Innovative low noise surfaces – comparison of damping and absorption

Elisabete Freitas[1], José Dias Rodrigues[2], Jorge Araújo[3] and Hugo Silva[4]

[1, 3, 4] University of Minho

Campus de Azurém, 480 058 Guimarães, Portugal

[2] University of Porto

Rua Dr. Roberto Frias, 4200 465 Porto, Portugal

ABSTRACT

While sound absorption is an acoustic related property reasonably well known and currently used to characterize low noise surfaces, damping is a property commonly used in other domains to define the energy dissipation of a material but rarely used to characterize this important mechanism in road pavements. This paper compares noise related properties such as damping and absorption of five road pavement surfaces. Two of which are innovative and therefore expected to be low noise since they have high voids content, incorporate fine grading aggregates and expanded clay. Other two incorporate rubber and waste high-density polyethylene giving them an elastic and stiff behaviour respectively. The fifth is a conventional material, asphalt concrete, used for control. Sound absorption tests and mechanical impedance tests were carried out in 30x30 cm slabs at 20ºC. To measure absorption, an impedance tube with an open end was put on the surfaces. To determine damping, the response of a hammer impact measured by an accelerometer on suspended slabs was analysed. Results show that the innovative surfaces have better acoustic related properties while the surface with high-density polyethylene provided the worst results. Furthermore, a strong correlation of damping and air voids was found.

Keywords: Damping ratio, Absorption; Noise, Tyre-road noise, Voids percentage

1 INTRODUCTION

Low noise surfaces design procedures includes the optimization of key properties such as texture and porosity, but lately importance has been given to the design of surfaces capable of dissipating energy like poroelastic surfaces [1]. Damping is a property commonly used in other domains to define the energy dissipation of a material but rarely used to characterize this important mechanism in road pavements. It can be easily determined from mechanical impedance tests which are also often used to determine stiffness. In the past, mechanical impedance tests were used to investigate the influence of stiffness on tyre-road noise, with limited success as reported in Cesbron [2]. Lately Biligiri et al. [3] used the phase angle as indicative of noise-dampening characteristics in the field. This author continued his investigation about the effect of pavement materials' damping properties on tyre-road noise characteristics through a theoretical approach to the problem concluding that mixtures with asphalt rubber do not have a theoretical behaviour while conventional mixtures do [4]. The reasons presented to explain such behaviour were that the extra binder, higher porosity and rubber inclusions, provide sufficient extra visco-damping effect, higher noise-absorption potential, and higher vibroacoustical damping capacity.

In order to characterize noise related properties such as damping and absorption and further investigate their relations with conventional asphalt mixtures properties, the present study compares five road pavement surfaces. Two of the road surfaces are innovative and therefore expected to be low noise since they have high voids content, incorporate fine grading aggregates and expanded clay [5].

[1] efreitas@civil.uminho.pt
[2] jdr@fe.up.pt
[3] a61858@alunos.uminho.pt
[4] hugo@ civil.uminho.pt

Other two incorporate rubber and waste plastic giving them an elastic and stiff behaviour respectively. The fifth is a conventional mixture used for control.

The materials and performance tests carried out, as well as the results obtained are described and analysed in the following sections.

2 MATERIALS AND METHODS

2.1 Materials

Prior to the execution of the present study, a mix design procedure was carried out to produce ten bituminous mixtures used in road surface layers with innovative materials. One of them is of AC14 surf type and is used for control purposes, two of them have 5% by volume of crumb rubber incorporated by the dry method, therefore substituting part of the aggregates by the rubber, one has 6% by binder weight of high-density polyethylene waste and the other six have 10% by volume of expanded clay. Table 1 summarizes the main characteristics and properties of these mixtures. With the incorporation of these materials in the bituminous mixtures it is expected to achieve different responses to the impact force and therefore different damping ratios. Also, it is expected to have different absorption coefficients not only due to their voids content but also due to the nature of the materials incorporated.

The dimension of the slabs was chosen to cope with other tests like rutting. Therefore they have 30x30 cm^2, except AJB whose dimension is 15x30 cm^2.

The following sub-sections describe all the materials used in the production of the studied mixtures.

