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Sound absorption coefficient of wet gap graded asphalt mixtures

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Abstract
Acoustic absorption properties of materials have often been used to reduce the generation and propagation of sound. The research carried out in this paper deals with sound absorption in relation to road surface layers. As the presence of water affects significantly the noise generated by the tyre-road contact, an evaluation of the sound absorption coefficient was made to several wet gap-graded mixtures with different levels of porosity and different contents of rubberized asphalt bitumen. A vacuum device was used to soak the interstices of the cores with water, which were then tested by means of an impedance tube, according with standard ISO 10534-2:1998. It was found that the values of the normal incidence sound absorption coefficient became smeared over the frequency spectrum in comparison with dry samples and that the quantity of rubber in the asphalt bitumen affected the way water fills the cores and, consequently, its sound absorption characteristics.

Keywords: absorption, water, tyre-road noise, rubberized asphalt.

1 Introduction

The reduction of noise resulting from the interaction between tyres and road surface is an old issue which gained new relevance recently. It is a consequence of the traffic growth and of the inevitable approximation of high-speed carriageways to the population.

The tyre-surface noise is a component of the total noise produced by vehicles, which prevails over the others for speeds from approximately 40 km/h [1] up to 110 km/h. The generation mechanisms depend, amongst other parameters, on surface characteristics such as aggregate gradation, texture, porosity, age, stiffness and distresses. Porous surfaces are very popular for traffic noise reduction due to their aptitude to absorb noise. They can reduce up to 6 dB(A) as opposed to a conventional layer.

On porous roads, sound energy is absorbed by the surface due to its porosity. Sound waves enter the upper layer of the road surface and are partly reflected and partly absorbed. The sound energy of the absorbed part is transformed into another type of energy. In roads this is mainly due to two effects: 1) by viscous losses as the pressure wave pumps air in and out of the cavities in the road; 2) by thermal elastic damping [2].

Noise absorption is influenced by road characteristics other than porosity, such as thickness of the porous layer and flow resistivity (which can be indirectly determined by the stone grading). Furthermore, the absorption is influenced by the angle of incidence of the sound waves on the road surface.

To achieve maximum reduction of traffic noise, it is important to adjust the sound absorption properties of the road surface to the traffic composition. To assess, evaluate and optimise the sound absorption properties of road surfaces, it is necessary to perform sound absorption measurements [2].

The work presented herein is a part of one task of the ongoing project Noiseless - *Noise perception, modelling and abatement using innovative and durable pavement surface layers*. This task aims to characterize the absorption of all road pavement surfaces used in Portugal using the available and ongoing test methods.

Because surfaces made of asphalt rubber are currently the option most often used either in new or in rehabilitated pavements in Portugal, this work deals with those surfaces. Therefore, two types of gap graded mixtures were chosen, one with medium air voids (18%) and another with low air voids (less than 5%). The mixtures were made in laboratory with two types of rubberized asphalt binders: a) with high and medium percentage of rubber; b) with a "normal" asphalt binder. Six slabs were constructed from where 72 cores were extracted and tested in the Kundt's tube both with dry and water saturated cores. This procedure allowed not only assessing the effect of rubber on noise absorption, but also the effect of porosity, core thickness and wetness. This paper relates solely to the water saturated cores, and the way the water inside the voids of the mixture affects the normal incidence sound absorption coefficient.

2 Methods to measure the sound absorption of road surfaces

Sound absorption of road surfaces can be measured in various ways considering their characteristics. Each method may be applied for specific purposes. In what respects to their applicability they can be used either in laboratory, such has the Impedance Tube Method, or *in situ,* such as the Extended Surface Method and the Spot Method.

In the Impedance Tube Method, standing waves are created within a tube which contains a test sample, using a loudspeaker (radiating pure tones, sine sweeps, MLS sequences, etc.). Using the pure tone method, the maximums and minimums of the sound pressure in the tube are measured by using a microphone that can be moved along the length of the impedance tube. The standing wave ratio (SWR), i.e. the ratio of sound pressure maximums and minimums, is used to determine the sound absorption coefficient of the test sample at certain frequencies. Another most recent version of the impedance tube method utilizes the two microphone arrangement, in which the sound absorption characteristics are obtained from the frequency response between both microphones. It is commonly accepted that this method ensures circa 100 times faster results [3].

