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In situ assessment of the normal incidence sound absorption coefficient of asphalt mixtures with a new impedance tube

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Abstract
Normal incidence sound absorption coefficient of materials is usually calculated with the use of an impedance tube following the ISO 10534-2 international standard. The same is applied in the evaluation of the sound absorption characteristics of pavement mixtures. In this research an impedance tube which was specifically designed to be used in field conditions has been developed. In order test the tube six asphalt slabs were constructed in laboratory and its sound absorption coefficient measured with the new impedance tube. Then, several road sections, with different types of surface, among dense asphalt layers and thin layers, namely with rubberized asphalt were tested. In this paper, some considerations are made regarding the performance of the new impedance tube and the sound absorption coefficient of each asphalt mixtures.

Keywords: Kundt-tube, asphalt, absorption.

1 Introduction

To evaluate the sound absorption characteristics of materials, several techniques are usually employed. Most popular among them are the reverberation room method, described in ISO 354:2003, which returns the value of the sound absorption coefficient in diffuse sound field. The drawback of this technique relates to the fact samples to be assessed must be present in the reverberation room, a fact sometimes proves to be impossible, or at least undesirable.
To solve this problem other techniques were developed. The spot method and the impedance tube method are examples of those techniques, which permit the *in situ* evaluation or the use of small samples of the material to be tested.

In the case of impedance tube, described in ISO 10534-1:1996 (standing wave method), and ISO 10534-2:1998 (transfer function method), it is necessary to extract a sample of the material with exact dimension of the tube utilized, fact that sometimes proves difficult, as the case of road pavements sound absorption evaluation. For this purpose, the International Organization for Standardization is developing a technique to standardize the use of an impedance tube specifically designed to evaluate the *in situ* normal incidence sound absorption coefficient of road pavements. In this paper, a prototype of such an impedance tube is presented, and details of his construction and measurements results are discussed. This kind of approach in the evaluation of sound absorption of materials has been largely studied and several papers presented. For that reason, this paper deals mostly about the construction aspects and implementation of this particular prototype.

2 Tube construction - description

The impedance tube herein discussed is an adaptation of the description in ISO 10534-2:1998 and developed according to [1]. Following their description and mathematical approach, the normal incidence sound absorption coefficient of materials can be evaluated using the complex transfer function of the pressure signals acquired by two distanced microphones, flush mounted in an impedance tube. The mentioned standard also describes a method to calibrate the microphones, both in phase and intensity, as even a minor mismatch between them would lead to errors in the final calculations. For those calculations, the distance between the microphones, the tube diameter and the distance from the microphone 1 (see Figure 1) and the material sample must be known. The tube diameter sets the frequency range of use.

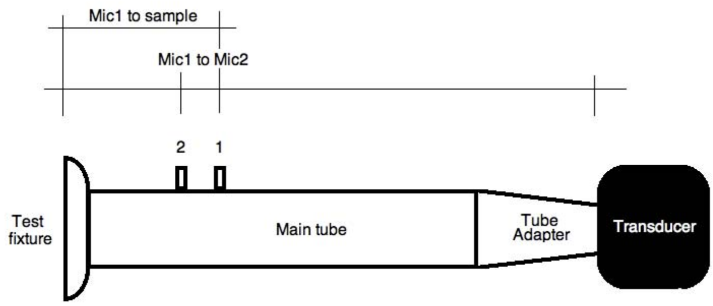


Figure 1 – Representation of the impedance tube developed.

One of the problems of the field use of these devices, particularly in road surfaces, is the impossibility of controlling external noise sources. Therefore, the signal used in the tests must have a high signal to noise ratio and the materials for the tube construction had to be carefully chosen. Furthermore, a high sensitivity compression driver was used (RCF N850), in order to improve the signal to noise ratio, and also allowing the possibility of driving easily the tube with high sound pressure levels. The driver used have a near flat frequency response between 500 Hz and 17 kHz. This led to the use of an equalized noise sound source in order to provide equal energy across all frequencies of use.

The impedance tube prototype developed for the *in situ* evaluation had in consideration the specific field conditions where it would be used. The most obvious one is the removal of the sample holder, for it wouldn't be of much use. Instead, the tube is placed directly over the surface of the pavement to be tested, through the help of a special base plate. Although several different materials compose the tube, the base plate is made of stainless steel, assuring resistance both to corrosion and mechanical damage, as it must deal with the tube weight over pavement surface (Figure 2).