Table 1 – Properties of the mixtures

Specimen	Dmax	Binder	Voids content	Thickness	Special aggregate	
	(mm)	(%)	(%)	(mm)	Type	(%)
E 5.9 MA	6	5.9	23.6	3	Expanded clay	10 (by volume)
E 5.9 A	6	5.9	16.3	3	Expanded clay	10 (by volume)
E 6.4 MA	6	6.4	24.7	3	Expanded clay	10 (by volume)
E 6.4 A	6	6.4	16.8	3	Expanded clay	10 (by volume)
E 6.9 MA	6	6.9	25.6	3	Expanded clay	10 (by volume)
E 6.9 A	6	6.9	18.7	3	Expanded clay	10 (by volume)
AC 14	6	5.0	8.3	4	-	-
AJA	14	5.3	6.7	8	Rubber	5 (by volume)
AJB	14	5.3	7.5	8	Rubber	5 (by volume)
PEAD	14	5.0	7.5	4	Polymers	6 (by binder weight)

2.1.1 Aggregates

The aggregates used in the asphalt mixtures produced during this study were of granitic origin, except the filler which was limestone. The grading curves were selected to give to the mixtures different properties.

2.1.2 Binder

The binder used in each mixture was selected to provide it with the best performance given the characteristics of the added materials (high-density polyethylene, crumb rubber and expanded clay), therefore three types of bitumen were used: 35/50 penetration grade, 50/70 penetration grade and polymer modified bitumen with SBS which is characterized by a softening point of 65ºC and a penetration of 52 (x 0.1) mm.

2.1.3 Expanded clay

The expanded clay is a material typically manufactured from bloating clays which, upon firing, expands or bloats into a frothy mass with a high proportion of semi-closed pores. Its main characteristics are the very light weight, attributed to a relatively high proportion of semi-closed pores, combined with a relatively high structural strength and low cost [6].

This material was already used in low porosity asphaltic mixes and demonstrated considerable benefits on the mechanic characteristics, friction and acoustic performance [5] and also in open graded mixtures demonstrating additionally good damping performance [7]. The dimensions of the expanded clay ranged from 2 mm to 4 mm.

2.1.4 Crum Rubber

Crumb rubber is a material commonly used in some bituminous mixtures due to its elastic and resilient properties, which gives a higher viscosity to the binder, and thus a greater resistance to cracking and fatigue and greater durability of the mixture [8]. Furthermore, it has been used in surface layers to reduce noise. The rubber used for this type of application is obtained from used tires, after a grinding operation that transforms them into granulate particles. The crumb rubber used in this study was obtained from the cryogenic process and its dimensions ranged from 0.5 to 6.3mm.

2.1.5 High-Density Polyethylene

High-density polyethylene is a polyethylene thermoplastic made from petroleum, recyclable, commonly used in the production of plastic bottles, corrosion-resistant piping, geomembranes, and plastic lumber. In the last decade it has been used to improve asphalt concrete performance due to its relative low cost and availability as waste material [9].

In this study it is intended to assess for the first time the effect of the high-density polyethylene in the acoustic performance of asphalt mixes which incorporate this waste material.

2.2 Methods

In order to evaluate the acoustic performance of the 10 mixtures produced and to investigate their relationship with materials properties, damping and sound absorption measurements were made at 20ºC.

The individual test procedures are presented in the following sub-sections while the results of each measurement are presented in Section 3.

2.2.1 Method to Evaluate Damping

Damping of a road surface is a measure for determining capacity of the structure to dissipate energy. It can be measured by applying an impact to the road surface and registering the frequency response of the structure in terms of its vibration. The damping ratio (ξ) associated to the resonance frequency of a vibration mode can be calculated then through the bandwidth method [10]. In a multi-degree of freedom system the damping ratio can be determined as shown in Figure 1 and Equation (1).

To avoid possible effects of the support on the response measured, all specimens were hanged has shown in Figure 2. Afterwards, an accelerometer was bonded to the specimen and it was submitted to a hammer impact in the opposite side. Next, the response to the impact was analyzed and the damping ratio was determined at each resonance frequency.