The Extended Surface Method [4] consists of a system composed of a sound source and a microphone at a fixed position from the sound source, which is placed over the road surface under test, or installed in a vehicle. It is based on free-field propagation of the test signal from the source to the road surface and back to the receiver, and covers an area of approximately 3 m^2. By means of a time window, the contributions of both the direct and the reflected sound are separated, and the sound absorption coefficient is calculated in one-third octave bands, from 250 Hz to 4 kHz. This method is appropriate for surfaces with a substantial sound absorption, such as porous asphalt surfaces [5].

The Spot Method is an *in-situ* method in all similar to the Impedance Tube Method. In this case the two microphone arrangement is used. A sound signal from a loudspeaker located at one end propagates through the tube. The open end of the tube is placed on the surface to be measured. The complex acoustic transfer function of the two microphone signals is determined and used to compute the normal-incidence sound absorption coefficient. This method is still being worked on to be used on surfaces of which sound absorption is relatively low, but must be measured or controlled [5].

The Impedance Tube Method has the disadvantage of requiring the extraction of samples while the others, like the Spot or the Extended Surface Method, require traffic control.

The direct result of all methods is the sound absorption coefficient as a function of frequency. The typical absorption curves are characterized by:

- α_{max}: the value at which the measured absorption curve reaches its first maximum. It is related to the porosity and flow resistivity of the absorbing material;
- $f_{\alpha,max}$: the frequency at which the measured absorption curve reaches its first maximum. It is defined by the effective layer thickness of the material (given by the actual layer thickness and the tortuosity) [2].

3 Study

3.1 Methodology

For the analysis of the effect of water on sound absorption, 6 slabs were constructed in laboratory. Each slab results from the combination of 2 types of gap graded mixtures and 3 types of asphalt bitumen. One mixture (GA) is characterized by a relatively high void content (18%) and the other (RA) by a low void content (less than 5%). The bitumens were characterized by high, medium and a zero percentage of rubber.

From each slab, 12 cylindrical samples with a diameter of 59 mm and 79 mm of thickness were extracted for acoustical analysis. Half of the samples were machine-cut to get 6 samples 30 mm thick (Figure 1 - a).

To saturate the samples with water and, in this way, simulate the conditions of a road pavement after strong rain, a picnometer filled with water was used. The vacuum pressure descendance and ascendance was controlled in order to prevent deformation of the samples, due to the fast removal of enclosed air spaces.

To evaluate the normal incidence sound absorption coefficient of the mixtures, an impedance tube with 60 mm diameter and two microphones placed 45 mm apart were used. Due to the samples roughness and the presence of water in the core, the distance adopted between the first microphone and the sample was 100 mm (about 1½ tube diameters). The impedance tube diameter and aforementioned characteristics imply a valid measurement frequency range between 250Hz to 3300Hz, covering the tyre-road noise generation frequency range between 500Hz and 2000 Hz.

The excitation signal used in the tube was provided by a MLS (maximum-length sequence) signal. According to ISO 10534-2:1998 [6], the microphones were calibrated before testing, both in phase and intensity, by using a 100 mm thick mineral wool cylinder placed in the sample holder. Also, and because of the naturally low absorption coefficient of asphalt layers, a calibration procedure was made in order to subtract the tube's self absorption to the final absorption. This value, despite of marginal quantity, would increment to the real absorption coefficient of the asphalt being measured. After these actions, all samples were submitted to the procedures explained below.

a) b)

Figure 1 – Core extracted from slabs used for testing (a). Kundt's tube used to measure absorption (b)

For wet conditions the following the procedure was adopted:

1. The air and water temperature were measured;
2. The samples were immersed for 10 minutes inside a picnometer in order to fill with water the air interstices. The pressure was kept always above 50mBar and below 100mBar. Both the air extraction and the nominal air pressure stabilization occurred for 15 minutes.
3. The samples were kept inside a recipient filled with water. This recipient was placed under the suspended impedance tube (Figure 1 - b);
4. One at a time, each sample was removed from the water container and placed over absorbing paper for 30 seconds;
5. The sample was put in the sample older of the impedance tube, which fitted snugly inside, and the measurement was made. Both the air and water temperature was kept constant under the range of 22ºC (+- 2) during all the described procedures.

