ASSESSMENT OF THE PERFORMANCE OF ASPHALT RUBBER LAYERS ON NOISE ABATEMENT

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ABSTRACT

Layers with a very high content of rubber have shown to be very effective on noise abatement despite their reduced durability. On the contrary, layers with a rubberized asphalt binder have shown to be durable, but their performance regarding noise abatement is not consensual yet. This paper aims at assessing the effect of the use of layers with rubberized asphalt binder on noise abatement. For this purpose seven road sections with different surface types, among which five gap graded and three with rubberized asphalt have been selected. In these road sections the tyre-road noise generated by a heavy truck and two light vehicles at three levels of speed were measured by means of pass-by tests. Surface texture tests were also performed. The results focused on the noise level variation versus speed, the average noise level for each speed level versus type of surface and the average noise level variation with regards to a reference surface. Mixtures with rubberized asphalt did not show a significantly better performance. In fact, the same performance may be achieved with other type of gap graded thin mixtures. The results obtained might be better explained if other parameters than the rubberized asphalt binder are taken into account. Further research on the effect of porosity and texture on noise generation is being done. It is intended to perform absorption tests in all the surfaces analysed in order to study this issue in depth and fully understand the effect of the rubber on noise generation.

OVERVIEW

The increase of noise due to traffic particularly in urban areas has led road administrations to look for assessment procedures and innovative noise abatement solutions, in view of better comfort and therefore better environmental quality. Traffic noise is the sum of the noise produced by all types of vehicles. In its turn, each vehicle has several noise sources, such as engines, exhaust and power train system noise, tyre-surface noise generated by the interaction of tyre and road and the wind noise, what provides the total noise produced by vehicles. For speeds above 40 to 50 km/h the tyre-surface contact noise is predominant (Bendtsen et al., 2006). For that reason it is very important to know the tyre-surface generation mechanisms and the effect of the surface properties on noise generation in order to support the design of surface layers with adequate acoustical properties.

The tyre-surface noise generation mechanisms come from radial and tangential vibrations of the tyre tread as a result of the impact and the adhesion of the treads on the surface, and from air vibrations around the tyre and in the grooves and cavities of the tyre tread. These mechanisms may be amplified by the horn effect and by the acoustical and mechanical impedance of the surface (Sandberg at al., 2002) which are affected by following parameters:

- surface characteristics – aggregate gradation (Bendtsen, 2006), texture (Sandberg at al., 2002), porosity, age (SILVIA, 2006), stiffness (Houari, 2004), distresses (Berengier, 2005);
- vehicles – type of vehicle (Descornet, 2005), tyre (Pucher et al., 2006), speed (Haberl et al., 2005);

- weather conditions – wind (Watts, 2005), temperature (Anfosso-Lédée, 2001), water on the surface (Sandberg at al., 2002);
- drivers' behaviour (Mancosu, 1999).

For the assessment of the tyre-surface noise there are two main standardized methods, consisting of pass-by and mobile measurements: the Statistical Pass-By method (ISO 11819-1:1997), and the Close-Proximity method (draft ISO/CD 11819-2). The Controlled Pass-by method is a variant of the first method that uses a small number of controlled vehicles instead of a statistical selection from normal traffic. Using test vehicles and test drivers to produce pass-bys at pre-defined speeds simplifies and shortens the measurement procedure. These methods are often used for the comparison of road surfaces. According to Sandberg et al. (2002), a low noise road surface is a road surface which, when interacting with a rolling tyre, influences vehicle noise in such a way as to cause at least 3 dB(A) (half power) lower vehicle noise than that obtained on a conventional and most common road surface.

Several studies carried out in roads with different types of surfaces and ages usually show that dense asphalt concrete, stone mastic asphalt and surface dressings are the ones that generate more noise opposed to double and single porous asphalt, thin layers and poroelastic surfaces (Anderson et al., 2006; Descornet et al., 2006; Bartolomaeus, 2006).