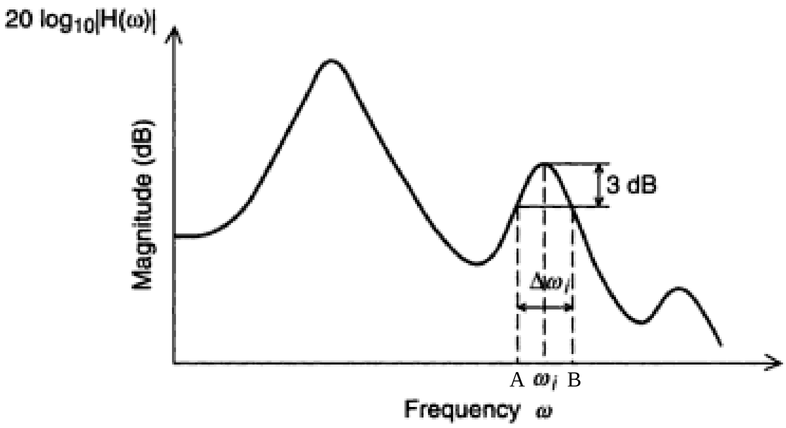

Figure 1 – Illustration of bandwidth method of damping measurement in a multi-degree of freedom system [11]

$$\xi_i = \frac{\omega_{Bi} - \omega_{Ai}}{\omega_{Bi} + \omega_{Ai}} \tag{1}$$

Figure 2 – Damping ratio testing set up

2.2.2 Methods to Evaluate Sound Absorption

For measuring absorption, a self-made impedance tube with 80 mm of diameter utilizing the two microphone arrangement was used [12]. This tube has an open end which is placed on the surface to be measured. The absorption coefficient is determined as a function of the acoustic impedance over a frequency range from 250 Hz up to 2.5 kHz (1/3 octave bands).

3 RESULTS

3.1 Damping

The damping ratios corresponding to each resonance peak, presented in Table 2 can be used to plot a graph to compare them as a function of the frequency. Figure 3 depicts the damping ratios for the first peak and Figure 4 for the second peak.

Table 2 – Damping ratios for the first and second resonance peaks

	1st peak		2nd peak	
Specimen	Damping (%)	Frequency (Hz)	Damping (%)	Frequency (Hz)
E 5.9 MA	19.4	232	13.7	1036
E 5.9 A	16.6	266	12.2	1172
E 6.4 MA	18.0	253	14.4	1079
E 6.4 A	12.8	317	9.9	1348
E 6.9 MA	18.0	237	13.9	1033
E 6.9 A	14.1	295	10.5	1306
AC 14	11.7	606	8.6	2338
AJA	10.0	988	-	-
AJB	10.4	1198	-	-
PEAD	7.9	632	7.6	2472

