UNUSUAL METHODS OF MEASURING SOUND ABSORPTION COEFFICIENT: SMALL-SIZED REVERBERATION CHAMBERS

Adéla Kapicová *

Katedra betonových a zděných konstrukcí, Fakulta stavební,
České vysoké učení technické v Praze, Thákurova 7/2077, 166 29 Praha 6, Česká republika.
`adela.kapicova@fsv.cvut.cz`

ABSTRAKT

Tato studie se zaměřuje na řešení problému nedostatku vhodných zkušebních metod v oblasti vývoje zvukopohltivých materiálů. Běžně používané metody pro měření zvukové pohltivosti materiálů vyžadují buďto velmi rozměrné a materiálově nákladné vzorky, anebo naopak vzorky příliš malé na to, aby dostatečně popsaly vlastnosti měřených materiálů. Tyto metody nejsou zcela vhodné pro počáteční fázi materiálového vývoje. Z toho důvodu se tato studie zaměřuje na nalezení alternativní metody, kterou by ty stávající bylo možné nahradit. Konkrétně se zabývá zejména dozvukovými komorami malých rozměrů. Praktická část studie sestává z provedení modifikovaného měření v Alfa kabině, průmyslově využívané malé dozvukové komoře. Toto měření je provedeno v modifikované verzi vhodné pro betonové vzorky o netypických rozměrech 400×400 mm. Výsledky jsou porovnány s výsledky z impedanční trubice; na základě porovnání je rozhodnuto o vhodnosti metody pro rozměrnější vzorky.

KLÍČOVÁ SLOVA

Zvuková pohltivost • Dozvuková komora malých rozměrů • Alfa komora • Beton • Akustika

ABSTRACT

This study is focused on solving a problem with the lack of measuring methods suitable for sound absorbing materials development. The conventionally used sound absorption measuring methods require either samples too large to be time-effective and economical in the early development stage, or too small to describe the material acoustic behaviour in sufficient detail. Thus, this study aims to find a suitable substitutional method that could replace the usually used ones. It focuses mainly on the topic of small-sized reverberation chambers. The practical part focuses on measuring in the Alpha cabin, an industrially used small-sized reverberation chamber. The measurement is performed in a modified version suitable for concrete samples with an unconventional size of 400×400 mm. The results are compared with the ones measured by the impedance tube method; based on the results, it is decided that this method is suitable for larger samples.

KEYWORDS

Sound absorption • Small-scaled reverberation room • Alpha chamber • Concrete • Acoustics

1. INTRODUCTION

Research into sound absorbing materials is currently a developing topic. In the case of materials for outdoor use, the main reason to develop new effective materials is the increasing noise pollution in cities, especially near frequented roads and railways. Since noise is one of the most important environmental health risks, actions to protect human well-being must be undertaken, and reasonable noise limits must be set and maintained, especially in residential areas (World Health Organization, 2018). To minimize the noise level, sound absorbing materials can be applied in the form of pavement surfaces, building claddings, noise barriers, etc. However, the currently applied solutions are unable to sufficiently deal with the worsening noise situation. Thus, more effective sound absorbing materials, in more forms for various applications, and with better overall performance, are needed (Vijay et al., 2014; Holmes, N. et al., 2014; Patil, G. S., 2020).

Sound absorbing materials for indoor use are developed to provide aesthetically pleasing and at the same time precise acoustic solutions for indoor areas with high standards for acoustical quality, such as concert halls, conference halls, theatres, recording studios etc., but also to provide sufficient acoustic performance of crowded areas with unpleasant noise levels, such as canteens, shopping malls, meeting rooms, etc.

The development of sound absorbing materials is dependent on the possibility to measure their sound absorption coefficient α (-). Currently, two methods are usually used: the impedance tube method, and the reverberation room method.

The impedance tube method is described by the standards ISO 10534-1 (ISO, 1996) and ISO 10534-2 (ISO, 1998). By this method, the sound absorption coefficient of cylinders with an approximate diameter of 98 and 43 mm is measured. This method provides the normal incidence absorption coefficient (the angle of incidence is singular).

