Review of the acoustic property of the open graded friction course (OGFC)

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Abstract

The road noise, resulting from the accumulation of noise emissions of vehicles, currently constitutes a serious problem of environmental quality. In order to expand the studies on the pavement using a coating with OGFC, in southern Brazil, it is aimed to check the acoustics functional properties of the layer, which were performed by laboratory test of five type of OGFC mixtures and compared with two conventional blends of asphalt concrete (AC) - (range B and C). Then, was performed in the laboratory the characterization of materials for molding of the test specimens following the Marshall methodology of asphalt mixtures and selection of grain sizes. The asphalt cements oil (CAP) used were binder CAP 60/85 and CAP 55/75. The sound absorption tests were conducted according to the procedure specified in ISO 10534-2:1998, and was performed in a impedance tube at ambient temperature. Also, a metal mold was used at the end of the tube to represent a rigid termination, where the sample was inserted. So, were generated graphics of sound absorption coefficient versus frequency domain for each tested specimen. The noise reduction coefficient (NRC) was calculated for each sample too, following the ASTM C 423. Thus, the OGFC samples showed major mean absorption than AC samples, where 5 types of OGFC had their NRC results between 0.25 and 0.35. In other hand, the dense mixed sample (range B and C) gave a NRC result of 0.20. Therefore, is proved that the use of porous asphalt mixtures as coating has demonstrated some advantages with regard to reduction of noise generated by the tire-pavement interaction.

Keywords: Open Graded Friction Course. Environmental Noise. Road Noise. Laboratory Tests.
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1 Introduction

The wide variety of noises coming from different industrialized and urbanized everyday processes is a matter of concern, not only the state bodies as society as a whole. Being a strong kind of environmental pollution, which is reaching directly each time more people around the world, the road traffic is considered its biggest contributor [1]. One way to mitigate the problem is the investigation of materials that form the pavement, looking for measures aimed at the safety and comfort of the user, as well as for people who are in its proximity.

The development of new types of coatings, that seeks to enable the removal of water on the track, as soon as possible, and in this context that comes up the open graded friction course (OGFC), which has as its aim to expand the studies concerning the paving draining in the southern region of Brazil, and still, achieve the objectives of this research, which was intended to verify the functional acoustic property of coating layer of type OGFC.

Therefore, it was established a program of laboratory tests in order to check the performance of five types of OGFC mixtures and compared with two conventional blends of asphalt concrete (AC) - (range B and C). Through these tests it were able to ascertain the functional acoustic properties of each type of blend.

The research methodology was entitled to materials and procedures used. It was performed in the laboratory the characterization of materials for moulding of specimens of asphalt mixtures and selection of grain sizes. The aggregates used in this research are from crushing process and the CAPs used were the CAP 60/85 and the CAP 55/75. So, it was made the specimens of asphalt mixtures of OGFC and AC type (range B and C the DNIT), using the Marshall methodology [2].

And, finally, there was the sound absorption test, with the purpose of measuring the sound absorption in all specimens molded to mixtures of OGFC and AC, using the method of impedance tube through the ISO 10534-2 [3] and ASTM-E1050 [4].

2 Open graded friction course

The prolonged exposure to road noise is related to an increase in diseases associated to environmental noise. In this way, it seeks to develop materials for evaluation and correction of environmental noise to reduce these impacts.

There are several types of asphalt mixtures, including asphalt mixture of type open graded friction course (OGFC), which features some particularities to obtain and own characteristics when in use, as the acoustic absorption.

According to the DNER-386/99 [5], OGFC is a type of material used as a coating on highways, which is a selection process characteristic of aggregates that cause the asphalt mass a particle size composition open and high empty index (18% to 25%) after compression. This high empty index is precisely what enables asphalt porous submit their noise attenuation characteristics.
The first open graded friction course was developed from experiments conducted in the United States, being subsequently transferred this technique of application for Japan and Europe (France, Netherlands, Spain, Italy, Portugal). At first, the OGFC is designed to reduce the risk of aquaplaning, eliminate the phenomenon of mirroring and increase adhesion between tire and pavement. However, there was also a reduction of noise generated by the tire-pavement interaction [6]. And, even if it have not been developed for this purpose, this type of asphalt coating is efficient in the process of absorption by the fact of presenting a high percentage of voids in the blend.

However, although the OGFC coating seem effective, yet pose problems as reduced durability and, over time, suffer a reduction in permeability with consequent increase of the noise. Furthermore, in regard to the reduction of noise, the effectiveness of draining layers can be even more committed in the presence of water. The value of increased noise, in these conditions, may determine a change in the current superficial layers selection method in new paviments, or rehabilitated pavements.

### 3 Methodology

The tests for the determination of the coefficient of sound absorption in impedance tube, by transfer function method with two microphones, were conducted in accordance with the procedure specified in ISO 10534-2 [3] and ASTM-E1050 [4]. The working principle and the equation is based on the flat wave propagation along the tube and the measurement of the sound pressure transfer in two different positions.

