Crumb Rubber Modified Asphalt Concrete for Low Noise Surfaces

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ABSTRACT. *The principal advantage of introducing some percentages of crumb rubber in production of asphalt mixtures is related to pavement environmental sustainability, since this process allows to recycle a significant amount of an industrial waste and, in some specific cases, to reduce tire/road noise emissions; there are some other not unanimously recognized advantages related to this process that are the improvement of asphalt mixture mechanical properties and durability as well as friction on pavement surface. This paper reports on a research project carried out to evaluate the advantages of using crumb rubber in construction of low noise gap graded asphalt concrete surfaces, specifically designed to reduce rolling noise by optimizing surface texture. The study also aimed to define the mechanical and functional performances of the mix obtained by using the wet process in order to assess its potential for use as viable alternative to other low noise asphalt surfaces aimed to improve pavement sustainability by reducing environmental, social and economic impacts. Results of laboratory and on site tests, carried out on one specifically built field trial, clearly show this mix can have optimal mechanical and functional performance as well as it can reduce tire/road noise and warrant greater durability of wearing layers; this considering, crumb rubber modified asphalt concrete can be classified as a construction material that can enhance the three dimensions of sustainability.*

KEYWORDS: *environmental sustainability, low noise asphalt surface, wet process, crumb rubber, pavement sustainability*

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1. Introduction

Scrap tires form a major part of the world’s solid waste management problem; in addition, market groups forecast that in the next years post consumer tires will increase. At the same time, the increasing demand for road transportation has caused serious problems of noise pollution due to vehicular traffic.

These are only two of the problems resulting from the continuous increase in transportation demand, which has prompted the international scientific community to search for innovative solutions that allow to use crumb rubber tire in asphalt pavements.

The advantage of using crumb rubber in the production of asphalt mixtures is not limited to the improvement of road sustainability, but it can be related to an improvement of mechanical properties or a reduction of noise emissions, in addition an increase of friction ([1], [2] and [3]). At the present time, the international scientific community is not unanimous in judging the positive effects of crumb rubber in terms of reduction of noise emission. According to Sandberg and Ejsmont [4] there is no evidence that the insertion of small quantities of crumb rubber within asphalt mixtures can allow to significantly reduce tire/road noise.

The use of crumb rubber in asphalt pavements dates back to many years ago ([5] and [6]). In the Wet process, crumb rubber and bitumen are mixed and left to react at high temperatures: the final result is known as “Asphalt Rubber (AR)” ([5], [6] and [7]). The AR is used as a modified bitumen in the production of porous asphalt concretes (open graded) and gap graded asphalt concretes characterized by binder percentages ranging between 7 and 9%, to which corresponds a crumb rubber percentage of 1 – 1.5% on the mixture weight. Moreover, for the need of allowing the reaction between bitumen and crumb rubber ([8], [9] and [10]), in the Wet process it is necessary to use specific mixers for production of the modified asphalt at high temperatures.

This paper reports on research conducted to evaluate the feasibility of using AR in the construction of low noise gap graded asphalt surfaces. The study also aimed to define the mechanical and functional performances of the resulting mix in order to assess its potential for use as a viable alternative, in terms of environmental compatibility and costs, to low noise open-graded asphalt surface. This mix allows optimal mechanical and functional performance, it reduces tire road noise and guarantees greater durability of wearing layer performance; in addition, it is environmentally friend, by offering a better life-cycle assessment for scrap tire.

2. Use of crumb rubber modifier in asphalt mixes

The material widely used in vehicle tires is Styrene-Butadiene-Rubber (SBR) that is a synthetic rubber copolymer consisting of styrene and butadiene. It has good abrasion resistance and good aging stability when protected by additives; crumb rubber used in this study comes from mechanical grinding of scrap tires at room temperature; they are represented by 50% by weight of truck tires and 50% by weight of car tires. Figure 1 represents size gradation of crumb rubber used to produce gap graded mix, according to the wet processes, overlaid to the typical CRM gradations for production of the Asphalt Rubber. The size gradation of crumb rubber fulfils the requirements of CRM for the production of Asphalt Rubber [11].