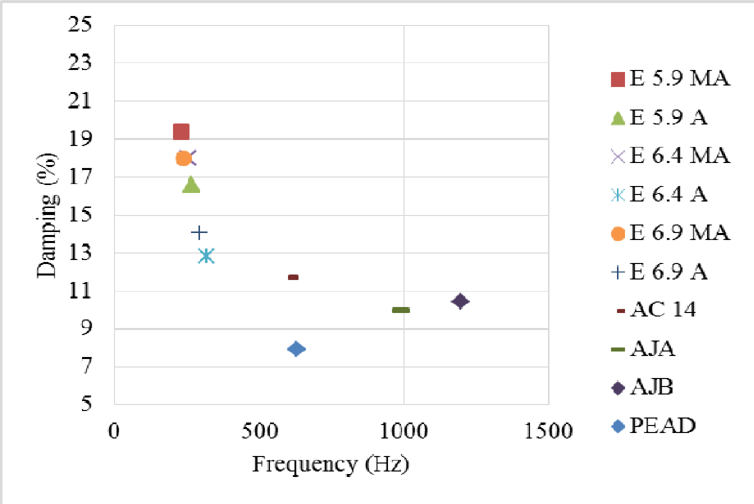

Figure 3 – Damping ratio versus frequency for the first resonance peak

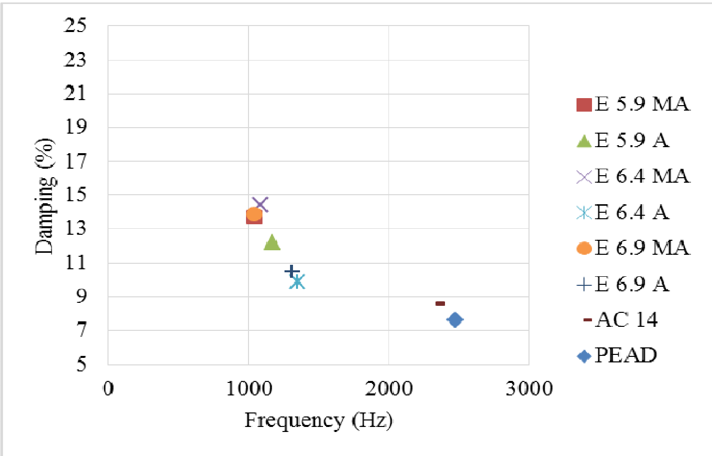

Figure 4 – Damping ratio versus frequency for the second resonance peak

AJA and AJB did not have a second peak within the measuring frequencies (up to 4000 Hz) probably due to their high thickness (8 cm).

The damping ratios determined for the first peak which occurs below 1200 Hz ranged from 7% to 20% while for the second peak they were slightly lower, ranging from 7% to 15%.

The control mixture had a damping ratio of 11.7 % at 606 Hz for the first peak and of 8.6% at 2338 Hz for the second peak.

The mixtures with crumb rubber had nearly 1.5% less damping than the control mixture however at frequencies corresponding to tyre-road noise peaks.

The control (AC14) and PEAD mixtures had different damping ratios at approximately the same frequency in the first peak (these materials have the same thickness) and exhibit a similar performance in the second peak. As could be expected the incorporation of high-density polyethylene reduces damping.

Mixtures with expanded clay have the best performance. The first peak occurs at low frequencies, below 320 Hz, but the second one occurs at frequencies near to the tyre-road noise higher levels, close to 1000 Hz.

In order to better understand these results, in the following subsections the effect of materials properties like binder content and voids content and the correlation between damping and absorption will be further analysed.

3.2 Sound Absorption

Sound absorption is an acoustic property essential to reduce noise which depends mostly on the amount of voids of the material under testing. The mixtures studied were designed to have a wide range of voids, from 7.5% up to 25.6%. Table 3 presents the absorption coefficient for 1/3 octave bands and the average absorption coefficient for each mixture. Mixtures with expanded clay and also with higher voids content have high absorption coefficients at frequencies around 1000 Hz, while the others have approximately half of their absorption coefficient at frequencies below 400 Hz.

In terms of average absorption coefficient, it drops about 20% when the voids content drops about 7%, as can be seen in Figure 5. Furthermore, Figure 5 suggests a strong correlation between absorption and voids content, as expected.

Table 3 – Absorption coefficient versus frequency and corresponding average for each mixture

Frequency (Hz)	5.9 MA	5.9 A	6.4 MA	6.4 A	6.9 MA	6.9 A	AC14	AJA	AJB	PEAD
200	0.58	0.34	0.52	0.33	0.51	0.41	0.31	0.32	0.25	0.23
250	0.60	0.36	0.51	0.32	0.54	0.37	0.30	0.31	0.30	0.24
315	0.61	0.42	0.54	0.39	0.58	0.42	0.35	0.36	0.35	0.31
400	0.57	0.42	0.51	0.40	0.55	0.41	0.29	0.30	0.29	0.25
500	0.63	0.45	0.56	0.45	0.59	0.45	0.20	0.19	0.19	0.15
630	0.71	0.50	0.65	0.46	0.69	0.51	0.17	0.16	0.15	0.13
800	0.68	0.51	0.62	0.44	0.66	0.52	0.17	0.15	0.15	0.12
1000	0.73	0.49	0.72	0.35	0.71	0.45	0.15	0.14	0.14	0.11
1250	0.68	0.38	0.68	0.27	0.64	0.33	0.14	0.15	0.12	0.10
1600	0.60	0.34	0.56	0.29	0.48	0.33	0.18	0.21	0.17	0.14
2000	0.41	0.36	0.41	0.35	0.40	0.34	0.22	0.27	0.21	0.17
2500	0.46	0.49	0.44	0.52	0.46	0.47	0.29	0.55	0.29	0.32
Average	0.61	0.44	0.57	0.39	0.42	0.58	0.22	0.25	0.21	0.18