The reverberation room method is described by the standard EN ISO 354 (CEN, 2003). The necessary sample area for

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* Školitel: doc. Ing. Petr Bílý, Ph.D.

measuring is between 10 and 12 m^2. This method provides the random incidence absorption coefficient, which is more relevant for most uses.

There is a huge gap between the measurable sizes. For strongly non-homogenous materials, measurements with samples of diameters 98 and 43 mm cannot thoroughly describe the material's sound absorption quality. Nevertheless, it is usually also not possible to manufacture 10 m^2 of newfound material – for economical, ecological, and time reasons. A method allowing the measuring of smaller samples is thus desired; this need was already addressed by many researchers.

Some researchers suggested to substitute the measuring of sound absorption coefficient by the estimation of sound absorption based on the material´s composition and its volumetric characteristics (Losa, M. et al., 2012), or by measuring e.g. material's porosity, pore geometry, and pore size distribution, air permeability etc. (Laukaitis, A. et al., 2006; Horoshenkov, K. V. et al., 2001). Recently, a different approach was also taken, in the form of constructing small-sized reverberation chambers (see Figure 1), i.e. devices allowing measuring the sound absorption of smaller samples. These chambers were also developed to provide the laboratories the possibility to measure absorption coefficients without having to use any external laboratories (Rasa, A., 2016).

As the target of this study was to find a direct method to measure the sound absorption of small-sized samples (approximately 40×40 cm in size), this topic was closely reviewed with the intention of constructing such a chamber in our laboratory. Various chambers were found, ranging between 0.23 m^3 (Müller, M., 2016) and 48 m^3 (Rasa, A., 2016) in volume. The largest one was constructed from a spare office, providing a room for measuring samples with an area of 2.4 m^2. Del Rey, R., et al. (2017) described a chamber with a volume of 1.12 m^3, suitable for the measuring of samples 0.3 m^2 in area, and with the lowest measurable frequency equal to 485 Hz. The chamber was manufactured from gypsum wallboard, sound insulation, and alucobond composite. Healy, A. (2019) described a chamber with a volume of 3.31 m^3, suitable for measuring samples with an approximate size of 0.36 m^2, with the measurable frequency range being 500−5000 Hz. This chamber was supposed to be light and cheap; thus, for the chamber's construction material, 18 mm thick MDF boards were used. Vivolo, M. (2013) proposed the idea of a concrete chamber with a volume of 0.83 m^3, in which the sample of the area of 0.27−0.32 m^2 could be measured. The lowest measurable frequency was set as 400 Hz.


(a) (b)

Figure 1: *Small-sized reverberation chambers: Del Rey, R. (2017) (a), and Healy, A. (2019) (b).*

Except for these experimental small-sized chambers, one commercially used chamber was also found – Alpha cabin (Rieter), the chamber with a volume of 6.5 m^3, suitable for samples with an area between 1.0 and 1.2 m^2, and with a measurable frequency range between 400 Hz and 10 kHz. It is a measuring device usually used within the automotive industry.

The possibilities were discussed with the acoustics specialists. The idea to build a small chamber was consequently rejected, as the manufacturing would be complicated, likely inaccurate, and with unsure results. Moreover, such a chamber would likely not allow measuring sound absorption on low frequencies, which are the key frequencies for pervious and perforated concretes, the currently developed sound absorbing materials and the main objects of interest of the author.

2. MEASURING IN ALPHA CHAMBER

After the idea to construct a small-sized reverberation chamber was rejected, the possibility to conduct measurements in the Alpha cabin at TU in Liberec (see Figure 2), likely the only cabin of its kind in the Czech Republic, was arranged, mainly to see whether a measurement in a small cabin can lead to results of some value for the sound absorbing concrete research.