This test was conducted in an impedance tube made in acoustic engineering laboratory Federal University of Santa Maria, having diameter equal to 103 mm, with approximately 2.60 m long, with an 80 mm distance between the microphones and 406 mm between the microphone further away and the sample. Also, was used a metallic mold of 120 mm, height 110 mm in diameter and 80 mm deep at the end of the tube, where the sample was inserted (Figure 1).

![Low frequency impedance tube](image)

**Figura 1: Low frequency impedance tube**

Still, equipments as shown in Table 1 were used for the analysis.
Table 1: Equipment used

<table>
<thead>
<tr>
<th>Item</th>
<th>Description of the equipment used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Signal Analyzer B &amp; K Pulse-3160-042, 4 input channels and output 2</td>
</tr>
<tr>
<td>2</td>
<td>Compaq laptop with Software Pulse LabShop 15</td>
</tr>
<tr>
<td>3</td>
<td>B&amp;K Power Amplifier 2732</td>
</tr>
<tr>
<td>4</td>
<td>2 Diffuse Field Microphones, 1/2 &quot;model B&amp;K-4942-021</td>
</tr>
<tr>
<td>5</td>
<td>B&amp;K microphones calibrator 4231, 94 dB-1 kHz</td>
</tr>
<tr>
<td>6</td>
<td>Low Frequency Impedance tube</td>
</tr>
<tr>
<td>7</td>
<td>Starfer digital caliper, 0-150 mm</td>
</tr>
<tr>
<td>8</td>
<td>Digital Thermo-hygrometer Acepl</td>
</tr>
</tbody>
</table>

Complete the assembly instrumentation, stood the material inside at one end, so that one of its sides stayed in contact with rigid metallic mold ending. Then, arose a white noise (random feature), and measure the sound pressure in the two previously established positions.

It is worth mentioning that were placed in the surroundings of all samples, insulating tape so that the samples fit perfectly into the holder, sealing the 1 mm gap between the tube and the sample. For the carrying out of the tests, the microphones were calibrated before each measurement day. The Figure 2 helps to understand the procedures described.

Figure 2: Detail of insulating tape and placing the sample on metal support in the impedance tube

For the procedure of calculation of surface impedances, first obtained the frequency response function between the pressure in microphone 2, closest to the sample, and the microphone 1, given by:

$$ H_{12}(f) = \frac{p_{\text{mic2}}}{p_{\text{mic1}}} $$

(1)

This procedure was performed for the impedance tube, according to their working frequency range. The reflection coefficient is given by equation 2 [3,4]:

$$ R = \frac{H_{12}^* - e^{-jkS_1}}{e^{jkS_1} - H_{12}^* e^{2jkx_1}} $$

(2)
In that, \( x_1 \) is the distance between the surface of the sample and the microphone further away. The term with asterisk \((H_{12}^*)\) refers to the amplitude and phase correction of the frequency response, which will be reviewed at the next. Visco thermal losses in the wall of the tube can be seen in the number of complex Wave Equation 3 [3]:

\[
\tilde{k} = k_o - \frac{0.0194\sqrt{f}}{c_o d} j,
\]

(3)

Being \( k_o = \omega / c_o \) the wavenumber, the normal surface impedance is then calculated as follows [7]:

\[
\tilde{Z}_s = \frac{\rho_o c_o (1 + R)}{1 - R},
\]

(4)

The normal incidence absorption coefficient is:

\[
\alpha_n = 1 - |R|^2.
\]

(5)

Because of the possible differences of amplitude and phase between the microphones, it is necessary to perform a correction as described in ISO 10534-2 [3]. This amplitude and phase correction was performed through the exchange between the positions of the microphones, for each sample measurement. First, they measured the setting I (default), obtaining the transfer function, according to equation (1).

Then, reversed the positions of the microphones, calculating the new transfer function \( H_{12}^{II} \) for setting II (reversed), in the same direction channels.

\[
H_{12}^{II} = \frac{p_{mic2}}{p_{mic1}}.
\]

(6)

It was noted, that the signal analyzer channels have not changed, only the position of the microphones.

The new transfer function with stages corrected \( H_{12}^* \) is given by:

\[
H_{12}^* = (H_{12}^I/H_{12}^{II})^{1/2}.
\]

(7)

Given this, were done the sound absorption tests according to Table 2. In 6 samples, each binder content, of five mixtures of OGFC and two mixes AC, totaling 132 specimens. The results of the calculations of sound absorption coefficients presented for mixtures of OGFC and conventional asphalt concrete (range B and C) were formed by the average of six samples tested under the same conditions.
Table 2: Rehearsal schedule in the case of mixtures of OGFC and AC (range B and C)