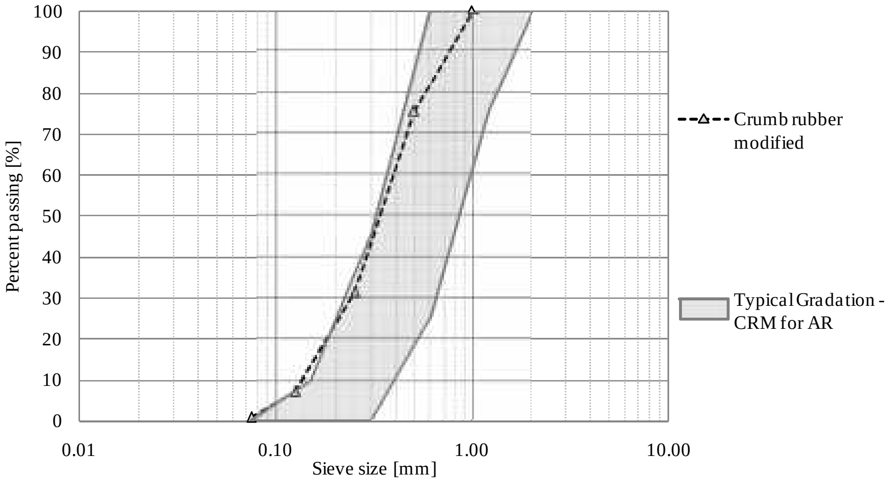

Figure 1. *The size gradation of crumb rubber*

3. Description of experiment

The experiment involved a first step of mix design to define the aggregate grain size distributions and the optimum asphalt contents to be used in the mix; in the second step, laboratory tests were carried out to evaluate mixture performance.

The gap graded asphalt mixture produced by the wet process, was utilized for a surface layer, 3 cm thick, laid on a roughly 150 m long test section within the “Leopoldo” research project [12]. This project has the specific aim of improving road safety and environmental compatibility.

Cores were taken from pavement to check the compliance with the design mixture in terms of aggregate gradation, asphalt content and air void percentage. The in-situ characteristics of the mixture was substantially the same of the laboratory mixture with regard to the aggregate gradation and the bitumen content;

as far as the air void contents of in situ mixture, they were approximately 2% more than the air void contents of the laboratory mixture.

This asphalt wearing course was then evaluated in terms of surface characteristics (friction and texture) and acoustic performance.

4. Mix design

Mix design was carried out by the volumetric method. The optimum asphalt content was identified by optimizing the air void contents.

4.1. Aggregate gradation

Physical properties of aggregates, determined according to the UNI-EN 1097-6/7 procedures, are shown in Table 1.

Physical proprieties	Basalt 4/6	Sand	Mineral Filler
Bulk Specific Gravity (kg/m^3)	2753	2629	2650
Apparent Specific Gravity (kg/m^3)	2863	2690	2650
Water Absorption (%)	1.39	0.86	0.00

Table 1. *Asphalt binders characteristics*

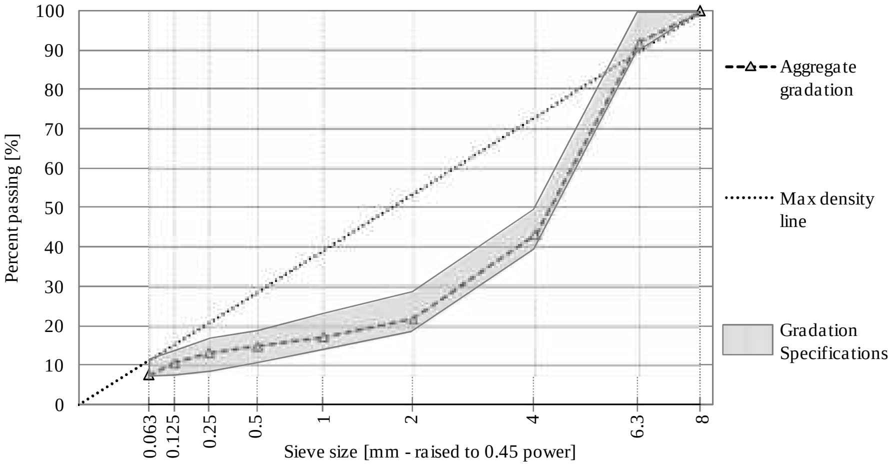

Figure 2. *Aggregate size gradation*

The grain size distribution of the studied mixture respects the aggregate gradation required by the project specifications for gap graded asphalt mixtures with the maximum aggregate size equals to 8.0 mm (Figure 2).

The resulting internal structure of the mixture determined by the discontinuous aggregate grading curve can be appreciated in Figure 3.

