HOW TO TEST ACOUSTIC PROPERTIES OF INTERIOR FINISHING MATERIALS AND STRUCTURES IN SCALE MODEL REVERBERATION ROOMS

A Szeląg Cracow University of Technology, Poland
K Baruch-Mazur Cracow University of Technology, Poland

1 INTRODUCTION

Materials and structures used as finishing elements in rooms where interior acoustics play a key role require the determination of specific acoustic parameters, such as sound absorption, scattering, and insulation. Measurements of these parameters are usually performed in laboratory conditions on specially prepared samples. Such research is costly and logistically complex due to the need for access to specialist acoustic laboratories, the need to prepare large-sized measurement samples and their transport to the test site. Therefore, in the scientific community, this type of research is being increasingly explored for certain applications on samples made on a much smaller scale, which is also associated with the need to scale up the entire measurement station. The possibility of using such tests has been confirmed experimentally and described in the literature. In the context of measuring the sound absorption coefficient of materials, it is worth citing previous works by Baruch et al.[1] or Day[2]. When it comes to sound scattering research, the works by Pan et al.[3] or Schmich-Yamane et al.[4] might be cited. In the field of research on the materials insulation, interesting literature items include, for example, paper written by Wang et al.[5]

Acoustic tests using small-scaled samples and measurement stations have not yet been commercialized, although its results and potential applications are very promising. This article does not further verify the correctness and effectiveness of such tests, but presents their interesting applications used to determine the acoustic properties of full-size interior finishing materials and structures.

2 MODEL REVERBERATION ROOMS

The research presented in this article was conducted at three different measurement stations. A brief description of the individual stations is presented below.

2.1 Measurement stand for sound absorption tests

The measurements of the samples sound-absorbing properties were carried out at the measuring station presented in Fig. 1. It was a reverberation chamber, which is an exact representation at scale of 1:7.73 of the chamber located at the AGH University of Science and Technology in Cracow. For the purposes of the tests, both the samples and the measurement frequency range were scaled according to a scale of 1:8. In this way, the standard recommendations regarding the minimum volume of the reverberation chamber of 200 m^3 were maintained. The chamber was adapted for testing in accordance with ISO 354 standard[6], both in terms of acoustic field dispersion (see Fig. 1, on the right) and the selection of measurement equipment, which consisted of the following components: a high-frequency sound source made of piezoelectric elements, a Brüel & Kjær loudspeaker amplifier, a measuring microphone with a 1/4” 46BE preamplifier, a G.R.A.S. 12AL microphone amplifier, a UMC204HD BEHRINGER U-PHORIA sound card and a computer.

Figure 1. Measurement stand for sound absorption tests: view of the chamber from the outside before installing the sound diffusing elements (on the left), view of the chamber from the inside after installing the sound diffusing elements (on the right) - measurement stand created for the implementation of the project POIR.01.01.01-00-0965/18 entitled "Development of integrated acoustic modification elements technology" funded by The National Centre for Research and Development (NCBR), Poland

2.2 Measurement stand for sound scattering tests

To measure sound-scattering properties of the samples according to ISO 17497-1 standard[7], the test stand described in the previous subsection was used with modifications to enable testing of the scattering coefficient s. Hence, an automatically controlled rotary table was installed in the reverberation chamber (see Fig. 2).

Figure 2. Measurement stand for sound scattering tests: view of the chamber from the outside (on the left), view of the chamber from the inside with the sample mounted on the rotary table (on the right) - measurement stand created for the implementation of the project POIR.01.01.01-00-0257/21 entitled "Development of noise reduction technology in urban areas in the form of a multifunctional hybrid external cladding system with maximized sound scattering and absorption functions" funded by The National Centre for Research and Development (NCBR), Poland

2.3 Measurement stand for sound insulation tests

The measurements of the samples sound-insulation properties were carried out at the measuring station presented in Fig. 3. These were coupled reverberation chambers which replicated the full-size reverberation chambers located at AGH University of Science and Technology. Both rooms, source and receiving, had a volume of about 0.35 m^3 (which is almost 180 m^3 at 1:1 scale). Detailed information on the construction and equipment of this measuring station can be found in the paper by Szeląg et al.[8]