Figure 2 – Detail of the impedance tube base plate

The upper frequency which is limited by the tube diameter (in this case, 80 mm) is 2500 Hz. The lower frequency usable is limited to the distance between the microphones. An increase in distance augments the certainty at lower frequencies. However, the distance between the microphones must be less than half of the wavelength of the maximum frequency used. In this particular case, a distance of 55 mm was set. Another microphone fixture is being designed in order to increase the certainty at lower frequencies. The frequency range where the tire/pavement interaction noise generation is most prominently is located in the range defined, between 350 and 2500 Hz.

The tube length, between the driver and the nearest microphone, was set to 645 mm. According to ISO 10534-2:1998, a minimum distance of 3 tube diameters must be used to assure a flat wave front. The main tube was made from a 600 mm length, 90 mm external diameter hydraulic tube (DIN 2448/1629 steel), with 5 mm thickness walls, giving 80 mm inner diameter. This ready available material guarantees a constant diameter throughout its length with rectified and polished inner surface (maximum peak to peak inner surface rugosity of 3 µm. This type of steel is sensible to oxidation degradation, which led to the application of a chromium inner surface treatment.

The use of a compression driver as the excitation source led to the need of a diameter match between the driver and the tube, from 40 mm to 80 mm. In order to reduce the mechanical vibration propagation of the driver to the rest of the equipment, extreme care was taken; all the screws and mechanical connections were covered by policloroprene rubber, allowing both air tight connections and vibration damping (Figure 3).

Figure 3 – Details of vibration damping rubber between compression driver and diameter matching component.

Figure 4 – Diameter matching between compression driver and principal tube.

Of course, this adaptation would be not only to allow the physical connection, but also of an acoustical impedance matching. To minimize reflections or diffraction of sound waves in the adaptor, a smooth interior curve shape was machined from a solid block of aluminium – titanium alloy (Figure 4).

The microphone holders were designed to permit the use of ½ in diaphragms. This diameter was chosen only because of their direct availability by the developer team. The holders assure an air tight fixing, given the possibility of flush mounting them with ease. The fixtures used permit a high degree of mechanical isolation of the microphone body from vibrations that can occur in the tube. It mainly consists in the compression of a rubber cylinder placed around the microphone pre-amplifier body. For a correct hole drilling in the tube, the diameter of diaphragm capsule of several brands and types of class 0 and class 1 omnidirectional microphones were measured. Due to the fixing method, only back vented microphone capsules can be used. An overall view of all the parts mounted in one, can be seen in the Figure 5.