In the first group the aggregate size, which is usually big, the low porosity and the positive texture are factors that highly contribute to the high noise levels. In the second group, the reduction of the noise generated by the texture impact mechanism is due to the small aggregate size. The gap-graded nature (indented or negative texture) also gives them good air drainage properties that contribute to the reduction of air-pumping noise and other similar mechanisms of noise generation (SILVIA, 2006). From this group of asphalt mixtures, the poroeslastic one must be highlighted since reductions up to 12 dB were achieved in experiments carried out in Japan, the Netherlands and Sweden (Sandberg and Kalman, 2005) as a result of their composition. These experimental poroelastic mixtures are characterized by high percentages of rubber granules, up to 90% by weight, and by high void volume. This combination leads to a reduced durability that needs to be increased.

In its turn, the use of mixtures with a small amount of rubber used to modify the binder (rubberized asphalt binder) is widely spread and has shown to be durable. These mixtures have a composition comparable to dense asphalt concrete, porous asphalt and the asphalt mixtures used in thin layers. Donovan (2005) has found noise levels similar to those of the porous asphalt on dense asphalt rubber concrete surfaces either in the United States or in Europe. In Portugal two studies were carried out with these types of mixtures. One compared a gap graded rubber asphalt with a "rough" dense asphalt and with cement concrete. The other one assessed the noise produced in a porous rubber asphalt mixture. In the first case, abatements of 5 to 8 dB(A) and 8 to 10 dB(A) were stated (Ruivo, 2004). In the second case, a reduction of 3 to 5 dB(A) was reported (Gomes et al., 2006).

Despite the promising results achieved with the implementation of surfaces with rubberized asphalt binder, questions regarding the effective effect of the small amount of rubber have been raised. This paper intends to give a number of insights into this issue by comparing noise levels measured in mixtures with similar compositions with and without rubberized asphalt binder.

STUDY METHODOLOGY

The study methodology was based on the procedure recommended in the standard ISO 118919-1:1997(E) *"Acoustics – measurement of the influence of road surfaces on traffic noise – Part 1: statistical pass-by method"*. Therefore, seven in-service road sections, the surface layer of which is composed of three main types of mixtures, have been selected: i) one on dense asphalt concrete; ii) three on gap graded asphalt; iii) three on gap graded asphalt rubber. The dense mixture will be considered as a reference and the second type of mixtures will be used to support the analysis of the effect of the rubber on noise abatement.

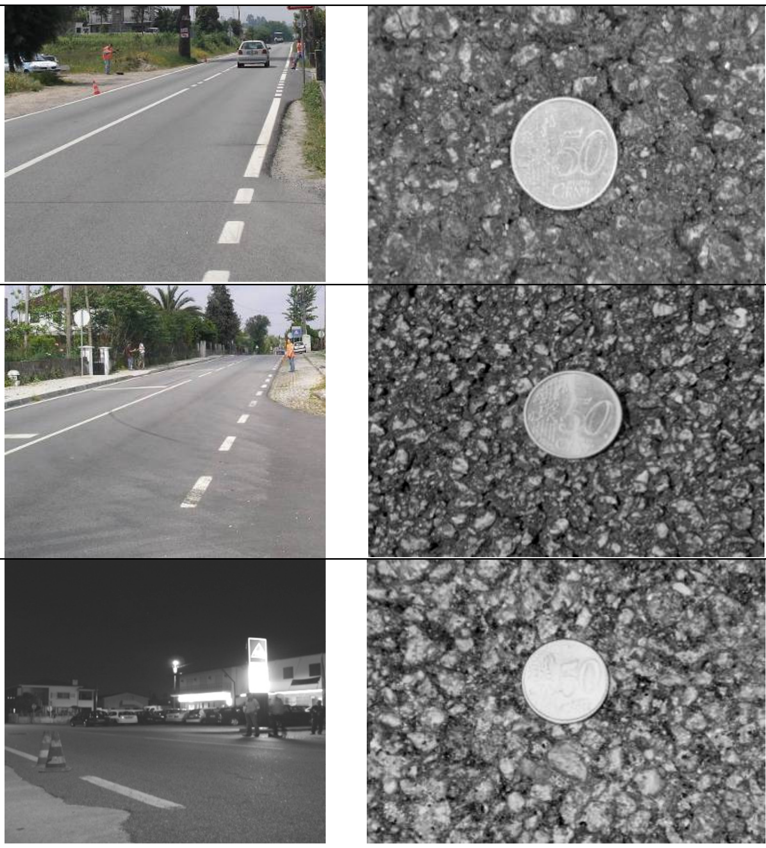
In each section the ordinary traffic was stopped during testing. Since all the roads have an important traffic flow, five sections were tested at night in order to avoid unnecessary disturbance. The noise measurements were carried out using three selected vehicles – a light vehicle, a heavy vehicle and a 4×4 light vehicle. A microphone was positioned at 1.2 m above the pavement surface and 7.5 m from the centre of the carriageway. Thus it was possible to guarantee that noise measurements were not going to be influenced by other vehicles and that measurements were carried out under the same testing conditions for what respects to the type of vehicle, type of tyre and testing speed.

