euronoise 2021
25th to 27th of October
Madeira, Portugal - online

Acoustic properties of high-capacity asphalt mixtures with alternate grain size

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Abstract

Most asphalt mixtures used in road pavements nowadays show a low void percentage with uniform and continuous grading, thus yielding a high structural capacity and cohesion for practical use. Nevertheless, there also exist some extra characteristics that are necessary to look into such as slip resistance, drainage, and noise reduction, this latter being necessary to reduce the noise pollution in urban and interurban areas. In this context, the development of new asphalt mixtures that let enhance the sound absorption performance of road pavements while preserving their functional features is of great interest. This work presents some preliminary results on the study of high-capacity asphalt mixtures whose alternate grain size resulted in a higher void percentage than conventional mixtures, making these suitable for noise reduction applications. Several specimens were prepared and tested both in the laboratory and in situ using standardized procedures that let determine their mechanical and acoustical properties. Additionally, theoretical predictions using an analytical model for porous media were compared to impedance tube data in terms of sound absorption, the predictions showing a good agreement when compared to experiments.

Keywords: high-capacity asphalt mixtures, alternate grain size, sound absorption.

1 Introduction

The fabrication of asphalt mixtures for the construction of road pavements is majorly focused on guaranteeing road safety and driving comfort while reducing environmental impact, other aesthetical and functional features such as slip resistance, drainability, and noise reduction being also of great interest. In this latter regard, the reduction of the sound pressure generated in the tyre-road interaction becomes a key point to reduce traffic noise [1] and for vehicles to be quieter both inside and outside the vehicle. To get these benefits, noise reduction asphalt pavements must show a high void percentage (around 15-20%) that allow the air to flow through its porous structure but still show a good durability and preserve the structural capacity of the bituminous mixture layer. For that purpose, a specific granulometry is necessary to obtain pores whose geometrical characteristics let enhance the asphalt performance and meet the previous requirements.

Nowadays, most asphalt mixtures used in road pavements are AC-type, these showing a low void percentage (between 4-6%) and a uniform and continuous granulometry, thus giving the mixtures a great structural capacity. Alternatively, BBTM-type and PA-type mixtures are discontinuous mixtures showing a higher percentage of voids than the AC-type, with values around 12-18% and above 20%, respectively. To achieve these high porosity values, a discontinuous granulometry can be adopted during the fabrication process (i. e. some granulometric fractions are skipped in the preparation of the mixture), the use of two or more discontinuity steps allowing not only the tortuosity of the pores to be increased but also some additional features improved. For instance, each fraction could be of a specific type of aggregate, seeking to enhance performance selectively (e. g. porous aggregates for higher sound absorption). The main drawbacks of these asphalt mixtures are the impact of missing aggregate fractions on the cohesion of the mixture [2] and the deterioration in the short and mid-term due to the oxidation of the bitumen and the clogging of the pores [3]. To deal with this issues and to increase the durability of these mixtures, polymer-modified bitumens and fibre additions are used, the mechanical strength of the mixtures being also increased [4].

In this work, the sound absorption and in situ noise reduction performance of high-capacity asphalt mixtures with alternate grain sizes were analysed. For that purpose, laboratory impedance tube tests were performed over two types of discontinuous asphalt mixture samples having different characteristics to determine their sound absorption coefficient according to the ISO 10534-2 standard [5]. On the other hand, in situ measurements over test tracks fabricated from these mixtures following the Close Proximity Method (CPX) described in the ISO 11819-2 standard [6] served to assess their noise reduction capability. Both the sample specimens and in situ road tracks of these asphalt mixtures were fabricated by the company Eiffage-Los Serranos S. A. In addition, sound absorption data was compared to predictions obtained using the theoretical model for granular porous media proposed by Horoshenkov and Swift [7] together with an inverse methodology [8], results showing a good agreement when compared to experiments. In general, preliminary results show that the use of these asphalt mixtures may constitute an interesting alternative to conventional pavements both for traffic noise reduction and improved road safety.

