1 - \left| \frac{P_2 - P_1 e^{iks}}{P_1 e^{-iks} - P_2} e^{-2ikl} \right|^2 \quad (5)$$

The sound pressures for points 1 and 2 were calculated by summing the respective transfer functions measured for the three source positions as is indicated in Figure 5. Before the division in Equation (5) the amplitudes of the numerator and denominator have to be smoothed. Figure 6.b) presents the terms of division after the smoothing, containing the responses of the measurement elements and the room. The effect of the comb filter is notable in both terms.

Table 1 – Microphone positions in the measurements

			
Microphone position 1	M_A	M_B	M_A
Microphone position 2	M_B	M_C	M_c
s, cm	1	1	2
l, cm	4	3	4

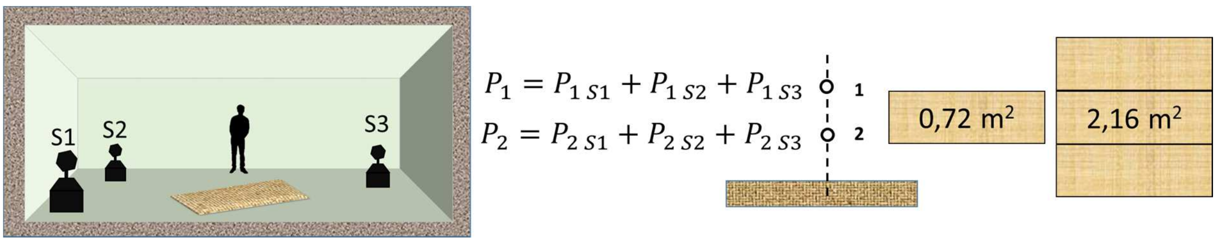


Figure 5 – Source positions in the reverberation room, addition of transfer functions for each microphone position and the two sample sizes

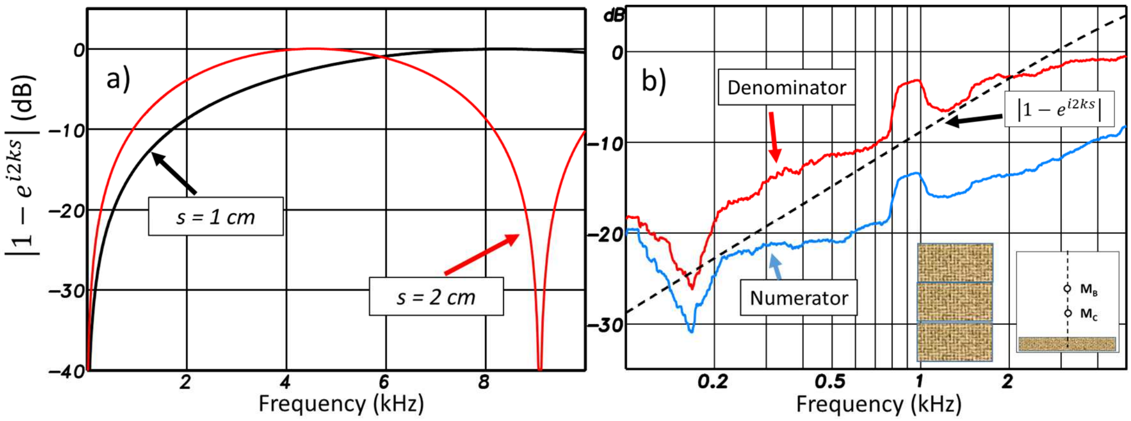


Figure 6 – Comb filter effect from the Equation (3): a) theoretical for two s distances and b) presented in the measured terms of division for s = 1 cm.

4. RESULTS

Figure 7 shows a comparison of the absorption coefficients calculated by Equation (5) for the two sample sizes. Each curve is relative for the 3 microphone pairs presented in Table 1. For the three panels sample, shown in Figure 7.a, the curves are similar above 300 Hz, but for the microphone pair M_A and M_B the absorption coefficient deviates to lower values at lower frequencies. More significant differences were found for the one panel sample, Figure 7.b, exhibiting an considerable underestimation tendency of the absorption values for lower frequencies. This deviation also depends on the microphone distance to the sample. A possible cause of the low frequency underestimation is the great importance of the sample area and the mean microphone distance from the sample on the reflection energy for larger wavelengths.

Comparing the results of the two samples sizes for the closest setting of microphone M_B and M_C, presented at Figure 8, good agreement for frequencies above 200 Hz is observed. Others alternative calculating could be done using the storage transfer function. The absorption coefficient for the three-panel sample sample and the closest microphones configuration (M_B and M_C), has also been calculated by taking the mean from the three coefficients obtained from each one of the source positions separatelly, i.e. α_{S1}, α_{S2} and α_{S3}. The results were found to be similar to the obtained before, as can be seen at Figure 9.a. Calculations can be done also considering any angle θ in Equation (4). For example, results for θ = 45° are compared with the results for θ = 0° at Figure 9.b showing a slight increase in α on the range of 200 to 2000 Hz.