3.2 Mixtures properties

The gap graded mixtures addressed in this study were formulated according to the European Standards. One of the mixtures is designated by GA (Gap graded Asphalt), with medium air voids (18%), and the other by RA (Rough Asphalt), with low air voids (less than 5%). Each one of these types of mixture was also formulated for a 50/70 base binder, which was modified with two percentages rubber (by asphalt weight): a) high percentage (hR%) - 18%; b) medium percentage (mR%) - 10%. For comparison purposes, two additional mixtures were formulated with the base binder. In the formulation procedure, aggregate grading, bitumen content and void content were kept the same for both mixtures as much as possible (Table 1 and Figure 2). The main differences between each mixture of the same type, which respect to the aggregate grading and the bitumen percentage, are a consequence of the need to "accommodate" the rubber.

The porosity actually achieved according to EN 12697-6 for each core is depicted in Table 2. As it can be observed there are differences between the porosity of the cores in the same slab that can reach 2%. It is a consequence of the compaction procedure. Furthermore, the 30 mm thick cores have generally a higher porosity despite the fact of being cored from the same slab as the 79 mm thick ones. That difference is a consequence of the rough surface of the cores.

Table 1 – Properties of the mixtures.

Sieve size (mm)	High rubber percentage (hR%)		Medium rubber percentage (mR%)		No rubber	
	GA	RA	GA	RA	GA	RA
14	100.0	100.0	100.0	100.0	100.0	100.0
10	90.1	87.9	87.3	90.3	87.3	90.3
8	76.3	73.4	72.3	77.7	72.3	77.7
4	23.8	25.5	24.6	36.3	24.6	36.3
2	9.9	17.3	18.5	28.1	18.5	28.1
0.5	6.8	10.7	11.5	17.7	11.5	17.7
0.063	3.7	4.6	5.2	8.3	5.2	8.3
Bitumen content (%)	8.5	8.5	7.0	7.0	7.0	7.0
Rubber content (%) (asphalt weight)	18	18	10	10	0	0
Fibber content (%)	0.0	0.0	0.3	0.3	0.5	0.5

Table 2 – Porosity of the cores.

	Core	High rubber percentage (hR%)		Medium rubber percentage (mR%)		No rubber	
		79 mm	30 mm	79 mm	30 mm	79 mm	30 mm
Gap Graded asphalt	1	16.2	21.0	15.0	17.0	14.7	17.7
	2	15.8	20.3	15.0	18.8	14.3	18.8
	3	16.6	18.0	15.5	18.8	16.4	18.2
	4	16.9	19.4	13.7	18.4	15.2	17.4
	5	16.5	21.0	14.8	18.5	15.9	19.5
	6	16.5	20.9	14.7	16.0	16.3	18.7
	Average	**16.4**	**20.1**	**14.8**	**17.9**	**15.5**	**18.4**
Rough asphalt	1	4.8	7.4	3.5	3.7	2.8	2.6
	2	5.4	6.8	4.5	4.6	3.2	2.5
	3	4.5	6.5	3.0	3.9	2.4	2.5
	4	4.6	6.5	3.0	4.5	1.3	1.9
	5	4.4	5.9	3.4	3.8	1.5	2.2
	6	4.6	6.4	2.6	4.1	1.8	2.1
	Average	**4.7**	**6.6**	**3.3**	**4.1**	**2.2**	**2.3**

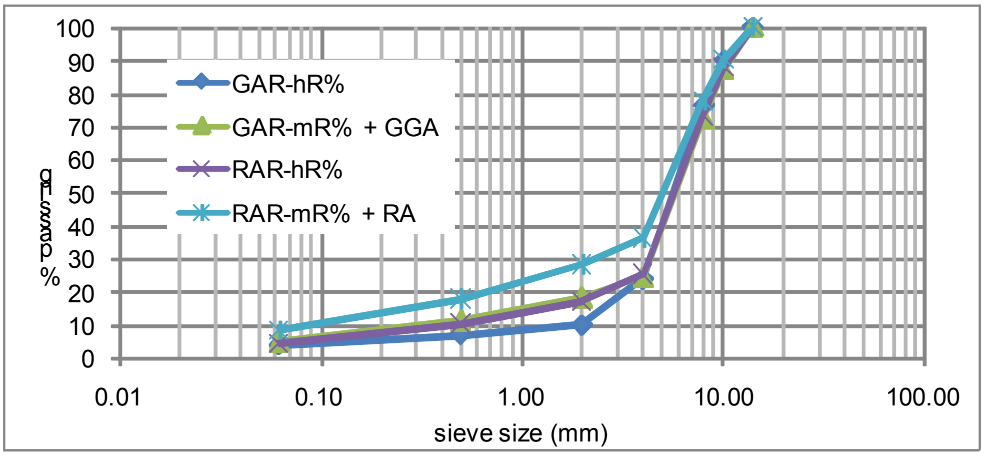


Figure 2: Grading curves of asphalt mixtures.