Figure 3. *Internal structure of the mixes*

4.2. Optimum asphalt content and volumetric properties of the mixture

The aggregates were mixed with Asphalt Rubber (AR) (Table 2), consisting of 20% CRM by weight of binder and the remaining 80% of 50-70 penetration grade bitumen. The optimum asphalt content of the mix was determined by gyratory compaction, assessing the volumetric characteristics of four mixtures with asphalt contents ranging from 7.5% to 9.0% (Table 3).

In determining the volumetric properties of the mixes, the aggregate absorption percentage was assumed to be equal to 1/3 of water absorption, as required by UNI EN 12697-5.

From the mix design it is possible to determine the optimum percentage of bitumen capable of minimizing the void percentage and guaranteeing at the compaction level N_{max} a void volume higher than 2% and at the compaction level N_{design} a void volume ranging between 3 – 5%. From the results obtained it was selected the optimum bitumen content equal to 8.5%.

	Unit	Value	Reference
Penetration at 25 °C	Dmm	25 – 55	UNI EN 1426
Softening point, Ring & Ball	°C	≥ 58	UNI EN 1427
Fraass breaking point	°C	≤ -7	UNI EN 12593
Flash Point	°C	≥ 250	EN ISO 2592
Elastic recovery at 25 °C	%	≥ 70	UNI EN 13398
Resistance to hardening RTFOT (163 °C – UNI EN 12607-1)			
Loss in mass	%	≤ 0.5	UNI EN 12607-1
Retained penetration at 25 °C	%	≥ 45	UNI EN 1426
Increase in softening point	°C	≤ 12	UNI EN 1427

Table 2. *Physical properties of aggregates*

	Number of gyrations	VA (%)	VMA (%)	VFA (%)	Gmb (kg/m3)	Gmm (kg/m3)	VG (%)	VB (%)
AC=7.5 %	$N_{initial}$=10	14.00	25.98	46.13	2191	2547	74.02	11.98
	N_{design}=50	6.81	19.79	65.60	2374	2547	80.21	12.99
	N_{max}=130	3.95	17.33	77.21	2446	2547	82.67	13.38
AC=8.0 %	$N_{initial}$=10	13.01	26.30	50.51	2191	2519	73.70	13.28
	N_{design}=50	5.85	20.22	71.09	2372	2519	79.78	14.38
	N_{max}=130	3.02	17.83	83.06	2443	2519	82.17	14.81
AC=8.5 %	$N_{initial}$=10	12.19	26.44	53.90	2197	2502	73.56	14.25
	N_{design}=50	5.01	20.43	75.47	2377	2502	79.57	15.42
	N_{max}=130	2.17	18.05	87.96	2448	2502	81.95	15.88
AC=9.0 %	$N_{initial}$=10	11.70	26.86	56.43	2195	2486	73.14	15.16
	N_{design}=50	4.54	20.92	78.31	2373	2486	79.08	16.39
	N_{max}=130	1.71	18.58	90.80	2443	2486	81.42	16.87

NOTE: AC, asphalt content as percentage of mass of aggregates; VA, air voids; VMA, voids in mineral aggregate; VFA, voids filled with asphalt; Gmb, bulk density of the compacted mixture; Gmm, maximum density of the mix; VG, volume of aggregate, the bulk volume including the aggregate pores; VB, volume of effective asphalt binder.

Table 3. *Volumetric properties of the mixes*

In Figure 4 the gyratory densification curve of the studied mixture is compared to the curves obtained for a dense asphalt concrete 0/8 mm (DAC 0/8) with 5.5% bitumen (50-70 penetration grade pure bitumen) and for a stone mastic asphalt 0/8 mm (SMA 0/8) with 7.2% bitumen (50-70 penetration grade polymer modified asphalt). The results show that the curve referring to the studied mixture has a slight steeper slope and a higher density than the curves referring to the DAC 0/8 and SMA 0/8. This highlights that, at the same compaction temperatures, the studied mixture shows better compaction properties as compared to DAC 0/8 and to SMA 0/8.

