MEASUREMENT OF SOUND ABSORPTION COEFFICIENTS OF MATERIALS TO BE USED IN SCALE MODELING

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Abstract. *Scale models are used in the analysis of the acoustic behavior of rooms because they fully reproduce physical phenomena such as diffusion, diffraction, and absorption, what is still a limitation in precision and time in numerical modeling, especially for complex geometrical shapes.*

To build a room scale model, importance must be given to the choice of its materials. They should follow similarity conditions to correctly simulate the surfaces of the original room. Unfortunately, there is a lack of information on sound absorption characteristics of different types of substitution similar materials.

The purpose of the work reported was the construction and validation of a 1:8 small-scale reverberation chamber to measure the sound absorption coefficients of different types of material, in accordance with the international standard ISO 354, in order to develop a catalogue of equivalent scale absorbing materials to be used in architectural acoustic studies with scale models of rooms. Some advantages of scale models are that they may be relatively cheap, their configurations can be easily modified and they can be very useful as teaching tools for Applied Acoustics. However, scale-model reverberation chambers have the same experimental difficulties as room scale models: the similarity conditions.

Validation tests were performed with two different internal surfaces of the chamber: the first in uncoated plywood, and then in varnished plywood. After each validation, the absorption coefficients of some types of materials, such as velvet and felt, were measured and compared with coefficients of materials used in real scaled buildings. Equivalence of absorption coefficients was noticed in some frequency bands, as shown by the results presented.

Keywords*: reverberation chamber, sound absorption, absorbing materials, scale modeling*

1. INTRODUCTION

Due to persisting limitations of numerical procedures in fully reproducing physical phenomena, such as diffusion, diffraction, and absorption, scale models of rooms have regained importance, as compared to numerical modeling. But the lack of information on sound absorption characteristics of different types of substitution similar materials leads to the necessity of equivalent materials to be used in room models.

In this context, the work presents a 1:8 small-scale reverberation chamber built in the Acoustic and Vibration Laboratory at COPPE/UFRJ, to measure the sound absorption coefficients of different types of material, in accordance with international standards, in order to develop a catalogue of equivalent scale absorbing materials to be used in architectural acoustic studies with scale models of rooms.

It must be taken into account that scale-model reverberation chambers have the same experimental drawbacks as room scale models and, as a consequence, the similarity conditions should be carefully followed. Such a chamber is relatively cheap, its configuration can be easily modified and it can also be very useful in teaching environments.

Two different internal surfaces of the chamber were tested and validated; and some types of materials were measured and compared with materials used in real scaled buildings.

2. SCALE MODELING

Despite the advances in numerical modeling, scale modeling is still a useful tool in the study of the acoustic behavior of rooms. It consists in the study of the acoustical characteristics in a reduced model of the room, in order to foresee the acoustic behavior in the real room, through measurements of the acoustical parameters in the model.

The materials used in scale modeling have to follow similarity conditions to correctly simulate the original room, and, for this reason, the selection of materials is the main difficulty in acoustical scale modeling. When it comes to absorption, the sound absorption coefficients of the model materials should be the same as those of the materials used in real rooms, but at n times the frequencies in the real room, where n is the scale factor of the model.

Generally, it is very difficult to develop or to find models for the materials used in real rooms, and the models are not made of the same materials as the real rooms. In practice, the sound absorption coefficients for the model materials are usually chosen to be approximately equal to the coefficients for the real room at the corresponding frequencies. Errors in this approximation may cause distortion problems.

The increasing variety of materials used nowadays in architecture and the lack of information on sound absorption characteristics of different types of substitution similar materials leads to the necessity of a catalogue with materials to be used in scale-models of rooms and their sound absorption coefficients at frequencies corresponding to those of absorption coefficients of real room materials.

In order to measure the absorption coefficients, a scale-model reverberation chamber is needed. One of the first studies in this area was performed by Spring *et al*. (1971) in the BBC Research Department. At those times, however, experimental signal had to be processed through analog filtering, so time scaling was done with tape speed changes.

Modern digital signal processing allows reduced models to regain utility. The acoustical parameters of rooms can be obtained through the impulse response measured from scaled sweep excitation in the models.

3. REVERBERATION CHAMBER AND THE EXPERIMENTAL PROCEDURE

Reverberation chambers are used to measure the sound absorption coefficients of materials, according to the international standard measurement procedure given in ISO 354 (1999). The procedure consists in measuring the reverberation times of the chamber as a function of the frequency before and after placing the sample of material under test inside the room, and then calculating its random-incidence sound absorption coefficients.