2 Material

2.1 High-capacity asphalt mixtures with alternate grain size

Asphalt mixtures with alternate grain sizes can be considered discontinuous granulometry asphalt where some of the aggregate fractions of the mineral skeleton are not included and whose aggregates have different geological nature. These characteristics allow both using aggregates with higher microporosity values and increasing the porosity of the whole mixture, thus letting the sound absorption of the asphalt increase. Even though most discontinuous asphalt mixtures used in practice only have one step of discontinuity, there can be conceived many asphalt mixtures with multiple discontinuities and still meet the manufacturing requirements of mixtures for roads specified in the UNE-EN 13043 standard [9]. Results for only two sets of all the fabricated discontinuous asphalt mixtures will be shown in the current work: BBTM-11B and PA-6. The granular properties of these mixtures are summarized in Table 1, their corresponding granulometric spindle obtained following the UNE-EN 13108 standard [10] being shown in Figure 1.

Table 1. Granular properties of the asphalt mixtures under test.

Mixture	Fine aggregate		Coarse aggregate		Bulk density (kg/m^3)
	size (mm)	type	size (mm)	type	
BBTM-11B	0-2	limestone	5-11	porphyry	2260
PA-6	0-0.4	limestone	2-4	arlite (20.5 %) porphyry (74.5 %)	2225

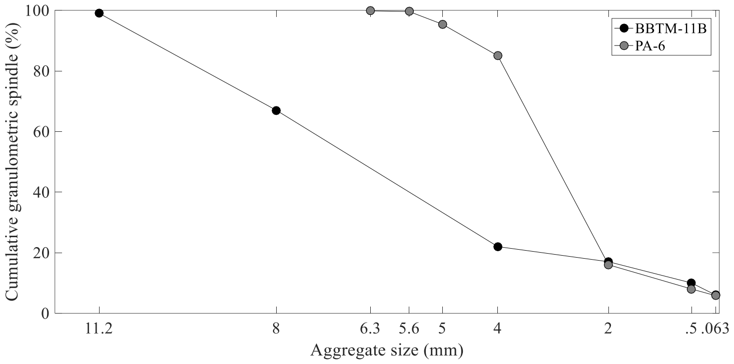
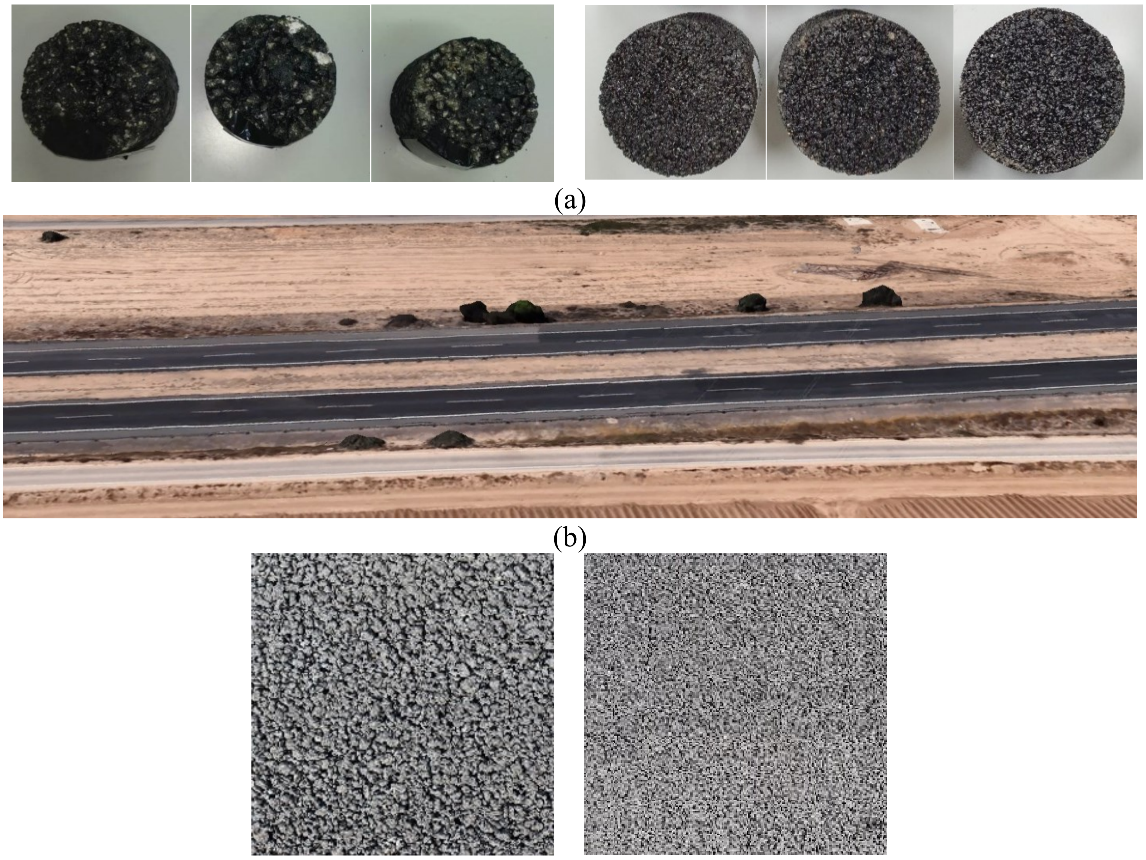