4 Results and analysis

The results obtained from the impedance tube measurements on the 30 mm and 79 mm wet samples are described in the following paragraphs.

The different volumes of the air voids and the orientation of the aggregate (due to the conformation procedure and aggregate size composition) result in different resonant frequencies of these small "air chambers" which are clearly visible in the curves represented in Figure 3 and 4. The results gathered from all the samples showed that cores taken from the same slab presented distinct sound absorption characteristics. Due to the conformation procedure in making the different mixture slabs, the variance of the density and percentage of air voids along the slab surface is inevitable. Since we're dealing with porous surfaces, they exhibit a natural condition to retain water inside its cavities. In case of rain weather conditions, the empty spaces will be filled with water. This will, therefore, alter the sound absorption characteristics, as the water entraps the air voids or, at least, reduce their volume.

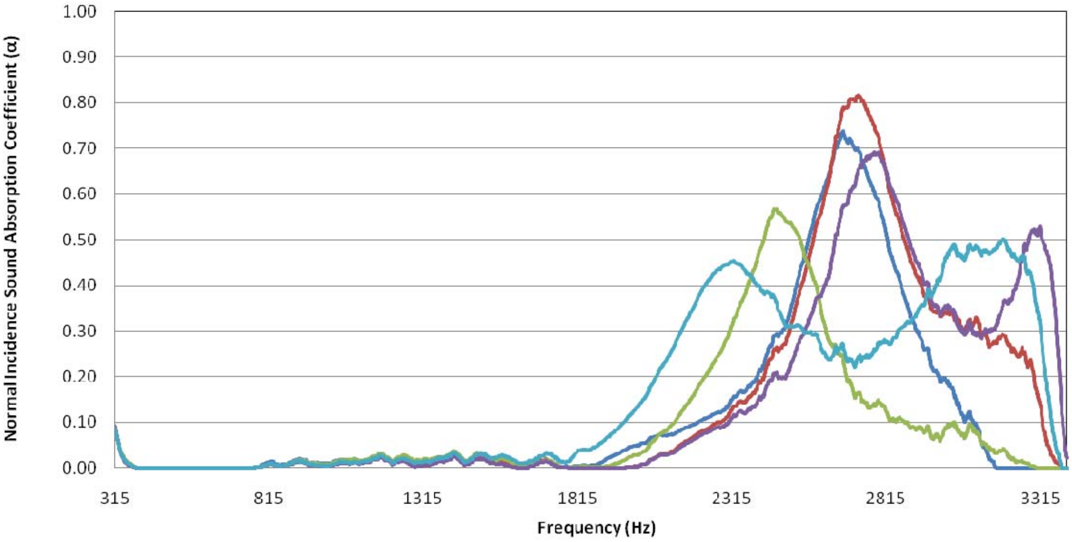


Figure 3: Wet cores with 10% rubber content and 4.1% medium air voids.