The reverberation chamber should be excited with a diffuse sound field. A completely diffuse field is the one where the energy density in every instant is the same throughout the room, condition called homogeneity, so the directional distribution of energy propagation is isotropic at any point in the sound field, what means that all directions of arrival of sound energy at any point are equally probable. Some methods for measuring diffusion in a room have already been investigated, for example by Cook *et al*. (1955), Schultz (1971) and Nélisse and Nicolas (1997), but a standard method has not been established yet.

The small-scale reverberation chamber built to this research is presented in Fig. 1. The volume is approximately 0.4 cubic meters, equivalent at 1:8 scale to a real volume of 200 cubic meters, a standard size. It was made in plywood, thickness of 30 mm, with one wooden-framed 10 mm thick transparent acrylic door. Inside the chamber, static curved acrylic sheet diffusers were randomly suspended from the roof at various angles (Nascimento, 2002).

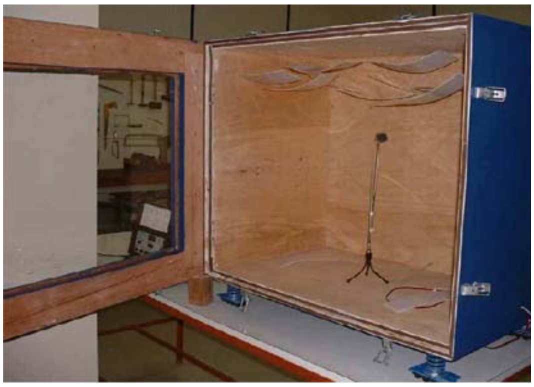


Figure 1. Small-scale reverberation chamber.

The experimental procedure used is in accordance with the standard ISO 354 and is described as follows (Nascimento, 2005):

The reverberation times are obtained from the measured impulse responses of the chamber. The chamber is excited by a tweeter loudspeaker emitting a sweep signal (varying from 800 to 20000 Hz), and the output signal is measured through a ¼-inch diameter condenser B&K 4135 microphone with pre-amplifier.

The impulse response is obtained from the convolution of the output signal with the inverse filter of the exciting signal, (Müller and Massarani, 2001), and the reverberation time is obtained by the integrated impulse response method (Schroeder, 1965).

As the scale factor of the mini-chamber is 1:8, the real world frequency range of the results is from 100 to 2500 Hz, due to limitations of the equipment used.

The average temperature inside the chamber during the measurements was 25.7 ^{o}C and 66.7 % of relative humidity. Both were kept constant with and without test specimen. The sound absorption of the air was not considered in the calculations.

4. DIFFUSION AND VALIDATION OF THE MINI-CHAMBER

According to ISO 354, sound diffusion may be improved with the installation of diffusers (static or rotating) inside the chamber and with changes in the shape of the room. To validate a chamber, the number of diffusers inside it should be increased in steps of approximately 5 real world square meters (in a 200 cubic meter chamber), until the absorption coefficient converges.

The test specimen used in the validation of the mini-chamber was cut in expanded polyurethane foam, with plain surface, total area of 280 x 560 mm^2 (equivalent to a “real world” area of 10 m^2), thickness of 20 mm, and its edges were covered by a steel frame, to avoid the edge effect.

Validation tests were performed for two different internal surfaces of the chamber: the first in uncoated plywood, and then in varnished plywood. In both cases, after trying some possible configurations, it was noticed that for areas of diffusers from 15 to 25 m^2, the absorption coefficients kept constant. Therefore, the result of the validation was that the best convergence occurred with 15 m^2 of diffusers (9 diffusers) in the chamber, so it was considered validated for 15 m^2 of diffusers as seen in Fig. 2 and Fig. 3. The graphics show the convergence of the sound absorption coefficients with the increase in the area of diffusers for both different internal surfaces of the chamber. The results are divided in two ranges of frequency, in one-third octave bands, from 125 to 400 Hz and from 500 to 2500 Hz.