A total of 188 vehicles pass-bys were effectuated, with the engine switched on, at three speed levels. The following measurements were made on each pass-by: maximum noise level and corresponding noise spectrum, vehicle speed, air and surface temperatures and wind speed. The surface properties such as the mean profile depth and skid resistance were also measured. The mixture properties were kindly provided by the Road Administration of the District of Braga.

TESTING CONDITIONS

Road sections and pavement surface

For the selection of the testing sections four main conditions were taken into account: i) type and condition of the surface; ii) security regarding the length required for accelerating and breaking; iii) presence of high reflective objects; iv) the slope of the road. In Figure 1 the test sites and the corresponding aspect of the surface are depicted. The main properties of the mixtures, such as the maximum aggregate size (MAS), porosity (P), bitumen percentage by total weight (BP), rubber percentage by weight of the bitumen (RP) and age, are also represented. In the same figure each surface is identified by the acronym of the corresponding mixture followed by the MAS.



Surface 1: S1(GG12)

Gap graded (rough)
MAS: 12 mm
P: 3.6%
BP: 5.1%
Age: 1 year

Surface 2: S2(GG6)

Gap graded
MAS: 6 mm
P: 6.6%
BP: 6.2%
Age: 2 years

Surface 3: S3(RAR15)

"Rough" asphalt rubber concrete
MAS: 15 mm
P: < 5.0 %
BP: 7.0 %
RP: 18%
Age: 7 years

Figure 1 – Test sites, aspect and properties of the surface (continues)

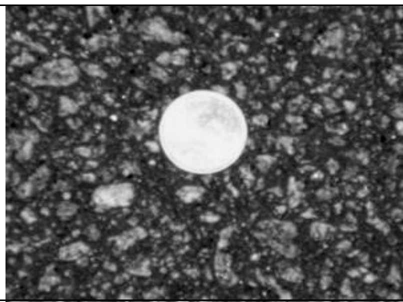
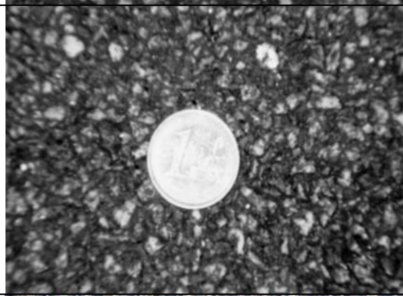
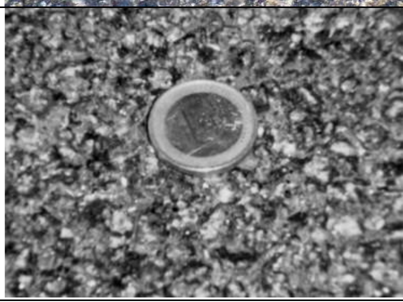
		**Surface 4: S4(DA16)** Dense Asphalt MAS: 16 mm P: 5.0% BP: 4.9% Age: 10 years
		**Surface 5: S5(GG7)** Gap graded MAS: 7 mm P: 6.1% BP: 6.1% Age: 4 years
		**Surface 6: (GGAR12)** Gap graded with asphalt rubber MAS: 12 mm P: 13.0% BP: 9.0% RP: 20% Age: <1 year
		**Surface 7: (GGAR10)** Gap graded with asphalt rubber MAS: 10 mm P: 14.0% BP: 9.0% RP: 20% Age: <1 year