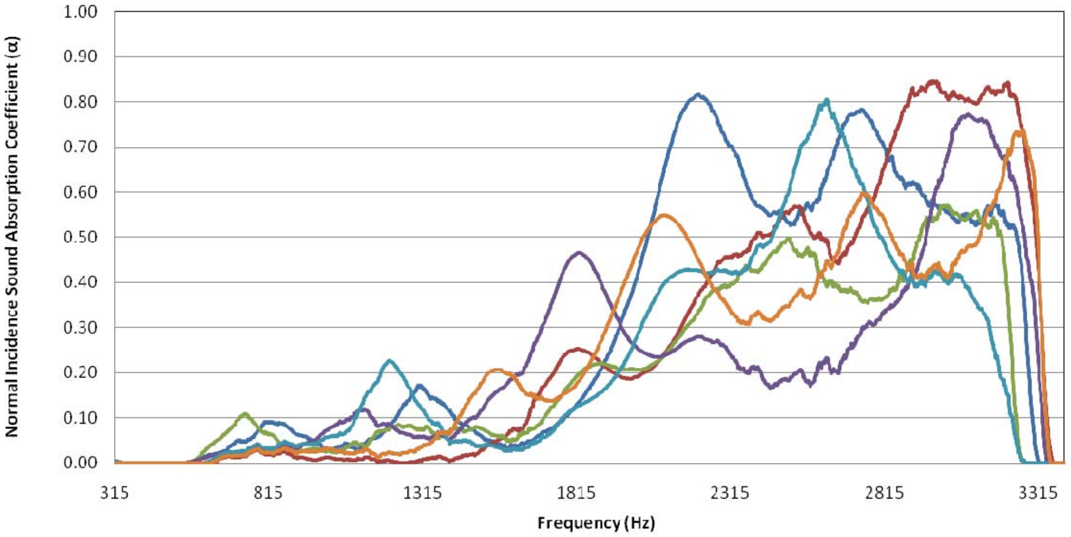


Figure 4: Wet cores with 10% rubber content and 17.9% medium air voids.

These differences, however, follow a trend since cores with the same percentage of air voids have also different sound absorption characteristics. As reported by other authors, this is probably due, to the shape and texture of the different cores at the most upper layers. Considering that the same slab has non-uniform absorption characteristics over its surface it was decided to arithmetically average the different absorption curves into a single representation of the whole slab. This is depicted in Figure 5 for the same percentages of air voids as in Figure 4.

Figures 6 and 7 present the results of the normal incidence sound absorption coefficient obtained from all the samples, in 1/3 octave bands. Figure 65 relates to 30 mm thickness samples and Figure 7 to 79 mm samples.

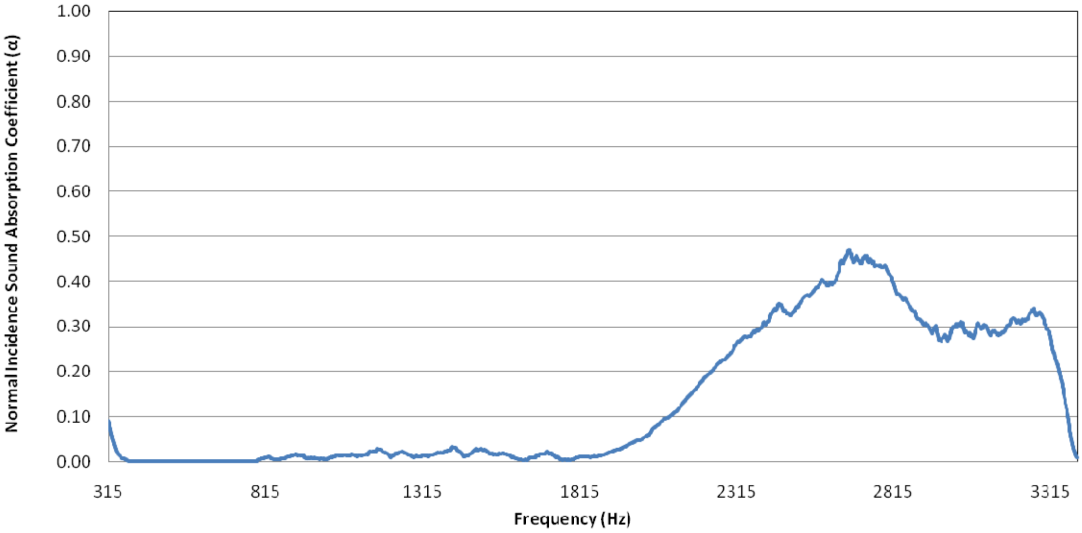


Figure 4: Average values from 6 samples depicted in Figure 3. Wet cores with 10% rubber content and 4.1% medium air voids.