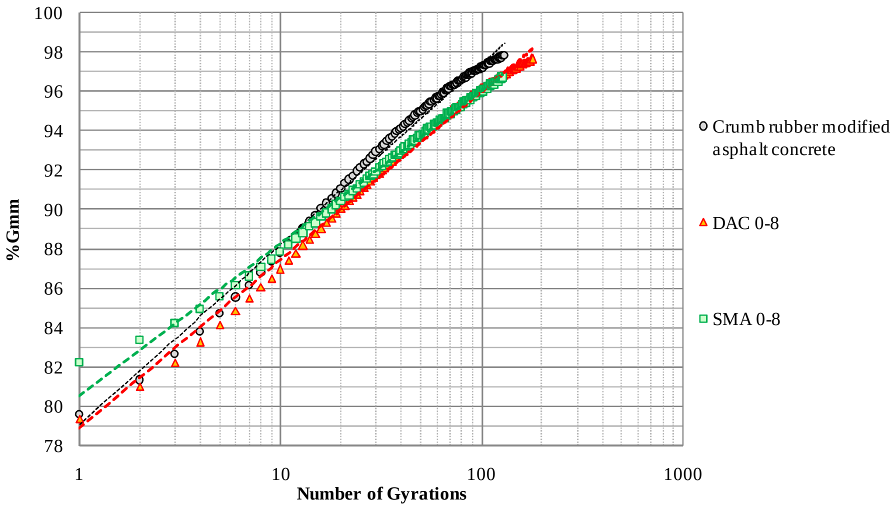

Figure 4. *The gyratory densification curves of the studied mixture*

5. Mechanical characteristics of the mixture

In order to characterize the mix from a mechanical point of view, Indirect Tensile Strength Tests, Resilient Modulus Tests and Fatigue Resistance Tests were carried out on specimens compacted by the Gyratory Compactor at N_{design}. These parameters allow to check both the compliance of the mixture with national specifications for wearing courses and to compare performance of AR with polymer modified asphalt. Considering the reduced thickness of the layer (30 mm), the rutting performance was neglected.

5.1. Indirect tensile strength

Indirect Tensile Strength (ITS) measurements were carried out at the temperature of 25°C, according to UNI EN 12697-23. ITS values (Table 4) are higher than the minimum values required by the national standards for gap graded asphalt mixes to be used as wearing courses. To evaluate moisture susceptibility, the Indirect Tensile Strength Ratio (ITSR) according to UNI EN 12697-12 was determined. This is represented by the ratio between ITS of samples after conditioning in water (ITS_w) and ITS of unconditioned samples (ITS_d). The results obtained (Table 4) clearly show that no problems pertaining to moisture susceptibility arise for the studied mix.

Sample	Mechanical properties			Specifications	
	ITS_d at 25°C (N/mm^2)	ITS_w at 25°C (N/mm^2)	ITSR (%)	ITS_d at 25°C (N/mm^2)	ITSR (%)
1	0.70	0.62			
2	0.70	0.73			
3	0.78	0.69			
Mean value	0.73	0.68	93.6	≥ 0.60	≥ 75
St. Dev.	0.05	0.06			
COV (%)	6.4	8.2			

Table 4. *Indirect tensile strength test results*

5.2. Resilient modulus

In order to evaluate mix stiffness, the laboratory resilient modulus (M_R) was determined by the indirect tensile test on cylindrical specimens (IT-CY) according to UNI EN 12697-26 Annex C procedure. M_R values of the studied mix are shown in Table 5 together with values determined on specimens of a stone mastic asphalt 0/8 mm (SMA 0/8), containing 7.2% bitumen (50-70 penetration grade polymer modified asphalt) and compacted according to the same procedure at N_{design}. Results obtained by the studied mix showed an increase of 50% in M_R mean values compared to the SMA 0/8. This increase can be explained by the greater stiffness of Asphalt Rubber binder as compared to polymer modified asphalt binder.

5.3. Fatigue resistance

The fatigue resistance was determined by the Indirect tensile test on cylindrical specimens (IT-CY) according to UNI EN 12697-24 Annex E. Tests have been carried out at the temperature of 20°C and at a load repetition time equal to 500 ms.

Figure 5 shows the plot of fatigue resistance curve for the studied mixture together with fatigue resistance curve determined on specimens of a stone mastic asphalt 0/8 mm (SMA 0/8), containing 7.2% bitumen (50-70 penetration grade polymer modified asphalt). The studied mixture shows fatigue resistance curve almost overlapping with SMA 0/8. This means that Asphalt Rubber binder shows fatigue attitude similar to that of modified asphalt binder. In particular the studied mixture shows a greater fatigue resistance at high strains and a lower fatigue resistance at low strains compared to the SMA 0/8.