(a) (b)

Figure 2: *Alpha cabin at TUL (a), measuring setup (b).*

2.1. Materials

The currently developed sound absorbing samples of size 400×400 mm were measured. Specifically: M38_1, 2, and 3, i.e. pervious concrete panels composed of aggregate of fraction 4/8 mm combined with reinforcing nets made of carbon or basalt fibres, and one of three types of sound absorbing layer – soft acoustic mineral wool (M38_3), stiff acoustic mineral wool (M38_2), and stered (recycled textile, M38_1). The front side of the panels was made of 30 mm of pervious concrete; the sound absorbing layer was placed behind it (see Figure 3a). The complete thickness of each of those panels was 50 mm.

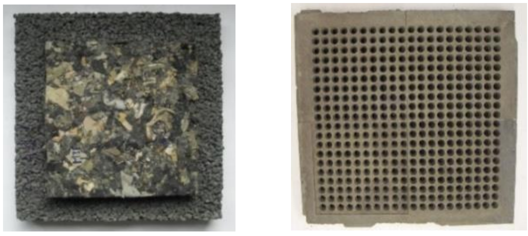
(a) (b)

Figure 3: *A pervious concrete panel M38_1 (a), and a perforated concrete panel B06 from its reverse side (b).*

Further, two perforated concrete panels were measured – specifically the types B12 and B06 – panels 30 mm in thickness, made of high-strength concrete containing basalt aggregate of fraction 0/4 mm. These panels are perforated – B06 with regularly spaced single holes (see B06 in Figure 3b), and B12 with regularly spaced groups of four holes. The last examined panel, M36+7, was a panel made of a 20 mm thick layer of pervious concrete with aggregate of fraction 4/8 mm, a reinforcing carbon net, and a 10 mm thick layer of pervious concrete with the Liapor aggregate of fraction 1/4 mm.

2.2. Methods

The measuring in the Alpha cabin is based on the standard EN ISO 354 – Acoustics – Measurement of sound absorption in a reverberation room (CEN, 2003). In general, in the reverberation room method, the reverberation times of the empty room and then of the room containing the test sample are measured. From the gained reverberation times, the equivalent sound absorption area of the test specimen is calculated. Based on that, the sound absorption coefficient of the measured sample is determined. In this experiment, these steps were performed in accordance with the standard.

The setup for the method is, in the case of the Alpha cabin, adjusted to the size of the cabin. The aforementioned standard specifies the distance of the sample from the walls, the distance between the positions of the sound source, the distance between the positions of the microphone etc.; those distances were reduced based on the cabin size and setup.

Moreover, the measured frequencies are also adjusted according to the size of the cabin. As a smaller volume makes it impossible to accurately measure lower frequencies, the measurable band moves, specifically from 100−5000 Hz (typical for a regular reverberation room) to 400−10000 Hz.

In this case, the method setup had to be further changed. As mentioned before, the Alpha cabin allows measuring samples 1.0−1.2 m^2 in size. However, the area of each of the prepared samples was only 0.16 m^2. Such a measurement usually cannot be performed because of the required minimal area, and it was never attempted before. However, a consultation with the acoustic experts from TU in Liberec led to the decision that the measuring method can be adjusted according to the samples. There was quite a strong possibility that the method will not work; however, it was necessary to find out whether the measuring of smaller samples can allow at least the comparison of the small samples with one another.

To satisfy the area requirement, it was decided that the missing area will be replaced by a material with a known sound absorption coefficient, with an approximate thickness of 5 mm. Its sound absorption coefficient was measured beforehand for 1.2 m^2 of this material; the results are shown in Figure *4* below.

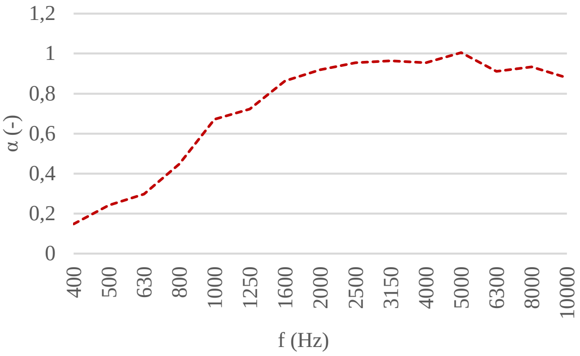

Figure 4: *Sound absorption coefficient of the background material.*

Afterwards, the concrete samples were measured. The background material was kept in place and concrete samples were sequentially placed onto its centre, as shown in Figure 2b. Thus, the concrete samples covered the area 400×400 mm, i.e. 13.3% of the background sample, and the total measured area was the necessary 1.2 m^2. The edges of the measured samples were covered by reflective tape to prevent the sound absorption of the sides.