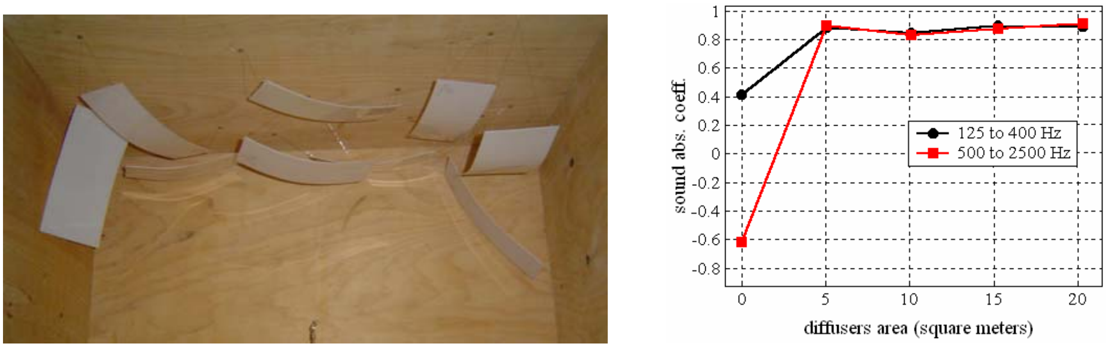


Figure 2. Chamber in uncoated plywood and convergence of absorption coefficients as function of the area of diffusers.

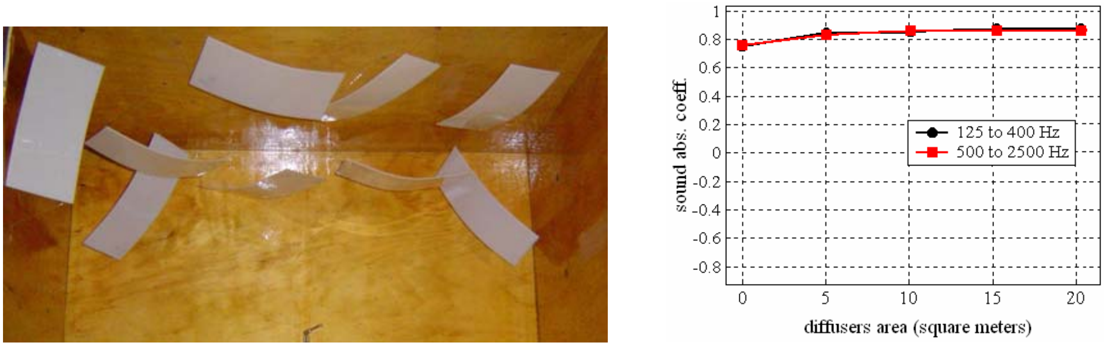


Figure 3. Chamber in varnished plywood and convergence of absorption coefficients as function of the area of diffusers.

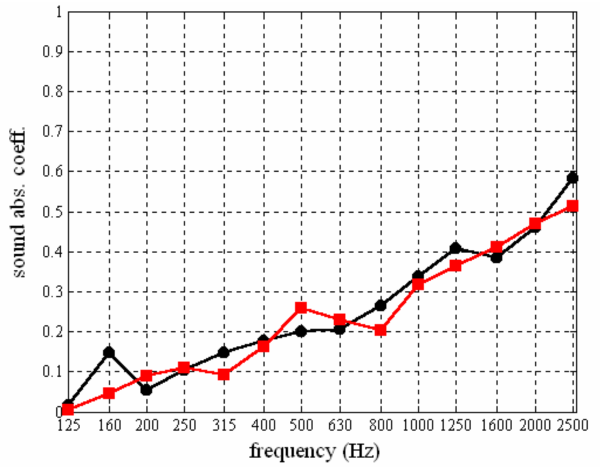
It is noticed that for the varnished configuration the presence of diffusers had little influence in the sound absorption coefficient convergence. This configuration also gives more accurate results than the uncoated plywood. Despite this, both results are presented, making possible a comparison between the two configurations.

5. SOME MEASURED MATERIALS

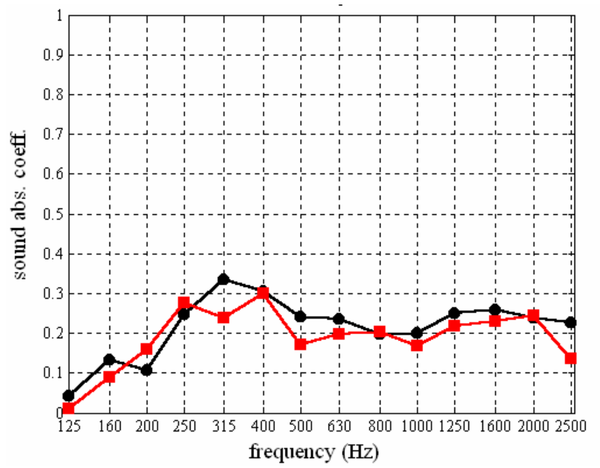
After each validation, with the chamber in uncoated plywood and in varnished plywood, the sound absorption coefficients of some types of materials were measured. The area of the test specimens was equivalent to a real area of 10 m^2. Table 1 lists characteristics of some measured materials and Fig. 5 shows the sound absorption coefficients.