Figure 1. Granulometric spindle of the discontinuous asphalt mixtures under study.

Three cylindrical samples 100 mm in diameter and 60 mm thick were extracted from each mixture so as to be tested in an impedance tube. Once the sound absorption of these specimens was determined, test tracks having a length of 700 m were constructed for each asphalt mixture under test in the road CT-32 near Cartagena (Murcia). The homogeneity of these road surfaces was guaranteed not only by the CPX measurement procedure whose results are presented later but also by measuring the International Roughness Index (IRI). Figure 2 shows pictures of the prepared cylindrical specimens and the test tracks constructed.


(a)

(b)

(c)

Figure 2. Asphalt mixtures under test: (a) laboratory cylindrical specimens: BBTM-11B (left) and PA-6 (right); (b) test tracks (upper road): BBTM-11B (right lane) and PA-6 (left lane); and (c) detailed view of the test tracks: BBTM-11B (left) and PA-6 (right).

3 Methods

3.1 ISO 10534-2: Transfer-function method

First, the sound absorption performance of the asphalt mixtures with alternate grain sizes under study was analysed. For that purpose, the Transfer-function method adopted in the standard ISO 10534-2 [5] was implemented. In this method, the sound absorption coefficient under normal incidence of a porous sample at the end of an impedance tube can be determined by measuring the pressure frequency spectrums of two microphones flush-mounted in the tube when a speaker reproduces a random noise signal. Figure 3.a shows the experimental arrangement of the impedance tube used for the measurements.

3.2 Horoshenkov-Swift model for granular porous media

In addition to the impedance tube tests, it was found of great interest to implement a theoretical model for porous media that let both determine the acoustic properties of the prepared asphalt mixtures and analyse the influence of their physical properties on the resulting sound absorption performance. Specifically, the model for granular porous media proposed by Horoshenkov and Swift [7] together with an inverse methodology [8] was used to predict the sound absorption coefficient of the asphalt samples under study. This model is based on the determination of four macroscopic physical parameters: porosity (ϕ), flow resistivity (σ), tortuosity (α_∞), and pore size deviation (σ_p); to predict the acoustic properties of granular porous media by assuming a pore size distribution close to log-normal. The expressions proposed for the complex dynamic density (ρ) and bulk modulus (K) of the fluid equivalent to the granular media can be written as follows

$$\rho = \frac{\alpha_\infty}{\phi}\left(\rho_0 - j\frac{\sigma\phi}{\omega\alpha_\infty}\tilde{T}\right) \tag{1}$$

$$K = \frac{\gamma P_0}{\phi}\left(\gamma - \frac{\rho_0(\gamma-1)}{\rho_0 - j\dfrac{\sigma\phi}{\omega\alpha_\infty N_{\mathrm{Pr}}}\tilde{T}}\right)^{-1} \tag{2}$$

