Signal analysis in the sound absorption measurement procedure: The importance of time subtraction and reference surface corrections

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The in situ measurement of the sound absorption coefficient (following the ISO 13472-1 standard) of highly absorbing materials, which are typically employed in room acoustics correction, presents some inherent difficulties. These materials present high sound absorption coefficient indeed, but usually low sound insulation index and are installed over highly reflective surfaces. This leads to some measurement problems, partially solved by means of the reference surface method. In this work some measurement examples on the same materials but with different boundary conditions are analyzed and the improvements on the results, due to reference surface normalization and time domain subtraction of free field response, are discussed.

1   Introduction

In a previous paper [2] improvements on the measurement method of the acoustic properties of a material using impulsive method [1] by equalizing the measurement chain have been discussed. In this work the study has been concentrated on physical aspects of the measurement. In an ideal case it is possible to perform a measurement on a sufficiently large area of material. In practice this is not always possible, so it is important to know how the final results are affected by non-ideal conditions. In particular, some conditions of the measurements have been chosen deliberately worse than suggested by the ISO standard [1]. The absorption coefficients obtained in each case have been analyzed and discussed. Finally the accuracy requested by the time-subtraction procedure has been tested, obtaining suggestions for the best possible analysis.

2   Methodology

The measurement method used in this paper follows the ISO 13472-1 standard [1]. This method allows measuring the absorption coefficient of a material *in situ*. A sound source (boxed loudspeaker) is suspended over the material surface which is going to be measured; A microphone is placed between the sound source and the material. The method is based on the measurement and analysis of composite impulse response of the described system.
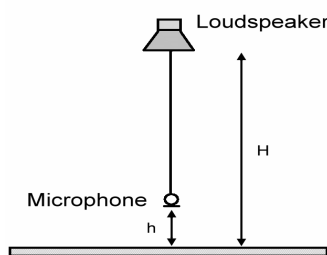

Fig. 1 – Geometry setup of the measurement

The impulse response is computed using MLS or Swept-tone test signals. The measurement on reflective material shows 2 peaks (see figure 2). The first peak corresponds to the sound coming from the source and arriving to the microphone. It contains only the spectral information about the measurement chain. The second peak is separated from the first by a time interval corresponding to the *2h* distance divided by the sound speed and contains the spectral information of the measurement chain filtered by the material under test.

The absorption coefficient can then be computed by means of the ratio of power spectra of the windowed direct and

reflected impulses, taking account of the geometrical spreading of sound waves:

$$\alpha(f) = 1 - \left| R_p(f) \right|^2 = 1 - \frac{1}{K_r^2} \left| \frac{P_r(f)}{P_i(f)} \right|^2 \qquad (1)$$

Referring to Eq.(1), $R_p(f)$ is the sound pressure reflection factor of the surface under test, K_r is a geometrical spreading factor [1], $P_r(f)$ and $P_i(f)$ are respectively the spectrum of the reflected and direct sound waves [2].

The direct wave impulse response used to compute the absorption coefficient, also called *freefield*, is taken from a separate measurement, so that a longer part of data can be included. The freefield measurement represents the semi-anechoical response of the analysis system.

Moreover, the subtraction technique [1] is implemented in order to reduce the influence of direct wave on the reflected data.
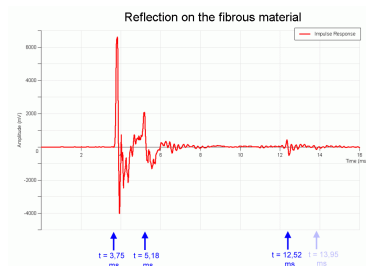

Fig. 2 – Example of direct an reflected waves

Frequency limits of this measurement depend on many factors, including area and shape of the material under test, distances between sound source, microphone and material and the time length of data window.

The following Eq.(2) allows to compute the so called *active surface*:

$$r = \frac{1}{H + h + cT_w} \sqrt{\left(H + h + \frac{cT_w}{2} \right)\left(H + \frac{cT_w}{2} \right)\left(2h + cT_w \right)cT_w} \quad (2)$$

where H and h are respectively the distances of the loudspeaker and microphone from the surface of the material under test, T_w is the length of data analysis window and c is the speed of sound [1].