Figure 1 – Test sites, aspect and properties of the surface (continuation)

Surfaces S1, S2 and S5 are thin layers composed of gap graded asphalt mixtures (GG) with less than 6% of voids. Surfaces S3, S6 and S7 are also thin layers. Within this set, surface S3 is a “rough” asphalt rubber concrete (RAR) and surfaces S6 and S7 are gap graded asphalt rubber mixtures (GGAR), the void content of which is about 13%. The rubber content by weight of bitumen is 18% to 20%. The thickness range of these six layers is [2.5 - 4] cm. Surface S4 is composed of dense Asphalt concrete (DA) the most common type of surface. It is used in all types of roads (rural or urban) and due to its ordinary properties it may be considered as a reference for noise levels.

The mean profile depth, converted then to the estimated profile depth (EPD), was measured with a High Speed Profilometer according to the Standard ISO 13473-1:1997, in a length of 30 m before and after the microphone location. The skid resistance was measured with the British Pendulum according to the standard ASTM E303 - 93 (2003). The results can be found in Table 1. The EPD is similar except for surface S1, which is notoriously rougher than the others, despite their differences in age and porosity. Nevertheless, values higher than 0.9 mm should be found when the gap graded rubber asphalt mixtures are concerned. This means that for this case more noise due to air pumping might be expected.

Table 1 – Estimated profile depth and skid resistance of the surface

Surface	Estimated profile depth (mm)	Skid resistance at 20ºC (BPN)
S1(GG12)	1.0	54.5
S2(GG6)	0.6	52.2
S3(RAR15)	0.6	50.6
S4(DA16)	0.7	51.4
S5(GG7)	0.6	51.8
S6(GGAR12)	0.7	50.0
S7(GGAR10)	0.8	52.6

Testing vehicles and speed

The three vehicles selected for testing (Figure 2) can be grouped into the following categories, as recommended by the standard ISO 118919-1:1997(E):

- Cars – 1 Volkswagen Polo (LV(P)),
- Other light vehicles – 1 Nissan Strakar (LV(S));
- Dual-axle heavy vehicles – 1 Volvo (HV);
- Multi-axle heavy vehicles – not included.

Figure 2 – testing vehicles

The testing speeds chosen consider the road category and the legal speed limitations. Therefore, three levels, which belong to the road speed categories recommended at ISO 118919-1:1997(E), were set. Accordingly, in each section the speeds established were:

- LV (P) – four pass-bys at 50 km/h, 70 km/h and 90 km/h;
- HV – four pass-bys at 50 km/h, 70 km/h;
- LV (S) – two pass-bys at 50 km/h, 70 km/h and 90 km/h.

Weather

The wind speed and the temperature need to be controlled. If the wind speed is lower than 5 m/s then noise measurements can be considered valid. The same happens when both the air temperature range is 5ºC to 30ºC and the surface temperature range is 5ºC to 50ºC.

Table 2 – Weather condition

Surface	Wind speed (m/s)	Air temperature (ºC)		Surface temperature (ºC)	
		Minimum	Maximum	Minimum	Maximum
S1(GG12)	2.12	19	29	29	36
S2(GG6)	1.70	21	26	29	33
S3(RAR15)	1.57	13	16	17	19
S4(DA16)	0.34	10	12	11	15
S5(GG7)	1.13	20	20	14	16
S6(GGAR12)	2.32	19	21	22	23
S7(GGAR10)	0.65	19	20	22	26

These weather conditions were totally respected as shown in Table 2. The effect of the weather conditions were not taken into account because the variation in noise level is much smaller than the data bias (< 1dB(A)).

ANALYSIS OF THE RESULTS

Noise level versus speed

In Figure 3 noise level versus speed for all the vehicles measured in each section as well as the linear regression line are presented. The resultant coefficients of determination (R^2) and slope (a) are gathered in Table 3.