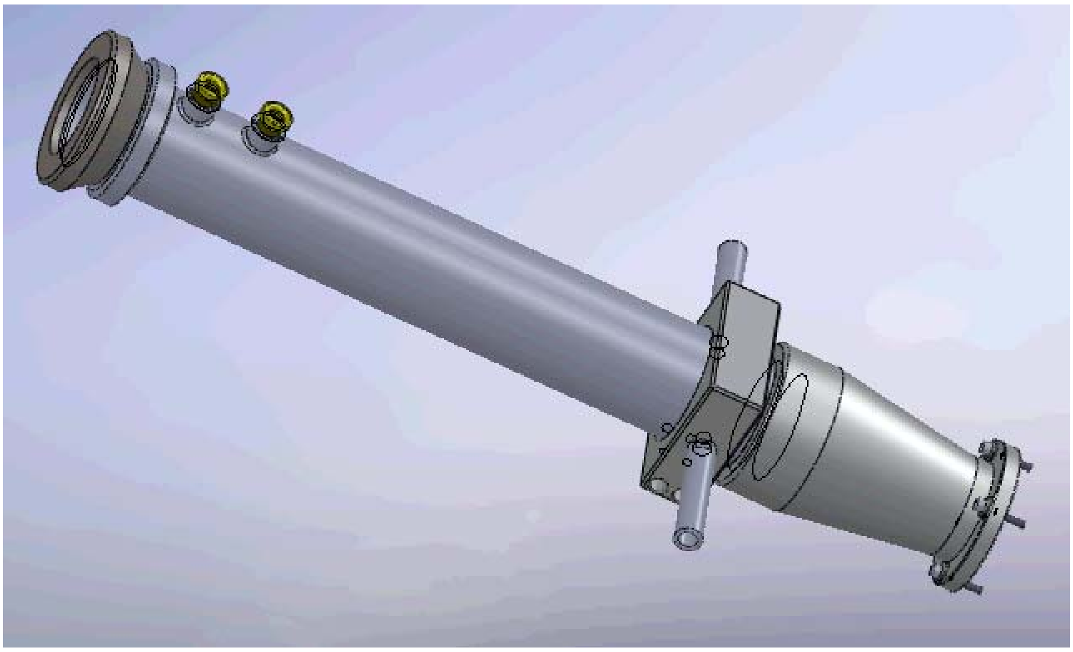


Figure 5 – Scheme of the mounted impedance tube showing its different parts.

3 Testing and measurements

The air tightness in the base-plate/asphalt surface interface was assured with the help of modelling clay. The use of petroleum jelly revealed inappropriate as the testing on sun heated asphalt can go beyond 50º C and its viscosity becomes too low to guarantee the needed consistence. All the measurements of sound pressure and frequency response were made with B&K Pulse Platform, using Type 4190 omnidirectional microphones. The normal incidence sound absorption coefficient was calculated with the use of WinMLS, running an ISO 10534-2:1998 measurement setup.

3.1 Self-absorption characteristics of the impedance tube

Some types of asphalt mixtures exhibits an exceptionally low normal incidence sound absorption coefficient. For that reason, the tube self absorption, despite being low, must be known, and its value corrected in the final measured results. This procedure was done by making a measurement on a flat polished heavy steel plate resulting in absorption coefficients between 0,009 and 0,04 as can be seen in Figure 6.

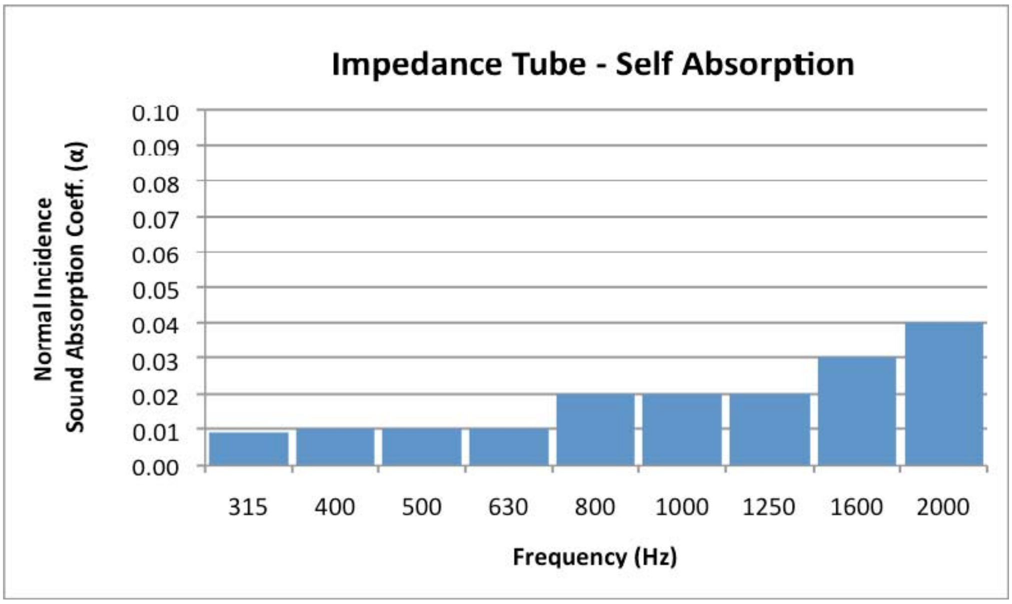


Figure 6: Measured Self Absorption with reflective surface

3.2 Sound isolation characteristics of the impedance tube

To evaluate the sound isolation of the tube, the microphone fixture 1 was closed and a microphone was placed in the fixture 2. The impedance tube was positioned in measurement position, with the test fixture isolated against the floor with modelling clay. A second microphone was then placed outside the tube, one meter apart and one meter high from the floor. Neither walls nor obstacles surrounded the equipment in a 3 meters radius. The impedance tube compression driver was driven with white noise, and the responses of both microphones recorded simultaneously. While the inside microphone measured a sound pressure level of 119 dB, the outside one measured 55.1 dB. The 1/3 octave band frequency responses can be seen in Figures 7 and 8.