Sample	Cycle duration (s)	Rise time (ms)	Test temperature (°C)	M_R (MPa)	
				Studied mix	SMA 0/8
1	3 ± 0.1	124 ± 4	20	3247	2872
2	3 ± 0.1	124 ± 4	20	3521	2020
3	3 ± 0.1	124 ± 4	20	3515	2851
4	3 ± 0.1	124 ± 4	20	3818	1723
Mean value				3525	2367
St. Dev.				233	585
COV (%)				6,6	24,7

Table 5. *Resilient modulus test results*

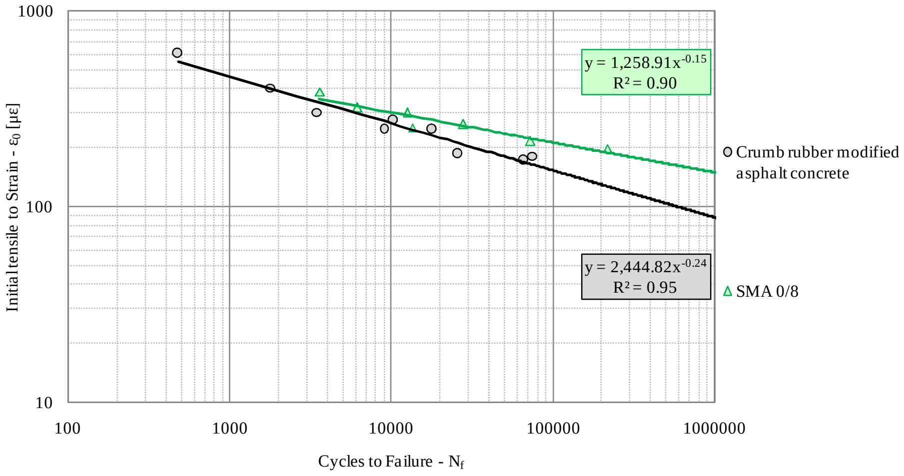

Figure 5. *Fatigue resistance curves*

6. Field performance

Performances of the experimental wearing course (Figure 6) were evaluated in terms of surface characteristics, texture, friction and acoustic performance only on a short time interval since the pavement was laid in 2010. In order to evaluate field performance over time, factors like real traffic loading and climatic situation should be taken into account, but this short time isn't enough to draw valid considerations that, at this stage, can be only qualitative. The evaluation of acoustical properties of experimental road sections was conducted by the Environmental Protection Agency of Tuscany.

Figure 6. *Crumb rubber modified asphalt concrete*

6.1. Texture

Surface texture was determined by recording the pavement profiles with a mobile laser profilometer.

The mobile profilometer was used for continuous recording of the pavement profile at sampling intervals of 1 mm. MPD values were evaluated from the profile, allowing ETD estimation ([13]) of the entire experimental section. Figure 7 shows the variation of the texture at different age; the texture is expressed in terms of the mean of ETD values over 10 m long sub-sections, together with the MTD threshold value. Over time, the studied mixture shows texture values which are higher than the threshold value.

Using the profile recorded by the mobile profilometer, we calculated the one-third octave band mean texture spectrum (L_{tx}) on the wavelength range between 2 mm and 250 mm, according to the ISO/CD 13473-4 and 5 procedures.

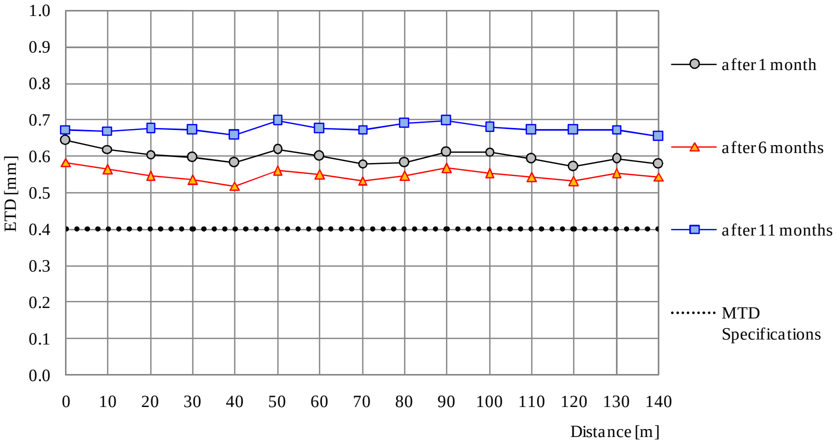

Figure 7. *Texture profiles*

Figure 8 shows the texture spectra of the experimental wearing courses together with the typical spectrum of a dense asphalt concrete (DAC) with maximum chipping size equal to 12 mm. In order to obtain a low noise asphalt surface capable of reducing tyre/road noise emissions as compared to the noise level of a traditional asphalt surface, the texture spectrum (Figure 8) should have the following characteristics ([13] and [14]):

- the highest L_{tx} value should be found in the wavelength λ fields < 10 mm;

- L_{tx} values should tend to minimum values in the wavelength λ fields > 10 mm.