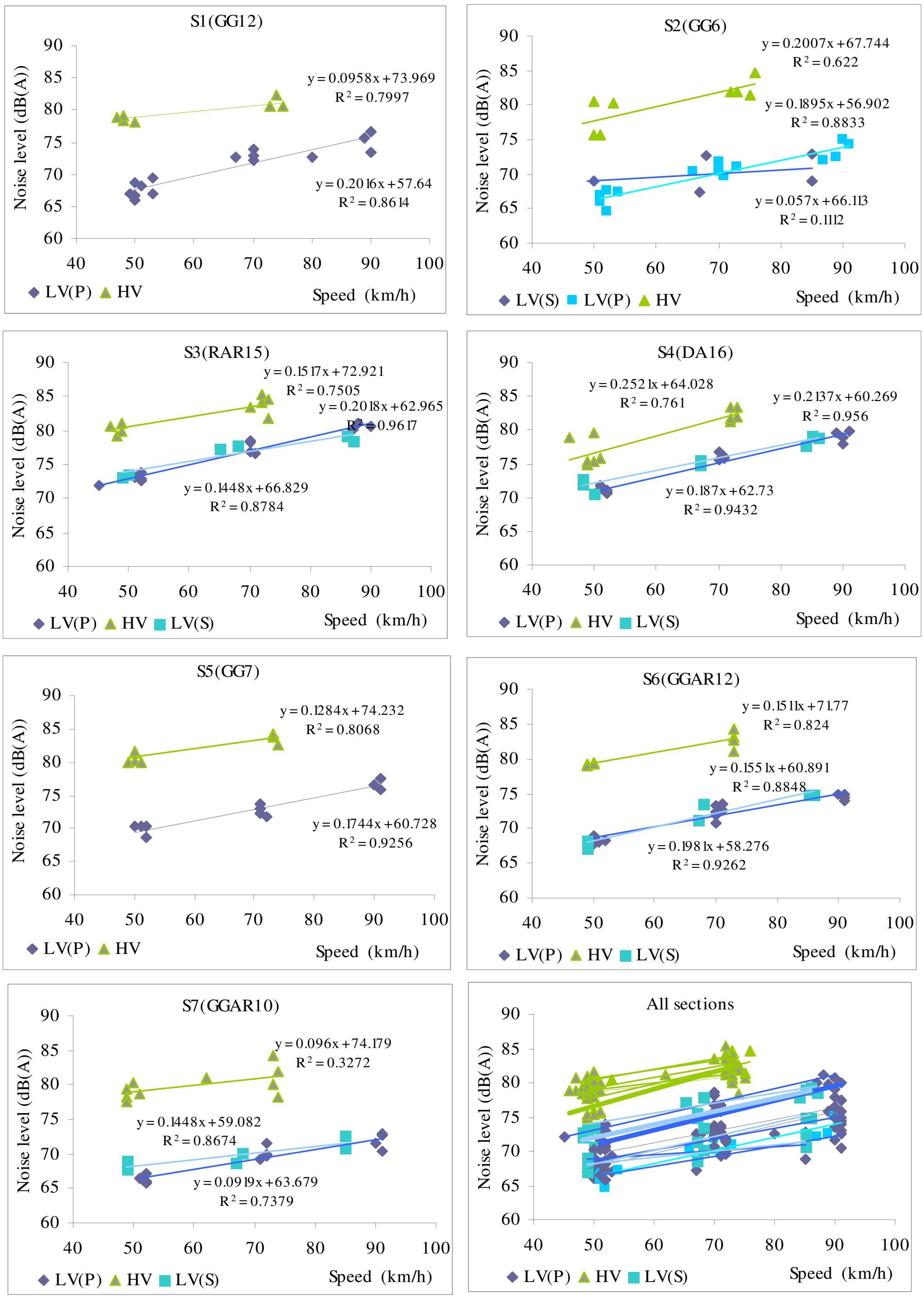


Figure 3 –Noise level versus speed for all vehicles and sections

Table 3 – Linear regression parameters

Surface	Light vehicle (Polo)		Heavy vehicle (Volvo)		Light vehicle (Strakar)	
	R^2	a	R^2	a	R^2	a
S1(GG12)	0.861	0.201	0.800	0.096	-	-
S2(GG6)	0.883	0.190	0.622	0.201	0.111	0.057
S3(RAR15)	0.962	0.202	0.750	0.152	0.878	0.144
S4(DA16)	0.956	0.214	0.761	0.252	0.943	0.187
S5(GG7)	0.925	0.174	0.807	0.128	-	-
S6(GGAR12)	0.885	0.155	0.824	0.154	0.926	0.198
S7(GGAR10)	0.867	0.144	0.327	0.096	0.738	0.092

In general the repeatability of the results is good. However, as expected, it is slightly poorer for the heavy vehicle. One of the possible causes for this is the difficulty in controlling particularly the truck acceleration, due to limitations regarding the geometry and the length of the section.