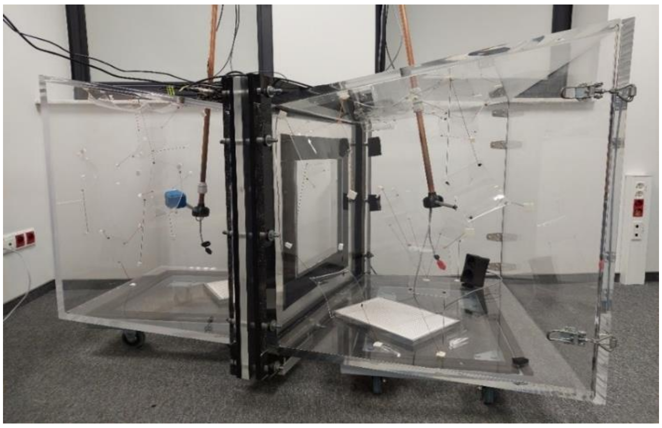

Figure 3. Measurement stand for sound insulation tests, i.e. coupled reverberation rooms with the equipment - measurement stand created for the implementation of the following projects: MINIATURA entitled “The influence of geometrical and structural-material parameters of scale experimental models on the phenomenon of structure-borne sound transmission and radiation” funded by National Science Centre, Poland and LIDER entitled “Innovative metamaterial cladding increasing the sound insulation of partitions by reducing resonance bands” funded by The National Centre for Research and Development (NCBR), Poland

3 APPLICATIONS

3.1 Sound absorption tests

The tested samples were room furnishings such as office desks, made at a 1:8 scale relative to full-size furniture. Initially, they were made of hard and sound-reflecting materials. In subsequent measurement variants, the same amount of highly sound-absorbing material was installed on different surfaces of these desks. During the studies, the acoustic absorption of a single desk for different locations of the sound-absorbing material was measured. The aim of the entire experiment was to determine whether it is possible to use desk surfaces that do not have a utility function (e.g. the bottom of the desk) as carriers of sound-absorbing materials while maintaining high acoustic efficiency of such a solution.

Fig. 4 shows equivalent sound absorption per each desk measured for different locations of the reference sound-absorbing material: without this material (Variant D0), with material under the table top (Variant D1) and with material on desk screens (Variant D2). Tests on smaller-scale samples allowed for a quick and cost-effective assessment of how the placement of sound-absorbing material on furniture, such as desks, affects their sound absorption performance. The presented diagrams show that even if the absorbing materials are placed under the furniture, the acoustic absorption of the element increases significantly. This is an interesting conclusion in the context of the possibility of concealing additional absorbing systems. More research results, both in the context of other locations of sound-absorbing material and research on other furniture, can be found in the paper Szeląg et al.[9]