Given a fixed geometrical setup (H and h distances), the relationship between the radius of active surface and the length of data analysis window T_w can be computed (an example is shown in Fig. 3).
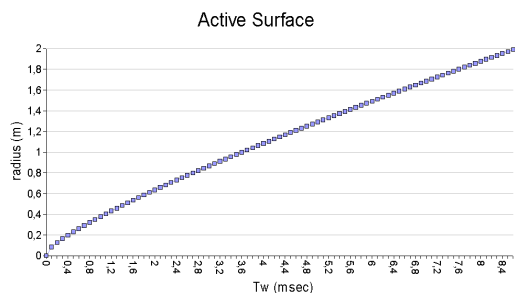
Fig. 3 – Active surface radius, computed
for *H*=1,35 m and *h*=0,1 m

When measuring materials having low absorption coefficients (as the case of porous material at low frequency), the normalization of the measured sound pressure reflection factor $R_{p,meas}(f)$ with a reference sound pressure reflection factor $R_{p,meas,ref}(f)$ measured over a reflective plane placed at the same distance of the device under test is mandatory. The normalized reflection factor is computed as:

$$R_{p,norm}(f) = \frac{R_{p,meas}(f)}{R_{p,meas,ref}(f)} \qquad (3)$$

3 Measurements description

Measurement tests were performed on samples of a polyester fiber material, marketed with the commercial name Fiberform, in form of panels of apparent density of 40 Kg/m^3 and thickness of 40 mm. Measurements performed inside an impedance tube on the same material, data from a mathematical model and results from a previous measurement obtained by means of reflection method (16 m^2 active area, *H*=1,5 m, *h*=0,25 m, T_w=7,4 ms) [2] are shown for comparison purposes. All the measurements presented here were performed at normal incidence and data are presented in 1/3 octave frequency bands on the full frequency range 100 Hz – 5 kHz, also in the event that the actual frequency range is narrower.

The time length of data window gives the actual frequency resolution: the lower frequency limit of validity of the measurement follows the law $f_{min} \approx 1/T_w$ [2]. A data window length of 7,4 ms allows valid results starting from the 200 Hz 1/3 octave band.

Problems in the measurement may arise when a sufficiently large area of the specimen cannot be reached, especially when performing an *in situ* measurement.

In addition, the normalization over a reflective plane in an *in situ* measurement may be a problem, since a large, heavy, single panel reflective surface is not easy to be transported on the measurement place.

In this work the measurements were performed with different geometries and specimen positions:

– measurements on Fiberform placed on a reflective floor. In this case the floor itself can be used as

reference reflective plane, just removing the specimen (see Fig. 4).

Fig. 4 – Fiberform on the floor

– measurements on Fiberform hung on a framework (see Fig. 5)

Fig. 5 – Fiberform hung on the framework

In this case, two types of reflective surfaces were placed behind the specimen: two plates of plywood or a single gypsumboard panel. Dimensions and details of these materials will be specified later. The same reflecting surfaces were used also for the normalization procedure.

Two types of freefield response were measured and used for the absorption coefficient computation in the case of measurements with the specimen mounted on the framework:

– the ones marked as "Horizontal" are obtained simply rotating the loudspeaker-microphone system of 180° towards open space, keeping the microphone exactly at the same distance from the ground (see Fig. 6).

– the ones marked as "Up" instead are obtained pointing the loudspeaker-microphone system to the sky (see Fig. 7).

Fig. 6 – Freefield measurement "Horizontal"

Fig. 7 – Freefield measurement "Up"

In common practice, the freefield measurement is taken using the second position, here called "Up", to have a longer, free from floor reflections, semi-anechoical impulse response, and consequently a better frequency resolution.

However, in this position the strains applied to the microphone brackets are different from the strains applied in the horizontal position. This causes often a slight difference between the shape of the freefield measurement and the direct wave in the measurement, causing a small amount of residual signal after the subtraction [2].

For this reason, in this work, the absorption coefficients measured on the specimen mounted on the framework will be computed using both the freefield measurements marked "Up" and "Horizontal", comparing the obtained results.

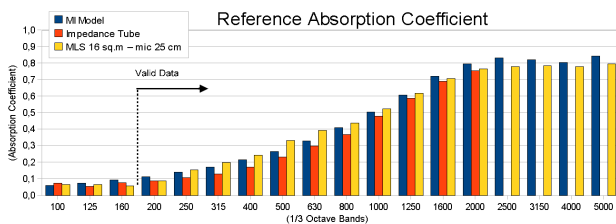## 3.1   Reference measurement

Fig. 8 – Reference absorption coefficient

In figure 8 a set of absorption coefficients measured on Fiberform (density of 40 Kg/m^3 and thickness of 40 mm) is shown. These data were measured in a previous work [2] with very good final agreement between different methodologies and are used in this paper as reference absorption coefficient.