For what respects to the curve fitting, a linear regression analysis was preferred instead of a regression with the logarithm of the vehicle speed as the quality of the fitting is nearly the same and generally good. This may be a result of the reduced number of testing speeds.

Based on the analysis of the curve slope (Table 3), it is stated that noise mostly increases with speed on surface S4(DA16). The opposite is stated on surface S7(GGAR10), although the slope differences are not significant (Figure 3). Therefore, the variation of the noise level with speed is similar in all surfaces for the three vehicles, what indicates that mixes with asphalt rubber have the same behaviour when noise and speed levels are concerned.

Average noise level versus type of surface

The average noise level for each nominal speed level (50 km/h, 70 km/h and 90 km/h) and type of vehicle is presented in Figure 4.

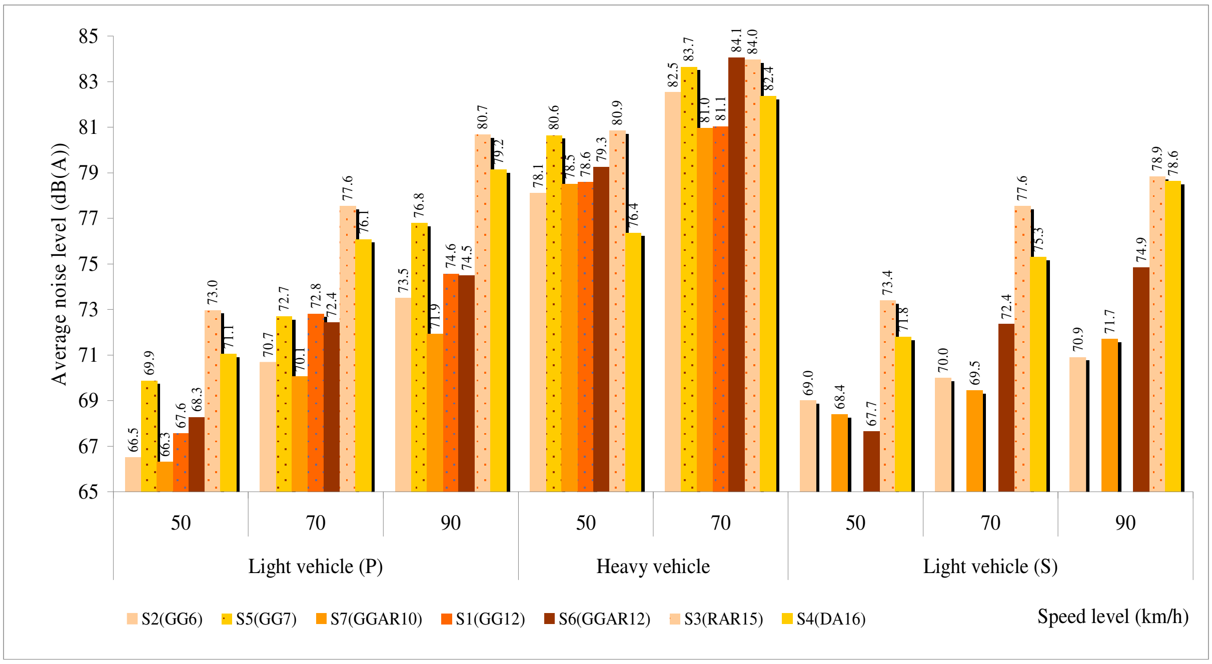


Figure 4 –Average noise level versus speed in each section (sorted into the increasing MAS)