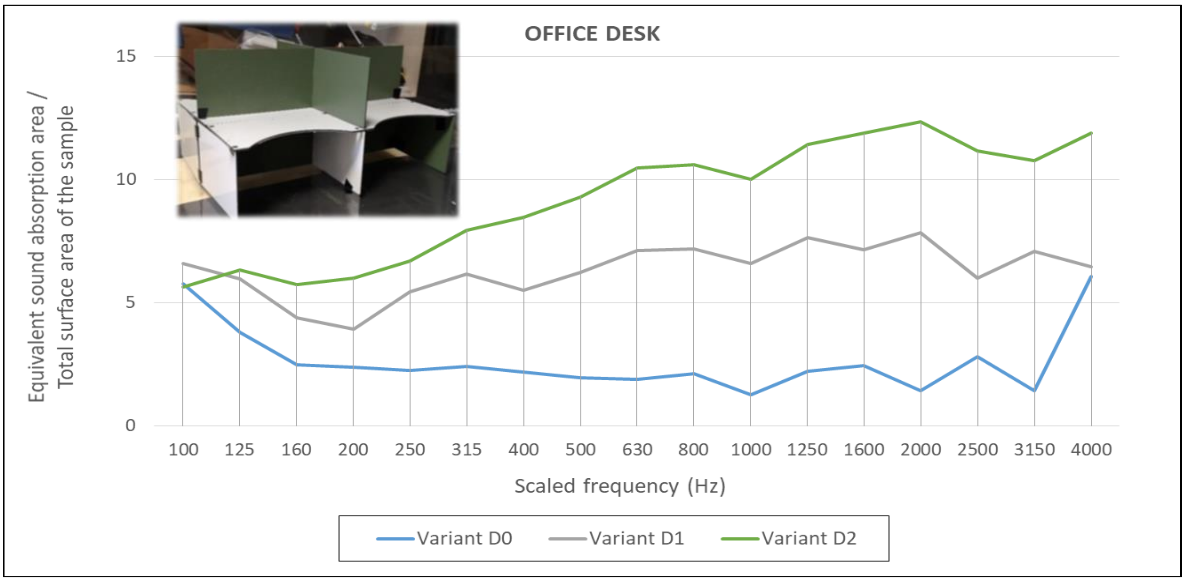

Figure 4. Measured values of the equivalent sound absorption area divided by total surface area of the sample for scaled office desk, both with (Variants D1-D2) and without (Variant D0) the reference material[9]; the results from the scaled rooms were scaled to actual measurement frequencies

3.2 Sound scattering tests

The tested sample was a certain Schroeder diffuser with the fins removed. The aim of the study was to calibrate the research environments: small-scale experimental environment (see chapter 2.2) and the numerical environment (FEM simulated in Comsol) with the full-scale experimental environment (standardized reverberation rooms) for further design work in the project POIR.01.01.01-00-0257/21. The research results presented in Fig. 5, i.e. measured or simulated values of scattering coefficient s, show a high degree of convergence between these three methods. Thanks to these results, it was possible to begin research on scattering-absorption structures using cost-effective research tools, i.e. simulations and measurements on small-scale samples.

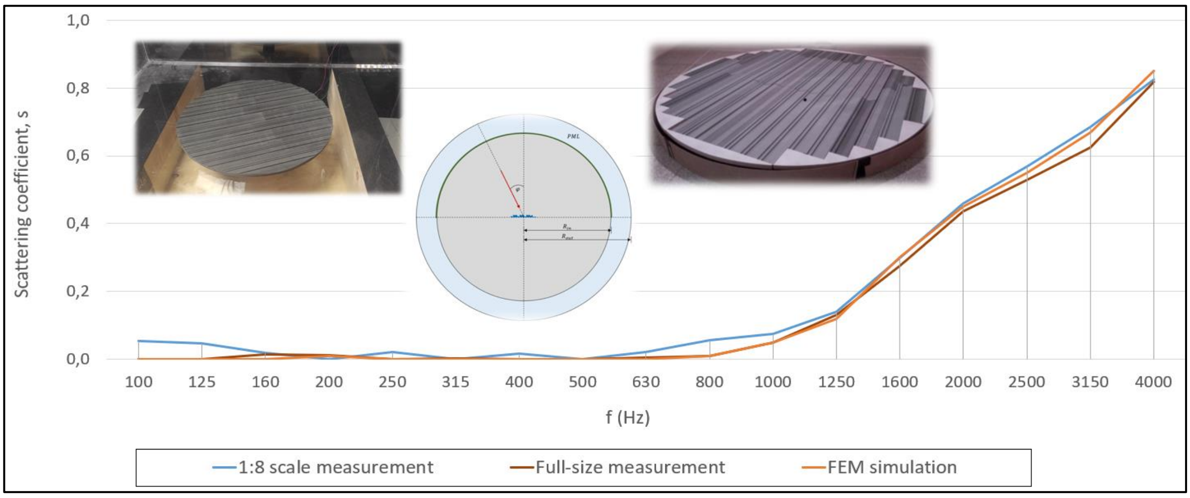

Figure 5. Measured or simulated values of scattering coefficient s for a certain Schroeder diffuser with the fins removed; the results from the scaled rooms were scaled to actual measurement frequencies

3.3 Sound insulation tests

The tested measuring samples were 1 mm thick steel plates with dimensions of: 17.5 cm × 17.5 cm, 35 cm × 35 cm, 65 cm × 65 cm, 12.5 cm × 25 cm and 25 cm × 50 cm. The installation of samples of different sizes in the reverberation rooms was possible thanks to interchangeable measuring collars adapted to the sample sizes. The aim of the experiment was to determine the influence of the sample size and shape on its insulation coefficient – sound reduction index R.