2.3. Results and Discussion

From measuring the combination of the background material with high sound absorption and the samples, the following results were obtained:

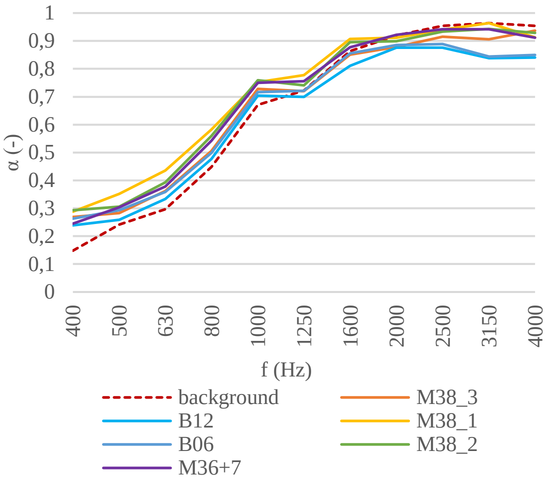

Figure 5: *Sound absorption coefficient of concrete samples 0.4×0.4 m placed on the 1.0×1.2 m sound-absorptive background; total area 1.2 m^2.*

As the samples covered only 13% of the background and thus the measured area, they caused only a slight shift in the sound absorption coefficient compared to the background-only results. Based on the results, it can be claimed that the sound absorption coefficient of concrete samples at low frequencies is higher than that of the background; and, on the other hand, the sound absorption of concrete at higher frequencies is lower. As pervious and perforated concretes usually absorb mostly lower frequencies, such results correspond with reality.

Based on the slight differences between the results of the panels, the sound absorption ability of samples with an in-built sound absorbing layer can be approximately evaluated – it can be claimed that sample M38_1 with the in-built absorbing stered layer is more promising in terms of sound absorption, as its results exceed the results of samples M38_2 and M38_3 for nearly all measured frequencies.

Furthermore, the attempt to calculate the sound absorption coefficients of the samples without the impact of the background was undertaken. This calculation was based on the assumption that the measured values (Figure 5) are the weighted averages of sound absorption coefficients for the background layer and concrete samples, where the weights are the areas of the given materials – i.e., 86.7% for the background and 13.3% for the samples. The following results for the panels were obtained:

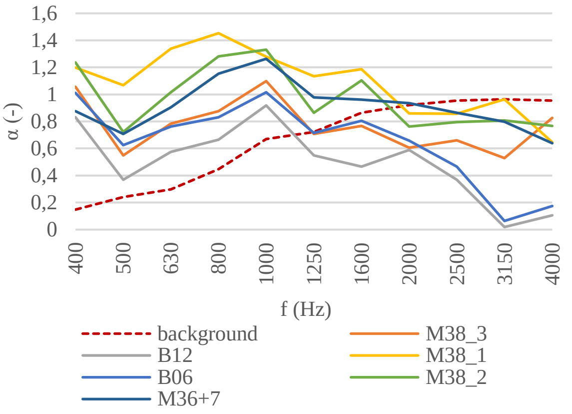

Figure 6: *Calculated sound absorption coefficients the of concrete panels.*

It is necessary to point out that these results are very inaccurate, which is confirmed by the excessive values for the sound absorption coefficients – its value should not exceed 1. The used calculation procedure is inaccurate, as it does not take into the account the different thicknesses of the materials, the different behaviour of the materials on different frequencies, and the background material actually being under concrete during the measuring and potentially acting as an additional sound absorbing layer behind a Helmholtz resonator. Thus, the gained results should be used only to compare the materials measured with this setup and by this method, as such results will have a similar measurement error.