As far as the light vehicles are concerned, surfaces S2(GG6) and S7(GGAR10) generate the lowest noise levels the range of which is [66 - 74] dB(A) for the three speed levels. On the contrary, surface S3(RAR15) generates the highest noise levels the range of which is [73 - 81] dB(A). For these conditions, the difference between the highest and the lowest value increases with speed and ranges from 6.7 dB(A) to 8.8 dB(A).

For the heavy vehicle and at a speed level of 50 km/h, surface S4(DA16) generates the lowest noise level while at 70 km/h surfaces S3(RAR15), S5 (GG7) and S6(GGAR12) have the highest values (84 dB(A)). In this case, the difference between the highest and the lowest value is significantly smaller and decreases with speed. Nevertheless, these differences are 4.5 dB(A) and 3.1 dB(A).

Nevertheless, for both the heavy vehicle and the speed of 50 km/h, the tyre-road noise may not dominate on engine noise. Therefore, the differences in the noise level may be due to engine noise variation at the different pass-bys. This could be checked by switching off the engine during pass-by.

Average noise level versus reference surface

With this analysis it is intended to determine the benefits on noise abatement for the tested surfaces relatively to the most common surface used in Portugal, with special focus on those mixtures with asphalt rubber.

In Figure 5 the variation of the average noise level for each nominal speed level (50 km/h, 70 km/h and 90 km/h) taking surface S4(AD16) as a reference is depicted. The negative values indicate that the noise level is smaller than the one of the reference surface.

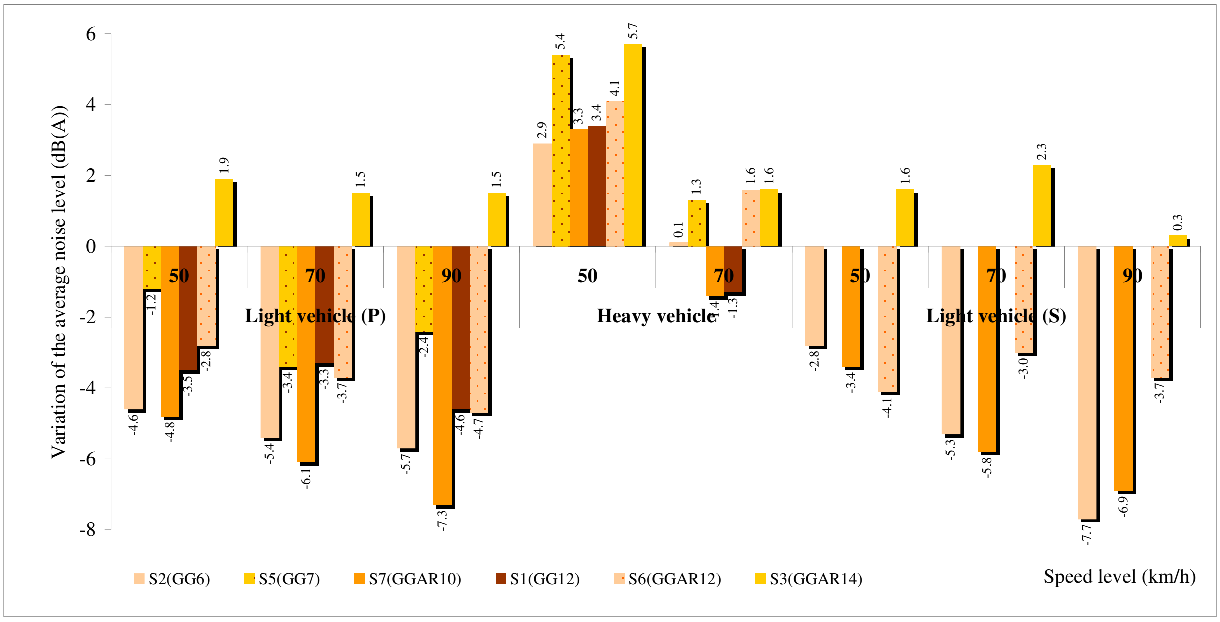


Figure 5 –Variation of the average noise level regarding reference surface S4 versus speed (surfaces sorted into the increasing MAS)