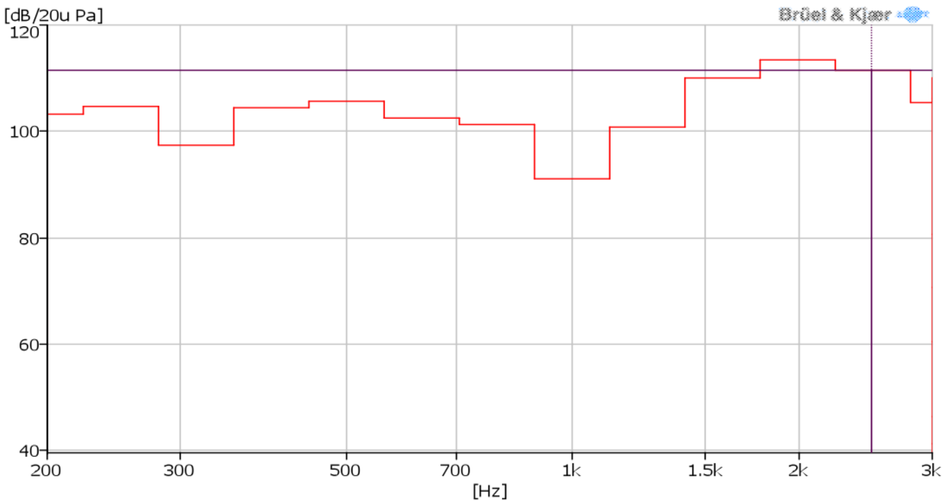


Figure 7: 1/3 octave band frequency response inside the tube with compression driver on.

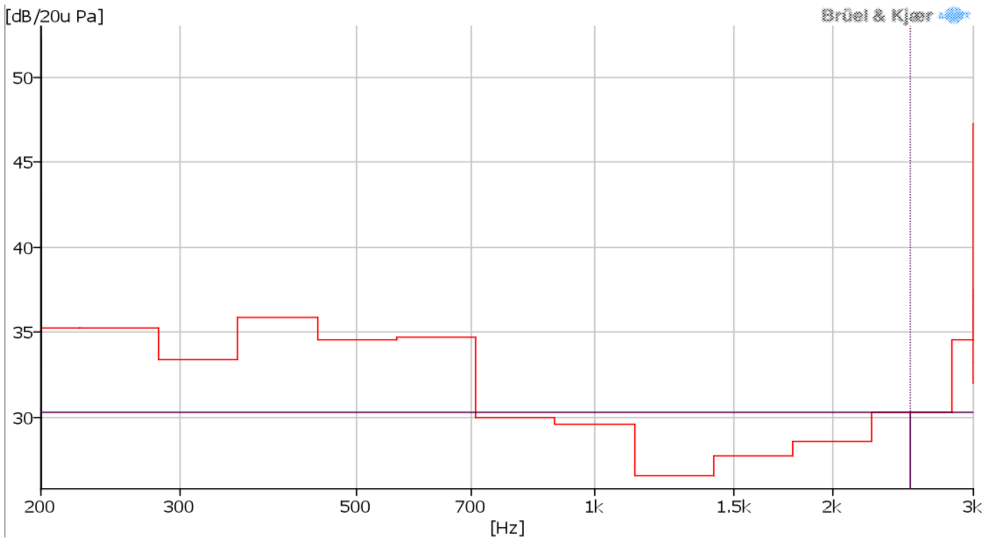
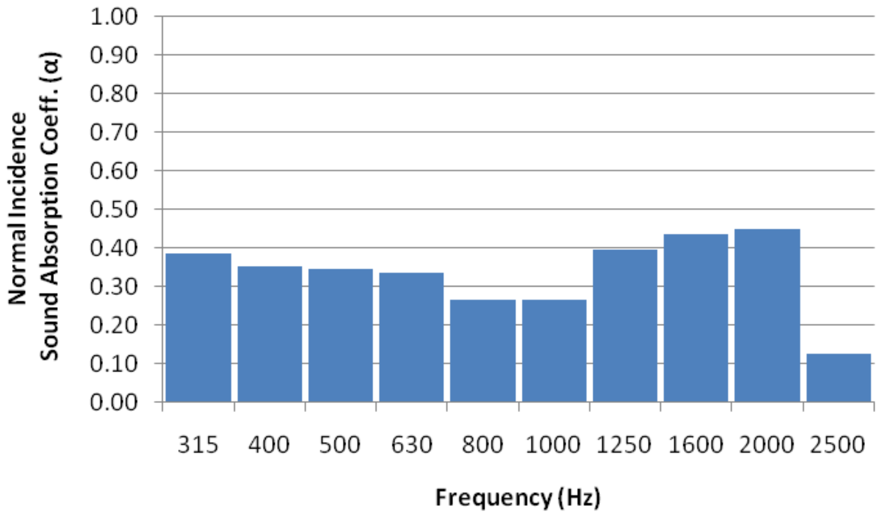