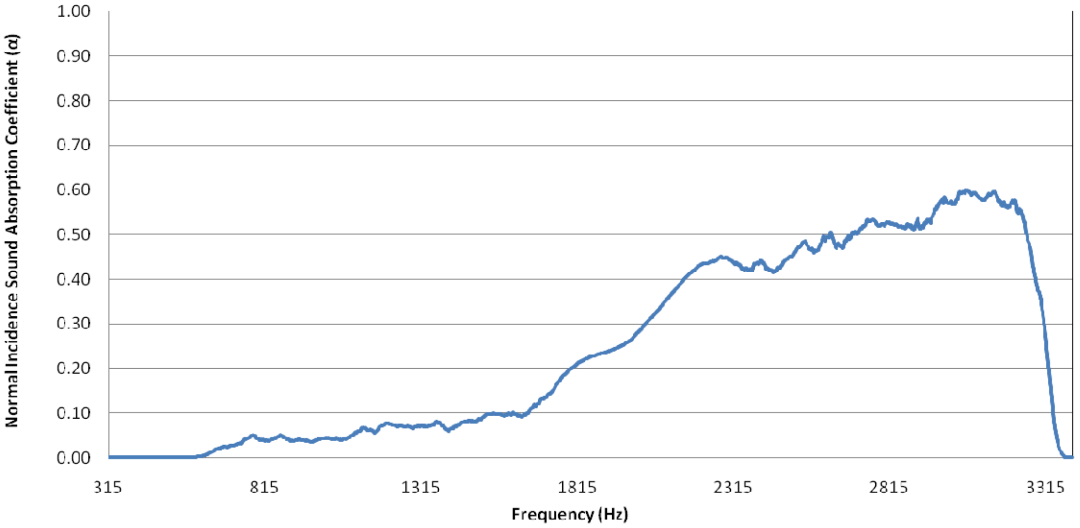
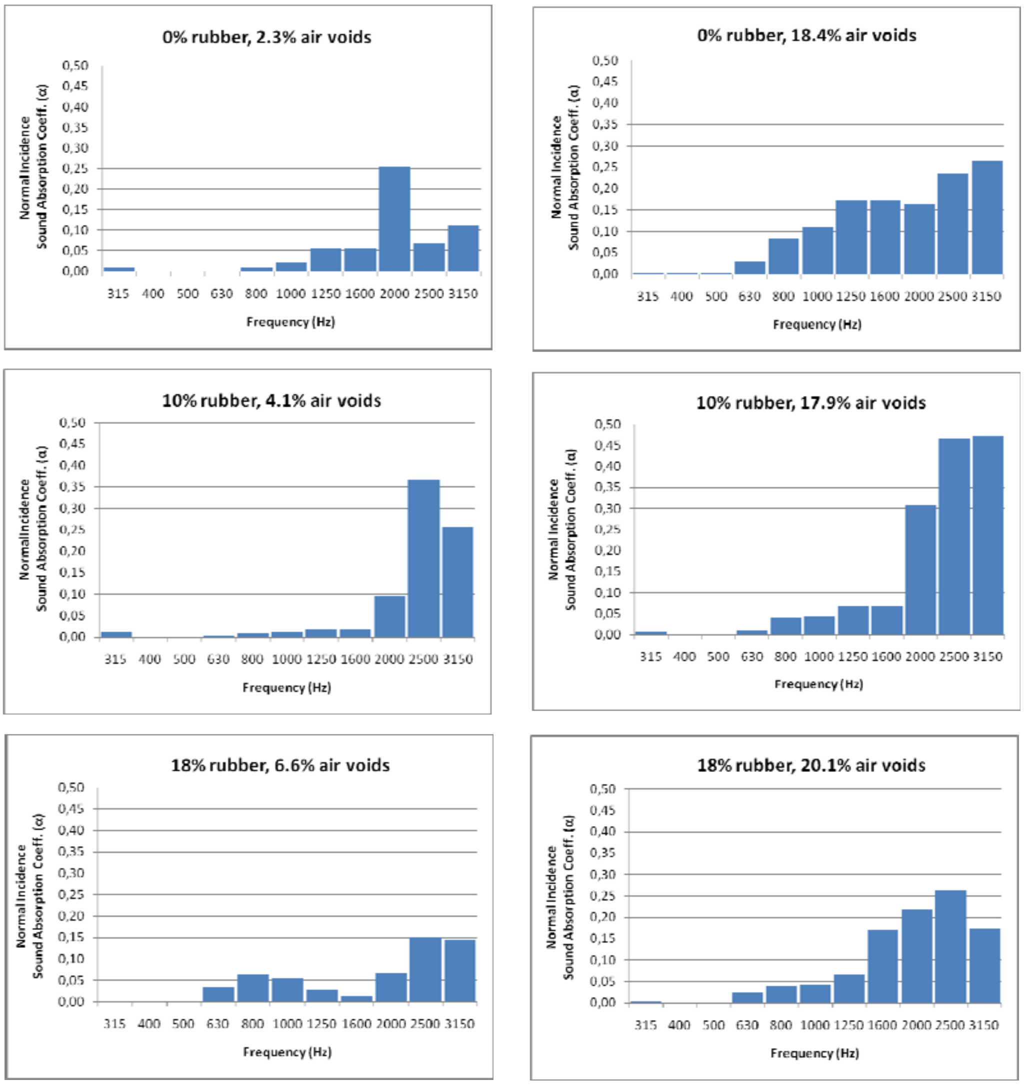