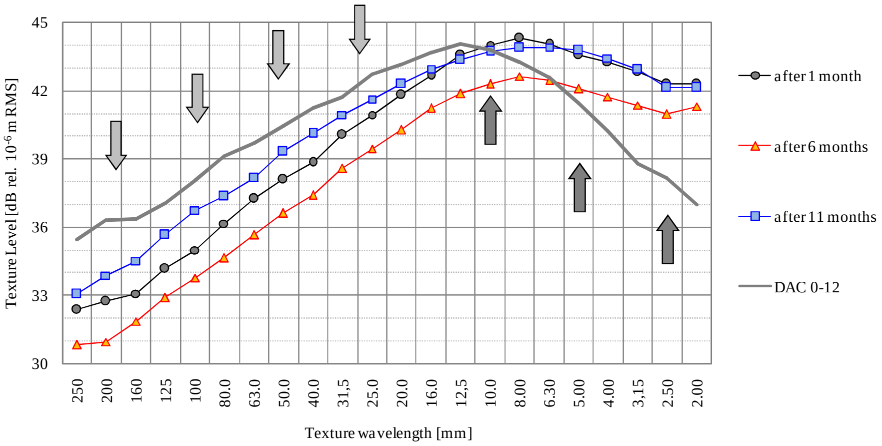

Figure 8. *Texture spectrums*

Figure 8 clearly shows that over time the studied mix fulfils these requirements; in particular the studied mixture shows an increasing macrotexture amplitude at low wavelengths and a decreasing macrotexture amplitude at high wavelengths. As described in the following sections, these results were confirmed by the measurement of rolling noise.

6.2. Friction

Friction measurements were carried out by using Skiddometer BV11 equipment. The test was conducted at a speed of 20 km/h, by adequately wetting the pavement in order to simulate the presence of a 1 mm thick water film.

By using the PIARC model, and after suitably calibrating the model parameters for the specific equipment used, the Friction Number (F60) of the International Friction Index (IFI) was determined on the basis of friction values measured by the Skiddometer BV11 and texture values (MPD) measured by the mobile profilometer.

Figure 9 shows the values measured for F60, averaged over 10 m, together with the friction threshold likewise expressed in terms of F60, determined from the national standards for a newly built traditional asphalt surface, which is characterized by a Speed Constant (Sp) equal to 33.85 km/h. The results show the optimum friction levels which can be obtained over time by using the studied mix.

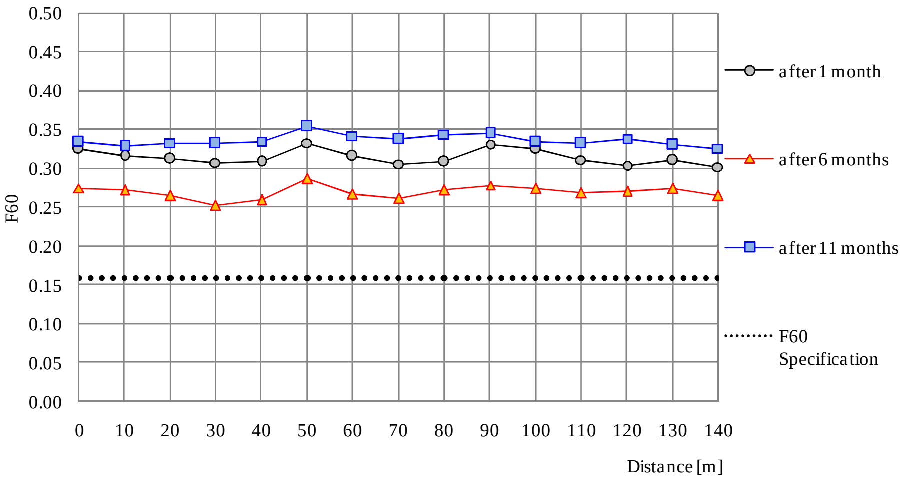

Figure 9. *Friction*

The friction levels measured are roughly two times the levels required by the technical specifications, which can be obtained by using crumb rubber modified in the production of asphalt concrete. This is due to the high adhesion of the asphalt rubber binder to the aggregate in order to guarantee optimal friction levels which also increase road safety by reducing significantly stopping distance.