where ω is the angular frequency, ρ_0 the air density, P_0 the atmospheric pressure, γ the ratio of specific heats, N_{Pr} the Prandtl number, and $\tilde{T}$ (ω) stands for a viscosity correction function defined by

$$\tilde{T} \qquad \frac{-a_1\varepsilon + a_2\varepsilon^2}{1+b_1\varepsilon} \tag{3}$$

with $a_1 = \theta_1/\theta_2$, $a_2 = \theta_1$, and $b_1 = a_1$, being $\theta_1 = (4/3)e^{4\xi} - 1$ and $\theta_2 = e^{3\xi/2}/\sqrt{2}$ when circular pore shape is assumed, where $\xi = (\sigma_p \ln 2)^2$ and σ_p is the standard deviation in the log-normally distributed pore size, and the parameter $\varepsilon = (j\omega\rho_0\alpha_\infty/(\sigma\phi))^{1/2}$ is dimensionless.

These effective properties are related to the complex characteristic impedance (Z_C) and wave number (k) by

$$Z_c = \sqrt{\rho K} \tag{4}$$

$$k = \omega\sqrt{\frac{\rho}{K}} \tag{5}$$

Once these effective properties are obtained, it is straightforward to obtain the surface impedance under normal incidence (Z_S) of porous granular material of thickness d when backed by a rigid wall from

$$Z_S = - \qquad (kd) \tag{6}$$

The sound absorption coefficient (α) is then calculated as

$$\alpha = - \frac{|}{|Z_S +} \tag{7}$$

where $Z_0 = \rho_0 c_0$ is the characteristic impedance of air, being c_0 the speed of sound in air.

Given that the measurement of the above referred macroscopic physical parameters may show some difficulties (e. g. guarantee complete saturation of the sample in methods involving water), an inverse methodology that implements the Nelder-Mead direct search optimization method [8] was used instead. Some recent examples of the applicability of this methodology on similar media can be found in [11, 12].

3.3 ISO 11819-2: Close-Proximity Method (CPX)

To assess the influence of the asphalt mixture on the noise reduction capability of the road pavement, the Close Proximity Method (CPX) described in the ISO 11819-2:2017 standard [6] was implemented. This method allows determining the average A-weighted sound pressure levels generated by the tyre-road interaction over a test track surface by using measurement microphones close to the tyre surface. In this work, a custom-made device was fabricated and installed on the right rear wheel of the vehicle used for the tests as depicted in Figure 3.b. Measurements of the sound pressure level (in dBA) were performed over three runs at different vehicle speeds (40 km/h and 50 km/h) for each test track under test, average values being obtained. The parameter used for the comparison of the different asphalt mixtures was the CPXI, which serves as an indicator of the influence of the road pavement on the lightweight traffic noise and is calculated from the measured sound pressure level for the third-octave bands between 315 and 4000 Hz. It should be noted that the influence of the type of vehicle or the test tyre characteristics (e. g. rubber hardness) were not considered insomuch as the main aim of this research was merely to compare the performance of the different asphalt mixtures.

(a) (b)

Figure 3. Measurement setups used to perform the experiments: (a) impedance tube (Transfer function method); and (b) device consisting of a supporting structure and two microphones (CPX method).

4 Results and discussion

4.1 Sound absorption results

Figure 4 shows the comparison of the average measured sound absorption coefficient under normal incidence and the corresponding values predicted using the theoretical model for the asphalt mixtures listed in Table 1. Results indicate that the asphalt mixture PA-6 shows a higher sound absorption coefficient than the BBTM-11B in the measured frequency range. On the other hand, predicted values show a good agreement when compared to measured ones, the use of the Horoshenkov-Swift model for granular media being thus a helpful tool for the analysis of these mixtures. It must be noted that the porosity values obtained for both mixtures were quite similar (between 26-28%), the improved absorption performance being therefore majorly attributed to the fact that the smaller aggregates used in the PA-6 mixture yields smaller pores that increase the sound attenuation inside the granular material.