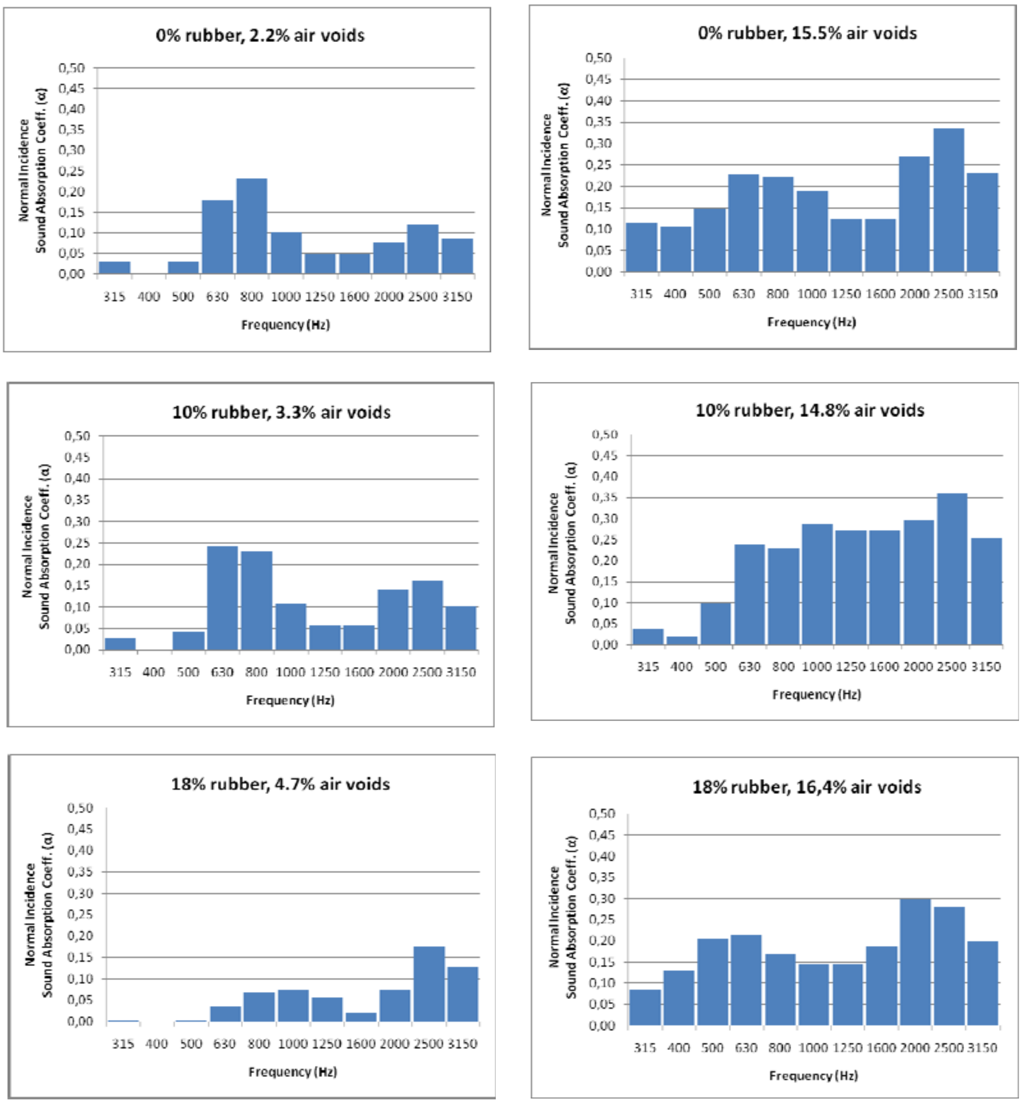