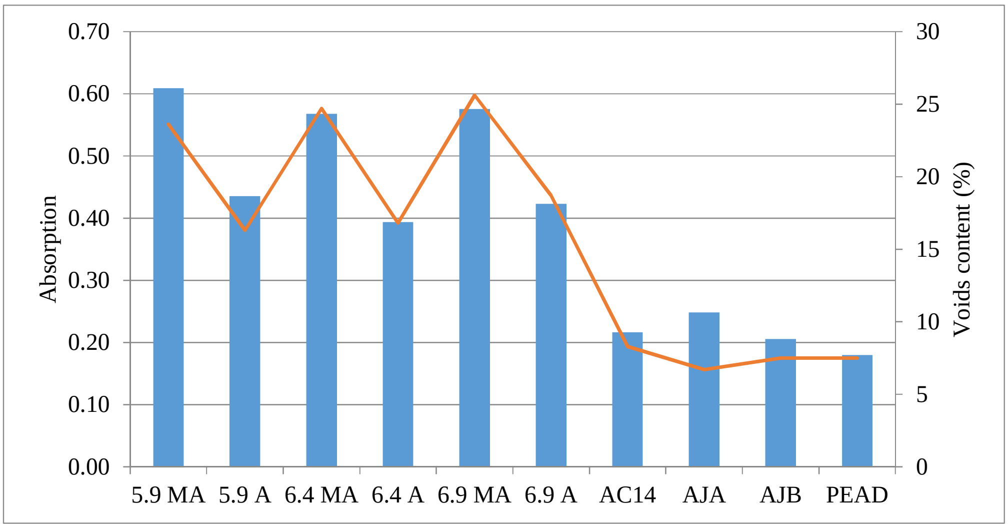

Figure 5 – Average absorption coefficient and voids content of each mixture

3.3 Damping Versus Binder Percentage

The binder percentages presented in Table 1 and the damping ratios determined for the first resonance peak, presented in Table 2, were used to plot Figure 6 and to investigate if there is a correlation between them. It suggests a linear trend of which slop seems influenced by those mixtures made with the same materials but with different voids content. This hypothesis is analysed in the following sub-section.

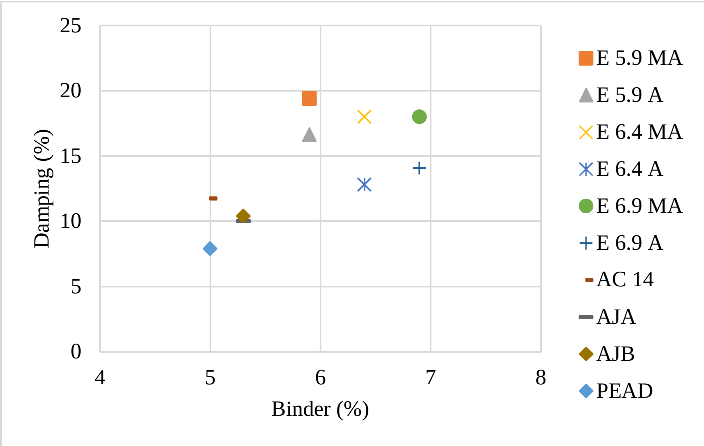

Figure 6 – Damping ratio versus binder percentage of each specimen

3.4 Damping Versus Voids Percentage

Figure 7 presents damping ratio determined for the first resonance peak versus voids percentage. A clear linear trend between those parameters can be observed. Therefore, voids content is a material property that contributes to dissipate energy in road pavements as it positively influences damping ratio.