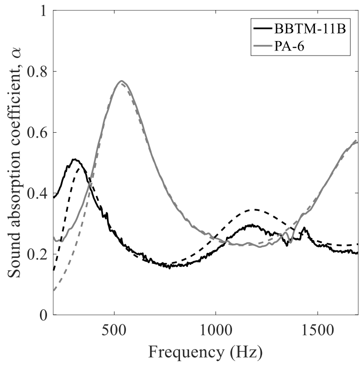


Figure 4. Comparison of the average measured sound absorption coefficient under normal incidence (continuous lines) and the corresponding theoretical predictions (discontinuous lines) for the different asphalt mixtures under study.

4.2 *In situ* noise reduction performance

Table 2 summarizes the values of the CPXI obtained at the different velocities for each of the tracks under test. It can be seen that the road pavement constructed using the asphalt mixture PA-6 produces a lower noise level and therefore an improved noise reduction performance. This assertion is confirmed in Figure 5, which shows that the measured average sound pressure level for the third-octave bands between 315 and 4000 Hz at a vehicle speed of 50 km/h is lower in the case of the PA-6 test track that for the BBTM-11B one. While these results are representative for an automobile flowing at constant speed up to 50 km/h, in which tyre-road noise normally dominates, a comprehensive study for other types of tyre and vehicle constitutes a future research that should be also considered.

Table 2. CPXI (dBA) obtained at the different velocities for each of the tracks under test.

Test track asphalt type	Vehicle speed	
	40 km/h	50 km/h
BBTM-11B	92.9	95.8
PA-6	88.2	90.7

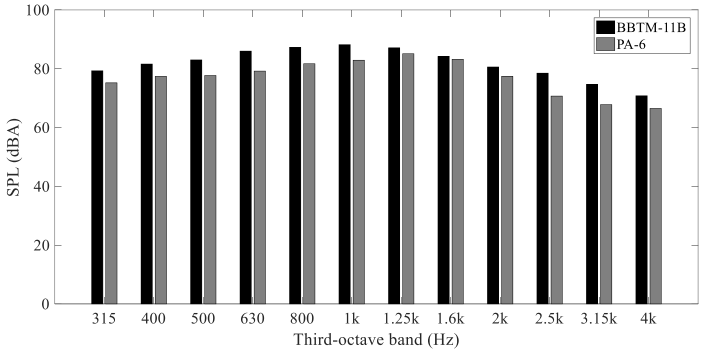


Figure 5. Third-octave band average sound pressure level (in dBA) of the test tracks under study at a vehicle speed of 50 km/h.

5 Conclusions

One of the key points to reduce the rolling noise generated in the tyre-road interaction is linked to the "air pumping" effect generated by the air compressed between the road surface and the tyre. Therefore, by properly designing the voids of the asphalt mixtures, this effect can be minimized and consequently a reduction of the produced noise achieved. Asphalts with a high void percentage result in a porous absorbent which may also lead to reduce the acoustic wave propagation of the engine noise and other aerodynamic effects, some other aspects influencing the rolling noise being the road surface texture and the pavement stiffness. In this work, the acoustic behaviour of high-capacity asphalt mixtures with alternate grain size showing a high void percentage was studied. Laboratory and in situ tests were performed both to assess the sound absorption coefficient and the tyre-road noise reduction of these asphalts when used as road pavements, respectively. Besides, the asphalts analysed not only improve grip on wet pavement, thus minimizing aquaplaning effect and reducing stopping distance, but also road visibility by suppressing the mirror effect. The drawbacks commonly found in discontinuous asphalts such as the shorter structural durability and the need for periodic cleaning to minimize the clogging of the pores were tackled by using modified bitumens, a more detailed analysis on this point being still necessary. In summary, preliminary results showed the potential of these asphalts as a cost-effective alternative to noise barriers for the sake of reducing traffic noise in interurban areas while minimizing the visual impact, thus encouraging further research that let conceive new innovative sound absorbing road pavements.

Acknowledgements

This work was developed under the research project "Research of high-capacity alternate granulometry asphalt mixtures" (id. 20181331) of the company Eiffage - Los Serranos S.A. co-financed by the European Regional Development Fund (FEDER) through the Spanish multi-regional operative program 2014-2020.

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