Table 1. Measured materials characteristics

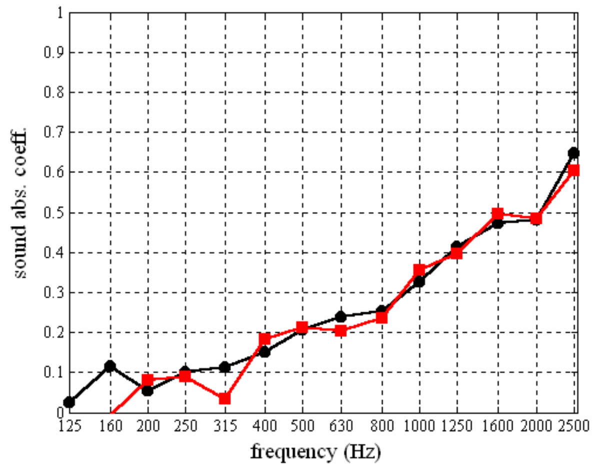
Materials	Thickness	Superficial density
Velvet	1,7 mm	0,219 kg/m^2
Cork	3 mm	0,864 kg/m^2
Felt 1	1 mm	0,165 kg/m^2
Felt 2	2 mm	0,244 kg/m^2
Chamois suede	0,7 mm	0,294 kg/m^2
Expanded Polyehtylene	5 mm	0,194 kg/m^2



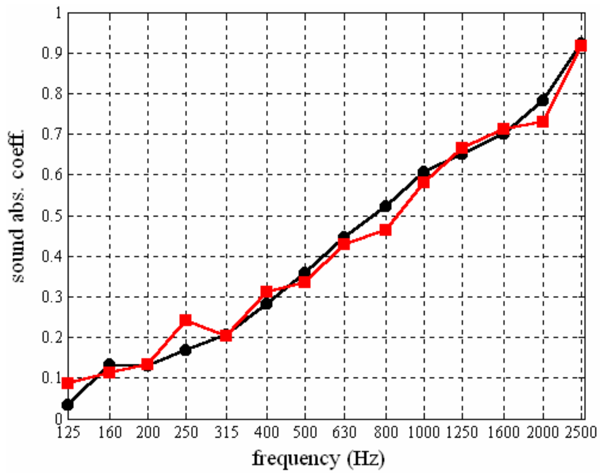
Velvet



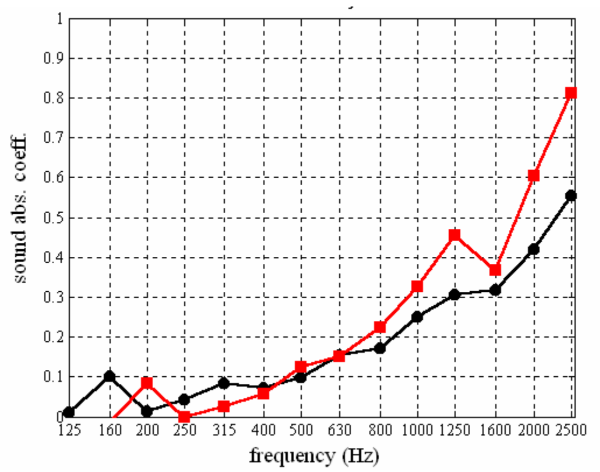
Cork



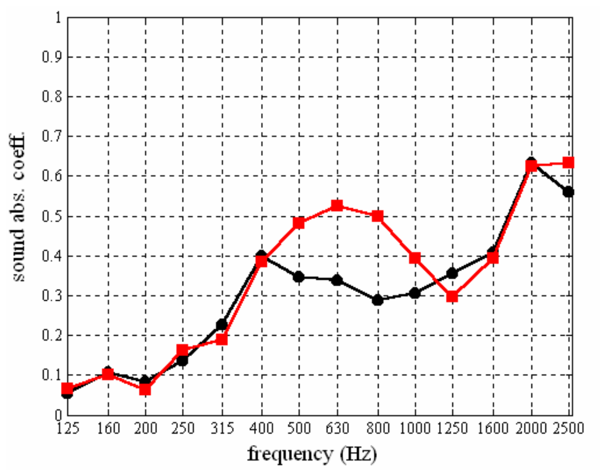
Felt 1



Felt 2



Chamois suede



Expanded Polyehtylene

Figure 5. Sound absorption coefficients of some measured materials as functions of frequency.
- ■ - uncoated plywood chamber, - ● - varnished plywood chamber.