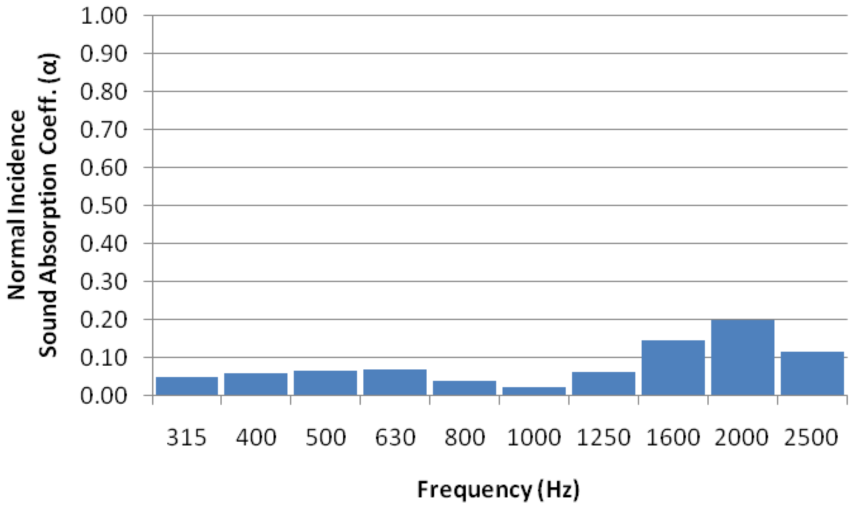
Figure 8: 1/3 octave band frequency response outside the tube with compression driver on.

3.3 Preliminary results in asphalt mixtures

Figures 9 and 10 present the measured normal incidence sound absorption coefficient of two asphalt mixtures. The first consists of a Gap Graded Asphalt, with medium air voids (18%), and the second a Rough Asphalt, with low air voids (less than 5%). Each one of these types of mixtures has a 50/70 base binder. The thickness of the measured slabs is 80 mm. For the data treatment, the self absorption coefficient of the tube were subtracted from the samples measured values, and averaged from 5 different position measurements (of the same slab).



Figures 9 – Gap Graded Asphalt, with medium air voids (18%).



Figures 10 – Rough Asphalt, with low air voids (less than 5%).

4 Conclusions and final remarks

The development of the new impedance tube allows an adequate evaluation of the sound absorption characteristics of asphalt mixtures measured *in situ*. This new approach, with the use of the transfer function method, allows for a quick evaluation of the normal incidence sound absorption coefficient, at various sound pressure levels, assuring excellent signal to noise ratios. Nevertheless, it must be noted that, due to the physical dimensions of the tube itself, only the frequency range presented, 350 Hz to 2500Hz, is of good use covering the noise tire/pavement interaction generated noise.

The sound absorption values obtained in the preliminary tests show good agreement with the expected for this type of pavements [7]. In the future, measurements will be made in standardized impedance tubes in order to validate the results. Also, measurements of different surfaces with different mixture contents will be made, with different excitation signals, at higher and lower sound pressure levels.

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