6.3. Acoustic performance

The basic assessment of acoustical properties of the research mix was carried out by an in situ set of measurements, according to the ISO 13472-1 ("Adrienne" Method), and to the ISO/CD 11819-2 ("Close-Proximity Index" Technique), as modified in [15]. Measurements were carried out at air and pavement temperatures within the ranges defined by the standards. Moreover, the software provides to automatically correct the output according to the same standards.

The Adrienne Method allows to compute the sound absorption coefficient of the asphalt surfaces, defined as the rate of energy not reflected by the ground, which is measured for normal incidence of acoustical waves. Figure 10 shows the sound absorption of the experimental wearing courses. Total extended uncertainties (i.e. the random uncertainty UcA composed with systematic one UcB with 95% coverage factor, see G.U.M.) are also plotted as error bars. The results show no meaningful absorption may be found for the studied mixture.

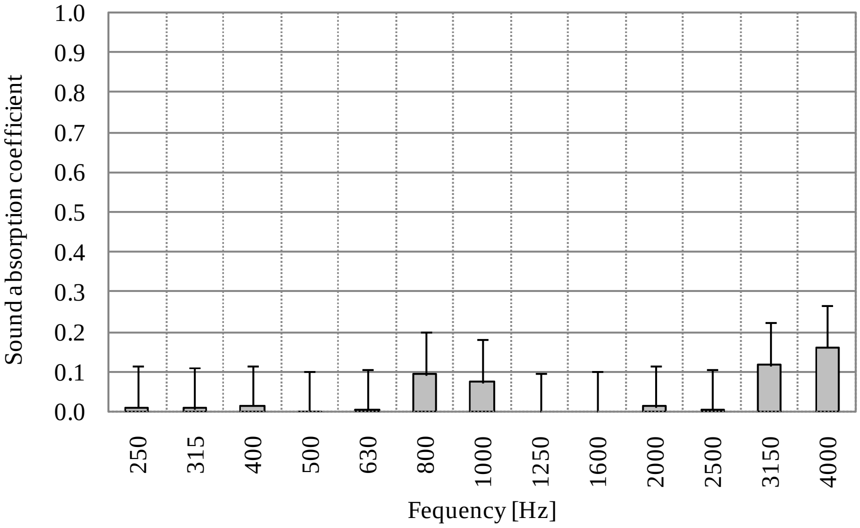

Figure 10. *Sound absorption coefficient.*

Concerning CPX method, it allows evaluation of the influence of pavement surface characteristics on tire/road noise. Acoustical measurements have been performed at speeds of 50 km/h and 80 km/h, at different times, in order to assess the time evolution of the studied mixture acoustic performance.

The global CPXL level differences between each experimental wearing course and an old traditional surface, which was composed of a DAC with 16.0 mm max chipping size, are about 4.5 dB(A) at 50 km/h and about 5.0 dB(A) at 80 km/h (Figure 11). The results highlight the benefits, in terms of reduction in tire/road noise emissions that can be obtained by using crumb rubber modifier in the production of low noise asphalt surfaces. Reductions of about 5.0 dB(A) can be obtained only with low noise porous asphalt surfaces.