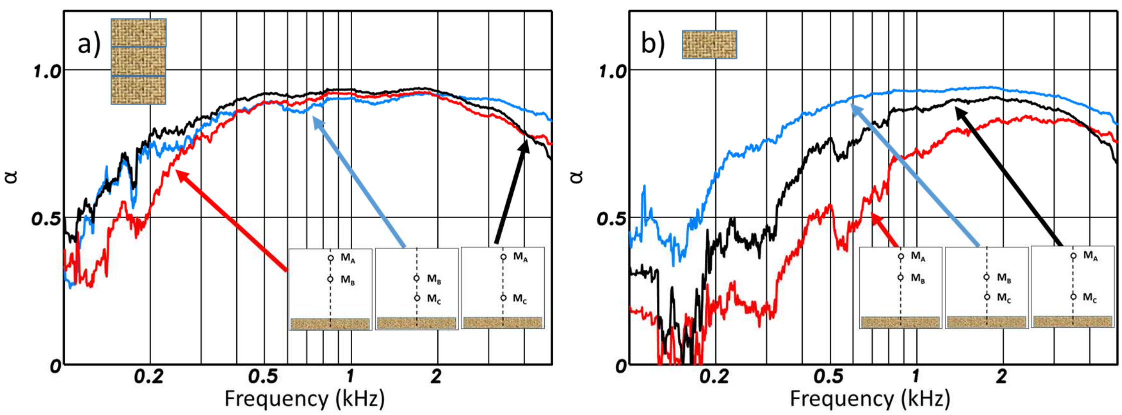


Figure 7 – Measured absorption coefficients for the three microphone configurations: a) for the three-panel sample and b) for the one panel sample

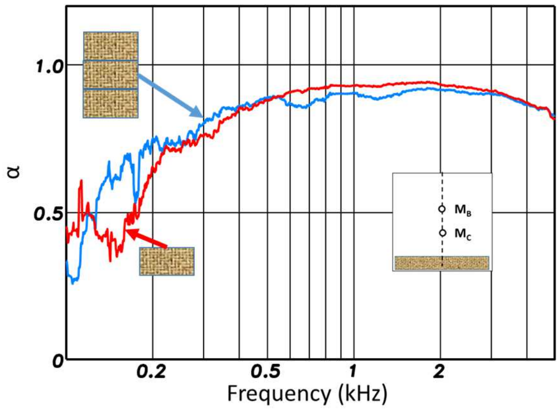


Figure 8 –Measured absorption coefficients for the closest microphone configuration: sample size comparison

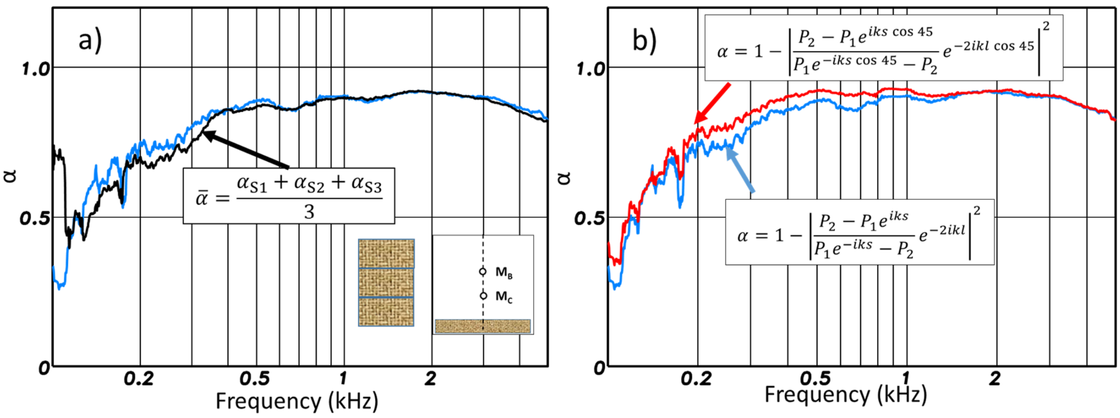


Figure 9 – Measured absorption coefficients for the closest microphone configuration and three-panel sample: a) comparison with mean absorption coefficient from the three source positions and b) comparison with absorption coefficient calculated by using 45° in Equation (4)

5. CONCLUSIONS

The presented method for measuring absorption of plane surfaces materials is simple and fast. Only one microphone was utilized in a reverberation room and the sound generations was done by a dodecahedron. Starting from a front wave interpretation of the two-microphone method, an extension was applied for the impulse responses obtained by swept sine technique, with all the reverberation contained inside them. In order to increase the number of random incident angle wave fronts the responses of three source positions was added before the coefficient calculation. In addition, before the calculation it was necessary to apply a smoothing process of the transfer function amplitude to deal with typical deep oscillations of the diffuse field. The smoothing used was the simplest and fastest option included on the Monkey Forest software. Influences of the smoothing process can be studied in future works. Calculations were done considering a phase corrections of zero degree in Equation (4). As showed above, it is possible to post processing the data by considering any other angle for the correction, but the significance of this possibility were not scrutinized by the authors.

The measured absorption coefficient curves presented are as expected for the material used in the samples. In addition, results dependence from the sample size and from the reception distance met the expectation. However, in this work a detailed validation analysis of the results was not performed. Future validation investigations are planned, by using measurements in free-field for individual incident angles and numerical simulations.

The method presented can be applied for small flat sample. This can be convenient to evaluate the sample homogeneity as required by the ISO 354 method that uses some acoustic panels arranged side by side. If reference materials would be used for reverberant room qualification, this method can provide supporting diffuse field results for small parts of a reference samples in a non-destructive way.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the Inmetro-PTB Project.

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