Although the absorption of the surfaces of the uncoated plywood chamber is bigger than the absorption of the varnished surfaces, this difference is not so much evident in the graphics above, where the curves have similar behavior. The main difference observed was for the expanded polyethylene, from 500 to 1000 Hz.

6. COMPARISON WITH MATERIALS USED IN REAL ROOMS

In order to compare the absorption of the measured materials with those used in real rooms, a program was developed. It contains data of sound absorption coefficients of known materials used in real scaled buildings and compares them with the coefficients obtained in the scale-model reverberation chamber, giving the equivalence of absorption coefficients of these materials. This equivalence corresponds to the materials that have the same sound absorption coefficient and its frequency.

An example obtained for the uncoated plywood chamber is the velvet. Its absorption coefficients are presented in octave bands in Tab. 2. In the scale 1/8, the measured velvet behaviors as a polyurethane foam with 1/2" thickness, in real scale, at the frequencies of 250 and 500 Hz. Some more equivalence sets are shown in the table.

Table 2. Equivalence of absorption coefficients for velvet.

Freq [Hz]	Sound. Abs. Coef.	Equivalent sound absorption materials and frequencies		
125	0,07	curtain: 14 oz/sq yd (at 125 Hz)	parquet on concrete (at 500 Hz)	wood / wood floor (at 1000 Hz)
250	0,11	foam: polyur. 1/2" (at 250 Hz)	wood / wood floor (at 250 Hz)	curtain: 10 oz/sq yd fabric (at 500 Hz)
500	0,22	foam: polyur. 1/2" (at 500 Hz)	empty metal/wood seats (at 500 Hz)	wood: 3/8" plywood panel (at 250 Hz)
1000	0,28	wood: 3/8" plywood panel (at 125 Hz)		
2000	0,41	people - adults (at 500 Hz)		

For the varnished plywood chamber, the example presented is the expanded polyethylene, in Tab. 3. As shown by the results presented, the equivalence of absorption coefficients was noticed in some frequency bands, but not in all the frequency range.

Table 3. Equivalence of absorption coefficients for expanded polyethylene.

Freq [Hz]	Sound. Abs. Coef.	Equivalent sound absorption materials and frequencies		
125	0,03	curtain: 10 oz/sq yd fabric (at 125Hz)	brick: unglazed(from 125 to 500 Hz)	carpet, 5 mm thick, on hard floor(at 250 Hz)
250	0,18	glass: window (at 500 Hz)	wood: 3/8" plywood panel(at 500 Hz)	empty metal/wood seats (at 250 Hz)
500	0,47	acoustic tiles (at 2000 Hz)	people - adults (at 1000 Hz)	
1000	0,44	people - adults (at 500Hz)		
2000	0,36	concrete block - coarse (at 125 Hz)	curtain: 18 oz/sq yd (at 250 Hz)	people - adults (at 250 Hz)

7. CONCLUSIONS AND APPLICATIONS

This work presented the measurement of sound absorption coefficients of some types of material in a 1:8 small-scale reverberation chamber, in accordance with the international standard ISO 354, with two internal surface configurations: uncoated plywood and varnished plywood.

The chamber was considered validated in both cases, with the same area of diffusers. Although the varnished configuration has shown an improvement in comparison with the uncoated, the absorption is still strong at high frequencies.

The measured sound absorption coefficients were compared with materials used in real scaled buildings, what gives support to the development of a catalogue of equivalent scale absorbing materials to be used in architectural acoustic studies with scale models of room.

This research area is challenging and approaches many different study areas: from basic and architectural acoustics to measurements, emission and acquisition of scaled sound signals, and the processing of these signals to obtain the desired acoustical parameters.

However, many aspects still have to be investigated, such as a new internal wall facing, to further reduce the absorption of the internal surfaces of the mini-chamber; and the effect of the sound absorption of the air, which may be considered and made to fit the scaling by drying the air inside the chamber. Also, more adequate equipment to scale model measurements can be used in the measurements, what would be useful to obtain more accurate results and to increase the frequency range.

The scale-model reverberation chamber can also be used for several other applications, such as the study of diffusion and ways of measuring it; the study of diffraction and edge-effect in scale modeling; the study of coherence and other theories about room acoustics; the use of chamber and models as a teaching tool for Applied Acoustics; and the use of the experimental results obtained in the chamber in the validation of numerical methods.

8. ACKNOWLEDGEMENTS

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10. RESPONSIBILITY NOTICE