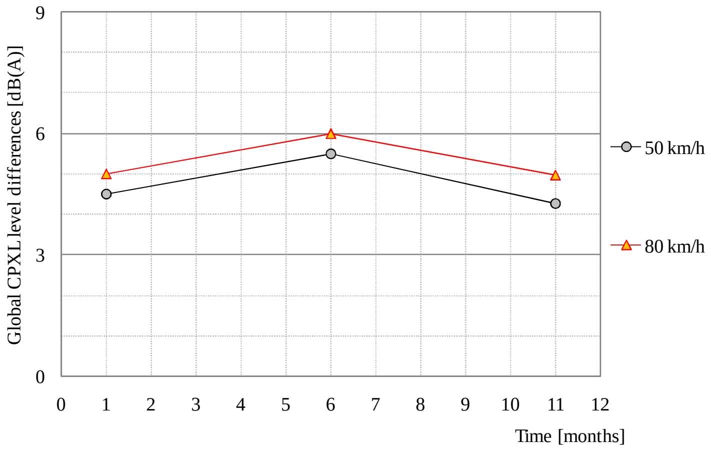

Figure 11. *Global CPXL level differences between the studied mix and DAC 0/16*

In order to quantify reduction in sound emission for each 1/3 frequency band, figure 12 shows the comparison of the differences between the CPX levels of the studied mixture and those of the reference mixture for the two reference speeds. The results show at 50 km/h a reduction higher than 5 dB in the frequency region ranging between 315-1000 Hz, while at 80 km/h at the same frequency range the reduction is higher than 6 dB. This means that by using the crumb rubber modified asphalt concrete it is possible to obtain high reductions on noise produced by vibration mechanisms.

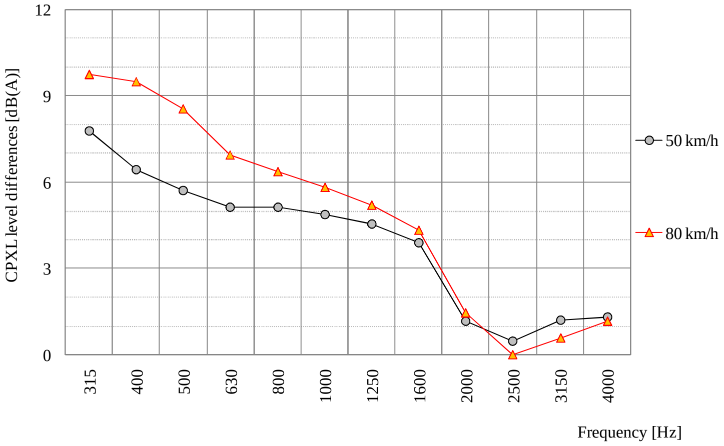

Figure 12. *CPXL level differences between the studied mix and DAC 0/16*

7. Conclusions

This paper aimed at evaluating the possibility of using crumb rubber modifier in the construction of low noise asphalt surfaces by using the wet process. Accordingly, the study also aimed at defining the mechanical and functional performances of the resulting mix in order to assess its potential for use as a viable alternative, in terms of environmental compatibility and cost, to low noise open-graded asphalt surface.

The results of laboratory and in situ tests showed that:

- the optimum bitumen percentage is equal to 8.5%. Furthermore, at the same compaction temperatures, the studied mix shows better compaction properties as compared to DAC 0/8 and SMA 0/8.
- The mix shows Indirect Tensile Strength values which are higher than the minimum values required by the national standards for gap graded asphalt mixes to be used as wearing courses. No problems pertaining to moisture susceptibility arise for the studied mix.
- The mix shows a 50% increase in the Resilient Modulus as compared to the SMA 0/8 with polymer modified asphalt binder. This increase can be due to the greater stiffness of the AR binder as compared to the polymer modified asphalt binder.
- The studied mix shows a fatigue resistance curve which almost overlaps with SMA 0/8 with polymer modified asphalt binder. This means that Asphalt Rubber binder shows fatigue attitude similar to that of modified asphalt binder. In particular

the studied mixture shows a greater fatigue resistance at high strains and a lower fatigue resistance at low strains compared to the SMA 0/8.

- The experimental mix shows texture values which are higher than the threshold value. The spectrum revealed a texture composed by fairly contained amplitudes for $\lambda > 10$ mm and high amplitudes for $\lambda < 10$ mm; this represents the essential characteristics for low noise asphalt surfaces.
- The friction levels recorded for the experimental mix underline the increased level of traffic safety that can be obtained by using crumb rubber modifier in the production of asphalt surfaces. Over time the mix shows friction levels which are roughly two times the levels required by the national standards for a newly built traditional asphalt surface. This is due to the high adhesion of the Asphalt Rubber binder to the aggregate.
- Acoustic absorption coefficient measurements show that no meaningful absorption may be found for the experimental mixtures.
- The global CPXL level differences between the AR wearing course and the reference traditional surface DAC 0-16 are about 4.5 dB(A) at 50 km/h and about 5.0 dB(A) at 80 km/h. It is important to highlight the benefits, in terms of reduction in tire/road noise emissions, that can be obtained by using crumb rubber modified in the production of low noise asphalt surfaces.

8. Acknowledgments

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