3.2   Measurements on the floor

Figure 9 shows the measurements performed on the floor, placing the microphone at 0, 5 and 10 cm from the surface (see Fig. 4). The distance loudspeaker-microphone was fixed at 1,25 m. The active area was a circle with radius of around 1,4 m and the analysis was done with a T_w of length 5,4 ms. This allows to have valid data starting from the band of 315 Hz. Time subtraction was computed with a freefield measurement of type "Up" and the floor itself was used as reference plane for normalizing the measurement.
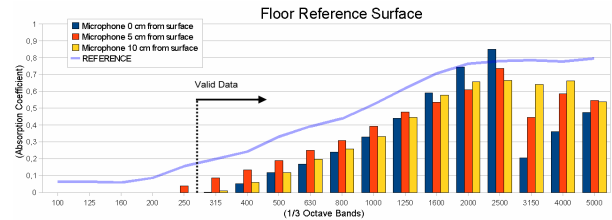

Fig. 9 – Comparison of the measurements on the floor

The measured absorption coefficients show a general underestimation of the values, in comparison with reference data. Worst results are observed when the microphone is closer to the material surface.

The underestimation may be explained considering the small size of absorption material surrounded by a highly reflective surface (the floor). High frequency oscillations may arise from stationary waves between the loudspeaker and the reflective floor.

3.3   Measurements using wood reference surface

Figure 11 shows the measurements done on the specimen mounted on a framework, placing the microphone at 0, 5 and 10 cm from the surface. Geometry setup is the same as the measurement on the floor.

Two plates of plywood (2,5 m x 1,25 m x 5 mm, density 800 kg/m^3) put side by side were used behind the fiber in the normal measurement (see Fig. 10) and in front of the loudspeaker for the reference plane measurement.

It is important to note that a measurement with this methodology on a porous material without a reflective plane on its back would be impossible because of the too low energy reflected.

Time subtraction was done with 2 freefield measurements, "Up" and "Horizontal".

Fig. 10 – Measurement with plywood reference surface (the picture shows the back of the measurement plane)

The absorption coefficient values shown in figure 11 are averages between the values obtained with the "Up" and "Horizontal" freefield measurements, plotted separately in figure 12.
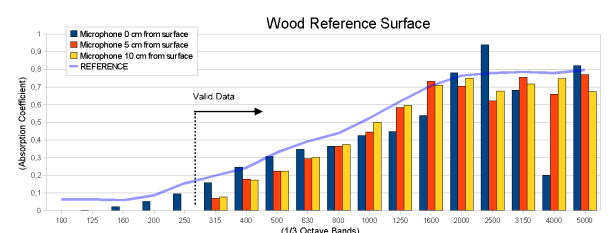

Fig. 11 – Comparison of measurements with plywood r.s.

In this case also, the measurements performed with the microphone closer to the material surface are the most critical. Especially at high frequency a sensible deviation from reference data can be noted in the measure with the microphone at 0 cm (i.e. touching the surface).
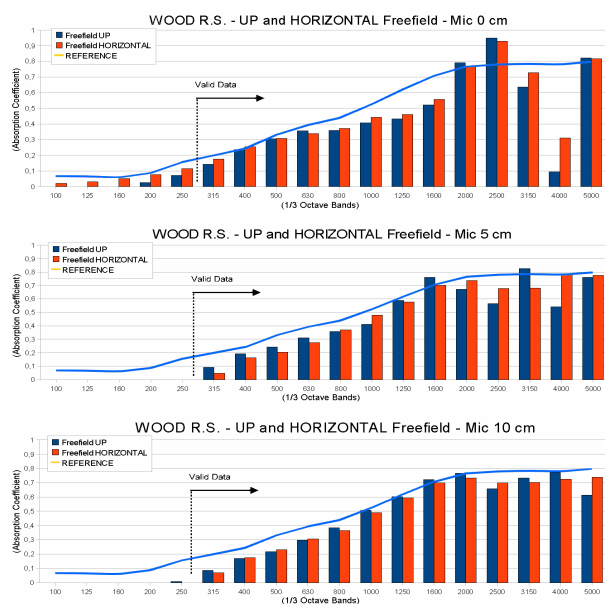

Fig. 12 – Measurements with plywood reference plane. Microphone at 0 cm, 5 cm and 10 cm from material. "Up" and "Horizontal" freefield measurements

Measurements computed using "Up" and "Horizontal" freefield responses are similar, but at all microphone distances a slightly better match with reference data can be found in the "Horizontal" case. This proves that the "Horizontal" freefield impulse response allows to obtain more accurate time subtraction.