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Type of Binder</th>
<th>Sample Number</th>
<th>Binder Content (%)</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>OGFC 1</td>
<td>60/85</td>
<td>6</td>
<td>3.00%</td>
<td>Range V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>3.50%</td>
<td>(DNIT - ES 386/99)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.50%</td>
<td></td>
</tr>
<tr>
<td>OGFC 2</td>
<td>60/85</td>
<td>6</td>
<td>3.00%</td>
<td>Range V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>3.50%</td>
<td>(DNIT - ES 386/99)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.50%</td>
<td></td>
</tr>
<tr>
<td>OGFC 3</td>
<td>60/85</td>
<td>6</td>
<td>3.00%</td>
<td>Range V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>3.50%</td>
<td>(DNIT - ES 386/99)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.50%</td>
<td></td>
</tr>
<tr>
<td>OGFC 4</td>
<td>60/85</td>
<td>6</td>
<td>3.00%</td>
<td>Range V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>3.50%</td>
<td>(DNIT - ES 386/99)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.50%</td>
<td></td>
</tr>
<tr>
<td>OGFC 5</td>
<td>60/85</td>
<td>6</td>
<td>3.00%</td>
<td>Range V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>3.50%</td>
<td>(DNIT - ES 386/99)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4.50%</td>
<td></td>
</tr>
<tr>
<td>AC B</td>
<td>55/75</td>
<td>6</td>
<td>4.50%</td>
<td>Range B</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(DNIT - ES 031/2006)</td>
</tr>
<tr>
<td>AC C</td>
<td>55/75</td>
<td>6</td>
<td>5.10%</td>
<td>Range C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(DNIT - ES 385/99)</td>
</tr>
</tbody>
</table>

Total = 132

With the results obtained, were built graphics of frequency x sound absorption average, comparing the sound absorption medium, of each type of OGFC, with the conventional asphalt concrete blends (range B and C).

The coefficient of absorption or noise reduction coefficient (NRC) was calculated for each binder content, following ASTM C 423 [7]. This standard defines the NRC as the arithmetic mean, rounded to the nearest multiple of 0.05, of coefficients of absorption of a specific material and mounting condition determined at an octave range central frequency of 250, 500, 1000 and 2000 Hz, and the NRC used to evaluate pavements coatings and constructions materials.

4 Presentation and analysis of results

In this chapter will be presented and discussed the results of the tests of sound absorption for blends of OGFC and AC (range B and C).

4.1 Results of tests

The Figures 4 to 8 show the results of the averages of the sound absorption coefficients for blends of OGFC1, OGFC 2, OGFC 3, OGFC 4, OGFC 5 and AC (range B and C).
Figure 4: Comparison of average sound absorption curve of OGFC1 with conventional asphalt concrete (range B and C)

Figure 5: Comparison of average sound absorption curve of OGFC2 with conventional asphalt concrete (range B and C)

Figure 6: Comparison of average sound absorption curve of OGFC3 with conventional asphalt concrete (range B and C)
Figure 7: Comparison of average sound absorption curve of OGFC4 with conventional asphalt concrete (range B and C)

Figure 8: Comparison of average sound absorption curve of OGFC5 with conventional asphalt concrete (range B and C)

Figure 9: Correlation between sound absorption coefficient and the percentage of empty volume of samples of OGFC
The Figure 9 shows the relationship between the results of the sound absorption coefficient (NRC), and their respective empty volumes on levels of binder 3.0, 3.5, 4.0 and 4.5%, of OGFC 1, OGFC2, OGFC 3, OGFC 4 and OGFC 5 blends. The conventional asphalt concrete blends (range B and C) resulted an empty volume of 4.0%, in levels of binders: 4.5 and 5.1%.

Despite the different volumes of voids in the samples of OGFC, the results showed a slight variation in sound absorption coefficients for the different levels of binder. It was also verified as the Figures 4 to 8, that the absorption peaks of each binder content are on different frequencies. It was noted that the variation of the absorption peak value between 0.90 to 0.98 in the samples. However, these samples exhibit a maximum absorption between the frequency range of 500 to 800 Hz. It was also verified that the sound absorption coefficient decreased in proportion to the increase of the binder content in the samples of OGFC. This can be explained by the fact that due to the increased amount of binder, the porosity of the sample tends to decrease and with it, the absorption coefficient is reduced.

The conventional asphalt concrete blends (range B and C), as well as the Figures 4 to 8, did not provide good sound absorption coefficients, by varying the peak value of 0.40 to 0.50 absorption. However, these are in the frequency range between 300 to 550 Hz. This fact can be explained by the low percentage of empty volume in conventional asphalt concrete samples (range B and C) and therefore the sound cannot penetrate the coating due to high flow resistivity. So, a greater portion of the sound on the surface of the material ends up being reflected.

5 Conclusion

Not surprisingly, for all sound absorption tests, the five OGFC blends, showed superior absorption coefficients in comparison with conventional asphalt concrete blends (range B and C). This high sound absorption of the OGFC, can be explained by the high voids volume of samples. Thus, the sound can penetrate between the pores and be absorbed by the material in a certain frequency range. Still, the ability of OGFC sound reduction is related to the proportion of voids, particle size distribution, provision of aggregates on its surface, age, filling process, among others.

With the results it can be concluded that in addition to improving safety conditions for users of the roads, the coatings with OGFC provides reduction of noise levels outside the vehicle, caused by traffic, which tends to help mitigate the environmental impact of traffic noise of vehicles.

Acknowledgments

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References