Figure 5: Average values from 6 samples depicted in Figure 3. Wet cores with 10% rubber content and 17.9% medium air voids.



a) b)

Figure 6: 1/3 octave band normal incidence sound absorption coefficient for 30 mm thickness cores with 0%, 10% and 18% rubber content and different average porosities: a) low average air voids; b) high average air voids.



a) b)

Figure 7: 1/3 octave band normal incidence sound absorption coefficient for 80 mm thickness cores with 0%, 10% and 18% rubber content and different average porosities: a) low average air voids; b) high average air voids.

From the normal incidence sound absorption coefficient values shown, it can be seen that a thickness increase does not lead to an increment in the overall absorption coefficient because of the high compaction of the mixture, but in the 30 mm cores, the absorption peaks reach higher values at narrow frequency ranges. Nevertheless, the absorption peaks differ from the 30 mm to 80 mm cores. The first occur in the range of 2500 Hz, and the second in the range of 630 Hz to 800 Hz. From a global appreciation, and as expected, an increase in the air voids percentage, leads to a greater absorption. It can be seen that the medium percentage rubber addition, of 10 %, led to a greater absorption coefficient.

Figures 8(a) and 8(b) show a comparison between results obtained from wet and dry samples (see [7]). The results pertain to samples of rubberized asphalt with contrasting rubber contents but with similar air voids percentage. In both situations, the presence of water implies a considerable decrease of the absorption characteristics particularly in the frequency range of maximum absorption of the dry samples. This fact is most probably related to the fact that the presence of water in the interstices between granulates stops the absorption mechanisms due to tortuosity and air flow resistivity within the material.

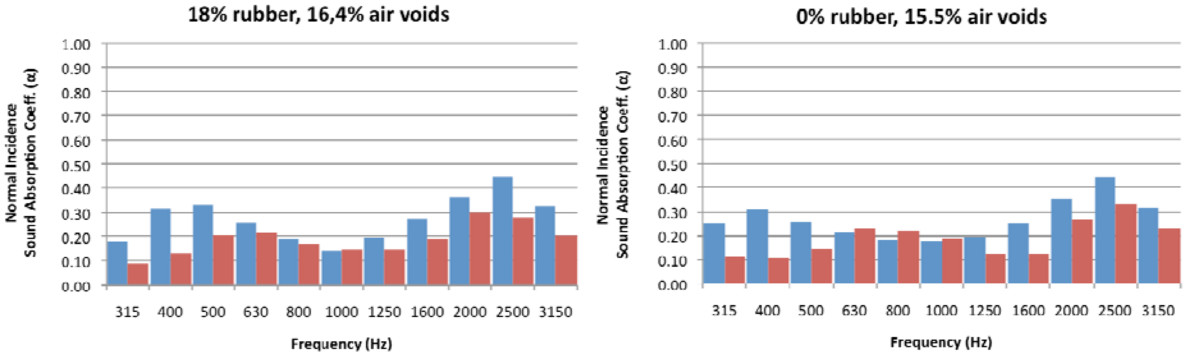


Figure 8: 1/3 octave band normal incidence sound absorption coefficient for 80 mm thickness cores with different moisture content (a) 18% rubber content and 16,4 % air voids and (b) 0% rubber content and 15,5 % air voids: Blue – Dry samples; Red – Wet samples.

5 Conclusions

In this paper, the impedance tube method was used to evaluate the normal incidence sound absorption coefficient in wet gap graded asphalt mixtures with modified binder and in porous asphalt. In order to study the effect of the rubberized asphalt and porosity in wet samples, mixtures with different rubber contents and air voids percentage were immersed in water. Two different thicknesses of the cores were tested, 30 mm and 80 mm, which showed quite distinct behaviour, mainly in what respects to the sound absorption coefficient frequency distribution. As expected, also in wet samples, higher thicknesses enabled much better absorption at lower frequencies in contrast with thinner cores. Lower density samples showed higher sound absorption coefficients than the higher density ones. When comparing with dry samples, the wet cores showed a clear decrease of the sound absorption coefficient mainly in the frequency range of maximum absorption of the dry samples

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