In relative terms, Figure 5 clearly shows that surface S3(RAR15) increases noise regardless the testing conditions.

At 50 km/h and for the heavy vehicle all surfaces generate more noise than the reference surface (> 2.9 dB(A)). This should be checked as previously referred. At 70 km/h surfaces S1(GG12) and S7(GGAR10) slightly reduce noise (1.4 dB(A)).

As far as the light vehicles are concerned, all the surfaces produced significantly less noise than the reference surface, with the exception of surface S3(RAR15). Surface S2(GG6) and surface S7(GGAR10) obtained quite similar results. The noise abatement for these surfaces, for the speeds of 50 km/h, 70 km/h and 90 km/h was about 5 dB(A), 6 dB(A) and more than 7 dB(A), respectively. Surfaces S1(GG12) and S6(GGAR12) also had similar results, comprising reductions between 3 and 5 dB(A).

CONCLUSIONS

This paper deals with the noise produced in seven selected surfaces in road sections under traffic loading, three of which with rubberized asphalt binder. The noise tests were based on the pass-by method. They were carried out using three vehicles (one heavy vehicle and two light vehicles) at three speed levels. From the analysis of the results regarding the noise level versus speed, average noise level versus type of surface and average noise level versus reference surface, the following conclusions may be stated:

- The repeatability of the results is generally good, as it can be observed by the small data bias;
- The noise level increases the most with speed on surface S4(DA16);
- The noise level increases the least with speed on surface S7(GGAR10);
- For both the three speed levels and the light vehicles, surfaces S2(GG6) and S7(GGAR10) generate the lowest noise levels and S3(RAR15) generates the highest noise level values;
- For the heavy vehicle at 70 km/h, surfaces S3(RAR15), S5(GG7) and S6(GGAR12) have the highest noise levels, with 84 dB(A);
- In relative terms, surface S3(RAR15) increases noise regardless the testing conditions;
- With the exception of surfaces S1(GG12) and S7(GGAR10) at 70 km/h, the noise level is higher than the reference one when the heavy vehicle is concerned;
- For the light vehicles, the noise abatement provided by surfaces S2(GG6) and S7(GGAR10) for the speeds of 50 km/h, 70 km/h and 90 km/h is about 5 dB(A), 6 dB(A) and more than 7 dB(A), respectively;
- Surfaces S1(GG12) and S6(GGAR12) also have similar results, comprising reductions between 3 and 5 dB(A).

As opposed to what was expected the mixtures with rubber did not show a significantly better performance than the other mixtures. In fact, the same performance may be achieved with other type of gap graded thin mixtures. The results obtained might be better explained if other parameters than the asphalt bitumen modified with rubber had been taken into account. Grading and porosity seem to have a greater influence. For example, surfaces S3(RAR15) and S4(DA16), which provided the highest noise levels, have both the biggest maximum grain size and the lowest porosity.

On the contrary, surface S2(GG6) has the smallest maximum grain size whereas the maximum grain size of surface S7(GGAR10) is 10 mm and both provide the lowest noise levels. The effect of the grain size on noise generation must have been compensated by the effect of the voids content (6.6% and 13.6%). Nevertheless, surfaces S1(GG12) and S6(GGAR12) provide similar noise levels and have similar grading. In this case neither the porosity nor the rubber seems to have an effective influence.

Further work is being carried out regarding the effect of texture spectra on noise generation. Besides this, it is intended to perform sound absorption tests in all the surfaces analysed in order to gain more insight into this issue and fully understand the effect of the rubber on noise generation.

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