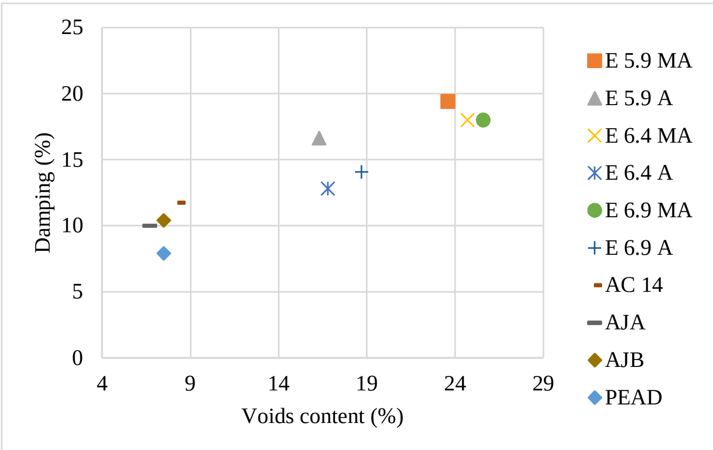

Figure 7 – Damping ratio versus voids content of each specimen

3.5 Damping Versus Sound Absorption

As aforementioned and checked, there is a positive relation between absorption and voids content and a positive relation between damping and voids content. Consequently it is expectable finding out a positive relation between damping and absorption. Figure 8 shows that effectively that positive relation occurs. This indirectly shows that designing road surfaces to have high damping ratios leads to less noisy road surfaces.

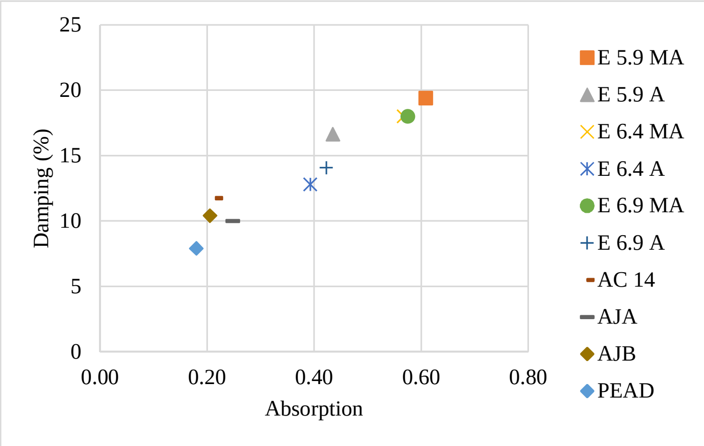

Figure 8 – Damping ratio versus absorption coefficient of each specimen

3.6 Correlation Between Parameters

To conclude the analysis made above, the correlation among damping, binder content, voids content and absorption was determined (Table 4). The correlations found are generally high except between damping and binder percentage. These results are a good indication that damping is moderately influenced by binder percentage but highly influenced by voids content. Given the fact that absorption is highly correlated with voids content, damping and absorption are also strongly correlated.

Table 4 – Properties Pearson correlation

Parameter	Damping (%)	Binder (%)	Voids content (%)	Absorption
Damping (%)	1			
Binder (%)	0.67	1		
Voids content (%)	0.93	0.84	1	
Absorption	0.96	0.78	0.98	1

4 CONCLUSIONS

This study showed that damping is rarely used in road pavements to assess the capacity of a layer or a layer system to dissipate energy. A few investigations demonstrated the potential of this property to explain tyre-road noise. Therefore, in this paper damping and absorption of five road pavement surfaces were compared and correlated with other material properties such as binder percentage and voids content. Sound absorption tests and mechanical impedance tests were carried out in 30x30 cm^2 slabs at 20ºC.

The results showed that damping of the control mixture (AC 14) was superior to the crumb rubber and waste high-density polyethylene mixtures. The effect of the introduction of unconventional materials in the mixtures seemed to be considerably smaller than the effect of voids content in damping or absorption. Generally, the average sound absorption decreased about 20% when voids content decreased about 7%.

Correlation tests indicated that damping is moderately influenced by binder percentage but highly influenced by voids content. Damping and absorption are also strongly correlated.

It is recommended to take into account these results in the design of new low noise surfaces.

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