Overall, based on the obtained results, it can be claimed that the pervious samples have a higher sound absorption coefficient, especially at higher frequencies, compared to the perforated concretes, and that the stered-containing sample should be the most advantageous sample of all the examined ones.

These results can be compared with the sound absorption coefficients measured by the impedance tube method for the cylindrical samples (see Figure 7). By this method, only samples M38_1, 2, and 3 were measured. Samples B06 and B12 were not measured; however, another two perforated samples, B01 and B04 with the same shape of perforations but smaller thickness, were measured. As the perforated samples absorb sound in a similar way, the profiles of their sound absorption coefficient curves should show a similar trend. Since samples B01 and B04 were thinner (20 mm only), their frequency maximums are likely different than the maximums of the panels; however, the maximum of a perforated concrete sample usually lays below 400 Hz, and such frequencies cannot be measured by the Alpha chamber. The trend on the higher frequencies should not be strongly affected by the thickness.

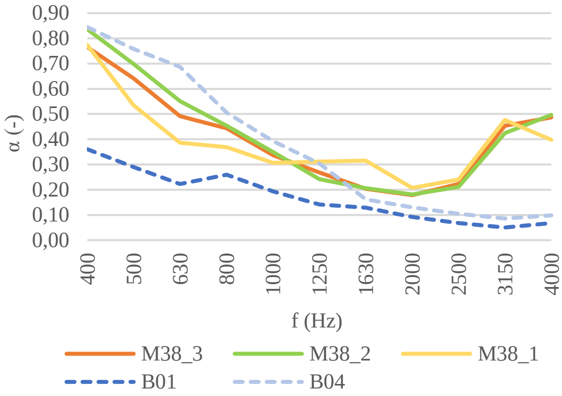

Figure 7: *Sound absorption coefficient measured by the impedance tube method.*

From the comparison between Figure 6 and Figure 7, it is apparent that the results gained by the Alpha chamber are far from the real sound absorption coefficients of the measured concrete members. However, it is also apparent that Alpha chamber can satisfactorily estimate the sound absorption trend at higher frequencies. For sample M38_1, the correctly evaluated trend was for the frequencies 1250−4000 Hz, where the placement of decreases and increases of sound absorption coefficient are similar for both measuring methods.

In the case of samples M38_2 and M38_3, the trend was quite correctly evaluated only for the highest frequencies. Nevertheless, the results of both methods show that when compared to M38_1, these samples have worse sound absorption at frequencies between 1250 Hz and 3150 Hz.

As for the perforated samples, a decreasing trend at higher frequencies was shown by both methods, and in both methods, the significant difference between perforated and pervious samples at higher frequencies is shown.

Overall, these results are in agreement with the claim of M. Vivolo (2013), according to whom the Alpha chamber reached the sufficient diffusivity and thus accuracy only for frequencies higher than 1246 Hz.

3. CONSLUSION

From the results, it is apparent that measuring small-sized samples in the Alpha chamber can be used for an approximate comparation of samples, but it does not provide the absolute values of sound absorption coefficient. Moreover, this method is more reliable at higher frequencies, starting at approximately 1250 Hz. Thus, this method is not ideal for the evaluation of the samples with the sound absorption peaks at low frequencies, and the search for a more suitable, accurate, and also more economical method continues.

However, finding a possibility of measuring in the Alpha chamber is still a valuable result, as it provides the opportunity to measure samples smaller than 10 m^2. It allows material research to be more economical, as it is easier, faster, and cheaper to manufacture 1 m^2 than 10 m^2 of any given material. With the use of the Alpha chamber, there is a potential for faster and more effective material research in the future.

The current target of the main research topic, the development of sound absorption concrete, is to manufacture 1 m^2 of some specific type of concrete and perform the proper measurement in the Alpha chamber. Such a measurement will first show the accuracy of the measurement performed in this study, and second, it will allow the proper evaluation of the suitability of the Alpha chamber method for the research that follows.

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