3.4 Measurements using gypsumboard reference surface

Figure 14 shows the measurements performed on the specimen mounted on a framework, placing the microphone at 0, 5 and 10 cm from the surface. Geometry setup is the same as in the case of the measurement on the floor.

A single plate of gypsumboard (2 m x 1,2 m x 12,5 mm, density 827 kg/m^3) was used behind the fiber in the normal measurement (see fig. 13) and in front of the loudspeaker for the reference plane measurement.

Fig. 13 – Measurement with gypsumboard ref. surface (the picture shows the back of the measurement plane)

The values of the absorption coefficient shown in figure 14 are averages between the values obtained with the "Up" and "Horizontal" freefield measurements, plotted separately in figure 15.
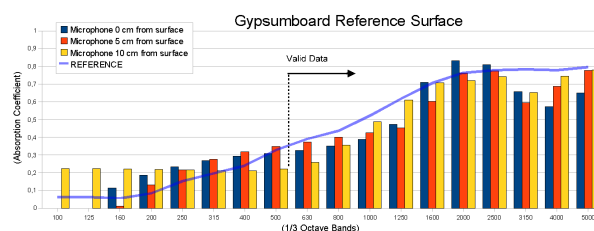

Fig. 14 – Comparison of measurements with gypsumboard reference surface

In this case, the width of the gypsumboard plate used for the measurement of 1,2 m means that the active area has a radius of only 0,6 m and the data analysis window T_w is 2 ms, allowing to have valid data only above 630 Hz.
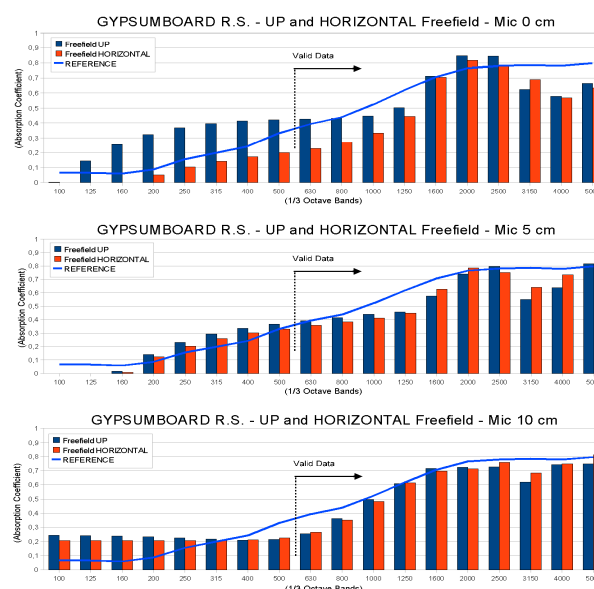

Fig. 15 – Measurements with gypsumboard reference plane. Microphone at 0 cm, 5 cm and 10 cm from material. "Up" and "Horizontal" freefield measurements

The measurements performed with gypsumboard lead to considerations similar to the ones obtained in the plywood case: when the microphone is closer to the surface the measurements give worst results; the computations done with "Horizontal" freefield impulse response generally match the reference curve better.

In-depth analysis and measurements (vibrational analysis) were done on both plywood and gypsumboard plates in order to assure that no resonance or critical frequencies could interfere with the absorption coefficient measurement.

3.5 Measurements without reference surface

A measurement on the specimen mounted on the framework without any reflecting surface behind is shown

in figure 16. It is clear that on lightweight fibrous materials the reflection method does not work without a suitable reflecting surface of sufficient size.
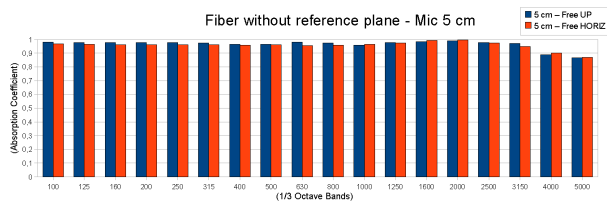

Fig. 16 – Measurement without reflecting surface behind the material

The totally unreliable absorption coefficient values shown in figure 16 are due to the lack of energy reflected by the device under test.