By analyzing the results shown in Fig. 6, it can be concluded that the influence of the sample dimensions on the obtained values of the sound reduction index is significant. Above the coincidence frequency (a visible decrease in sound insulation around 1600 Hz), an increase in sample size corresponds to a decrease in R, whereas below this frequency, larger samples exhibit higher R values. These results align more closely with the findings of Mleczko[10], who noted that smaller baffles, particularly in square shapes, exhibit reduced sound insulation. Conversely, the outcomes differ from those documented by Wareing et al.[11], especially regarding frequencies that fall below the coincidence frequency. This indicates that the connection between the size of the sample and sound insulation might be more intricate than conventional theoretical models suggest and is probably affected by elements like boundary conditions and the stiffness of the panels.

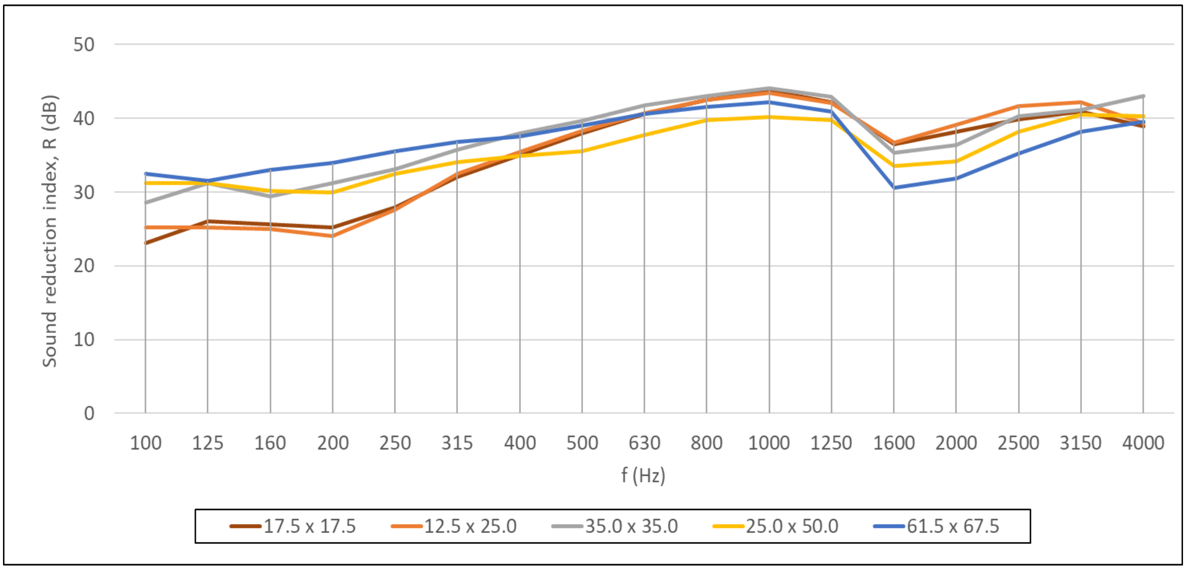

Figure 6. Sound reduction index R measured for a 1 mm thick steel sample of various shapes and sizes: 17.5 cm × 17.5 cm, 12.5 cm × 25 cm, 35 cm × 35 cm, 25 cm × 50 cm and 61.5 cm × 67.5 cm; the results from the scaled rooms were scaled to actual measurement frequencies

4 CONCLUSIONS

The presented research examples demonstrate that scaled test environments can successfully support the evaluation of sound absorption, scattering, and insulation characteristics of various materials and elements used in interior design. Such an approach is especially useful in early design stages, where fast and cost-effective verification of acoustic properties can inform further development. Thanks to the relatively simple setup and reduced material requirements, scale models can facilitate the testing of multiple design variants under controlled conditions. Furthermore, the use of small reverberation chambers makes it possible to investigate configurations that may not be feasible in standard laboratory settings, such as furniture with integrated acoustic elements or complex diffuser geometries.

This paper presents only typical tests on samples made also at smaller scale as the stand. However, scaled stands may be also used for tests of acoustic properties for full-size samples. However, the measurable frequency range remains limited at lower frequencies.

In conclusion, although scaled measurements have certain limitations, they provide valuable insight into the performance trends and comparative evaluation of solutions. As a result, they may be considered a complementary method in both research and practical applications, offering flexibility, accessibility, and reliability within their operating range.

5 REFERENCES

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