4   Subtraction technique accuracy

In figure 17 a) an example of direct and reflected waves of one of the measurements described above (fiber over gypsumboard reflecting surface) is plotted. Performing time subtraction and observing the remaining signal before the reflected wave, it can be noted that the result is much more accurate in the case of "Horizontal" freefield response b) than in the case of "Up" freefield measurement c), confirming the results found in the absorption coefficient computation discussed above.
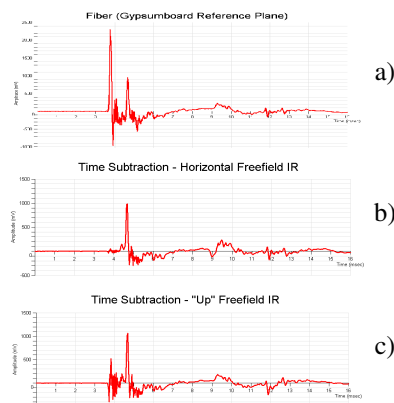

Fig. 17 – a) direct and reflected waves on a measurement; b) time subtraction, "Horizontal" freefield measurement; c) time subtraction, "Up" freefield measurement

The software used for computing the absorption coefficient (ALFA-Win©) finds the best alignment between freefield wave and measured wave. This is obtained by searching the minimal energy in the difference between both signals, time-shifting by a fraction of the discrete time step Δt one of the two time signals in an area around the direct component [1, annex G]. In the present work, the same absorption coefficient has been computed using different settings of the searching step (the fraction of Δt): $0.01\Delta t$, $0.1\Delta t$, $0.4\Delta t$, Δt, $1.5\Delta t$.

Figure 18 shows how different values of the searching step affect the computed absorption coefficient. Measurement data from a previous work (16 m² active area, H=1,5 m, h=0,25 m, T_w=7,4 ms, [2]) are used. It can be seen that a searching step of Δt or $1.5\Delta t$ does not allow to find the

better alignment. Values of $0.1\Delta t$ or $0.4\Delta t$ allow to compute a correct absorption coefficient. A searching step of $0.01\Delta t$ does not give substantial improvements in the computation.
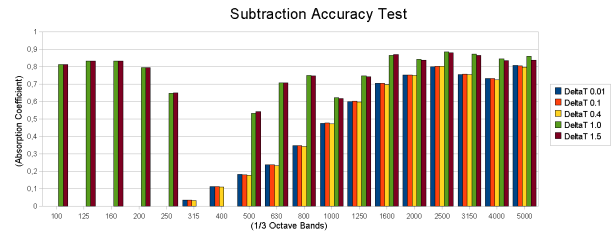

Fig. 18 – Accuracy test on time subtraction

All absorption coefficient computations performed in this work have been done with the default value of the software $0.05\Delta t$, which has been therefore proved to be suitable for this task.

5   Conclusion

The aim of this work was to describe how individual boundary conditions (small portion of specimen, small size reflective surface) may affect the computation of the absorption coefficient measured with reflection method. Some interesting results have been found: not always a longer freefield impulse response gives better results compared to a freefield impulse response measured with horizontal microphone brackets. The horizontal freefield measurement allows indeed to obtain a more accurate time subtraction. The measurements with the microphone closer to the material surface are usually less reliable and a distance of the microphone from the surface of at least 10 cm is recommended. When measuring lightweight absorbing materials, the use of a reflecting surface (both behind the material, and as reference plane) is required in most cases. The use of a heavy and small surface (in this paper the gypsumboard) does not give benefits, compared to a light and large surface, but, on the contrary, it reduces the low frequency resolution due to the reduced active surface area.

References

[1]   ISO 13472-1, Acoustics - Measurement of sound absorption properties of road surfaces in situ – Part 1: Extended surface method

[2]   P. Guidorzi , M. Garai: Sound absorption measurement using MLS method. How much is the final result affected by the non-linearities of the measurement chain? Proceedings of 19th International congress on acoustics, Madrid, 2-7 September 2007

[3]   M. Garai, P. Guidorzi: Experimental verification of the european methodology for testing noise barriers in situ: Sound Reflection. Proceedings of InterNoise 2000 (invited paper), Nice, France, 26-30 August 2000

[4]   M. Garai: Measurement of the sound-absorption coefficient in situ: the reflection method using periodic pseudorandom sequences of maximum length. Appl. Acoust., 39 (1993) 119-139