SPB and CPX results of rubberized surfaces in the Italian urban and extra-urban context

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ABSTRACT

Road traffic is the main noise source in urban context and a road surface with low emission characteristics is one of the most applied solutions for noise mitigation actions. Road pavement incorporating rubber (also known as rubberized surface) is a solution often applied all over the world and it has the great environmental benefit of recycling the scrap tires. In Italy the rubberized technologies have been introduced quite recently and some experimental installations have been acoustically studied in the last years. These experimental surfaces have been laid on extra-urban road and exposed to the wear due to the real traffic, in order to verify the time durability of the noise mitigation action too. In this work, data obtained from both Close Proximity method and Statistical Pass-By measurement sessions carried out on some rubberized experimental surfaces are shown. Results show clearly that the rubberized surface can be an efficient mitigation action also in the Italian context. Anyway, in some cases here analyzed the lowering of the emission level was almost negligible and this could be blamed to binding technical skills required by the rubberized surface technology but not perfectly complied during the installation.

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1. INTRODUCTION

Road traffic is the main noise source in urban contexts and road surface with low emission characteristics are one of the most applied solutions for the reduction of the population noise exposure. In several EU co-funded projects (as SILVIA (1), QCITY (2) and SILENCE (3)) many solutions were proposed and studied. One of the identified solution is based on asphalts pavements incorporating rubber (also known as rubberized surfaces), which has the great environmental benefit of contributing in the scrap tires recycling. In Italy, some studies were performed aiming to verify the efficacy of rubberized surface used as acoustic mitigation action in real scenarios. In this paper results of these studies are shown in terms Close Proximity (CPX) (4). In particular, the results obtained one year after the laying are compared for all the surfaces considered.

Moreover, results of the long term campaign on a rubberized experimental surface are presented in terms of both CPX and and Statistical Pass By (SPB) (5). This experimental surface was laid within the Italian LEOPOLDO project (6) which has been developed in Tuscany since 2006 to monitor the acoustical characteristics of several experimental surfaces.

2. RUBBERIZED SURFACE TECHNIQUES

Rubberized surface technology uses crumb rubber as a modifier in asphalt mixtures, as described in (7) or in (8), in some ASTM (American Society for Testing and Materials) documents (9) and its successive editions.

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The addition of Crumb Rubber Modifier (CRM) into the binder increases its elasticity and resilience, and it improves the durability and the resistance to fatigue and also the reflective cracking in hot mixes and chip seal applications.

Rubber can be incorporated into asphalt paving mixes through two main different methods, which are referred to as the wet process and the dry process. In wet processed rubberized surfaces the crumb rubber is blended with asphalt cement before the binder is added to the aggregate. On the contrary, in the dry process rubber granules are used as a substitute for a small portion of the fine aggregate (from 1 to 3%) and they are blended before the addition of the asphalt cement. Surface layers made of asphalt using rubber crumb have been laid all over the world in dense-graded, open-graded, or gap-graded mixtures(10) and they have been recognized as a low noise emission solution (11),(12),(13).

3. MEASUREMENT METHODS

The LEOPOLDO project analyzed surfaces with many different techniques, to assess low noise emission and structural characteristics. Acoustical performances have been monitored through Adrienne method (14), Impedance Tube (15), Statistical Pass-By and Close Proximity Method. A brief description of the implementation of the last two methods in our operative context is here provided, since all roads surfaces here considered are dense graded and neither Adrienne nor the Impedance tube method produce relevant results (i.e these surfaces are not acoustically absorbing).

3.1 The Close Proximity (CPX) method

The CPX method uses two microphones placed close to the tire to measure the tire-road noise as far as it dominates all other noise sources. In this paper, an adapted measurement and data post-processing methodology based on the CPX method is used (16). Results are shown in terms of tire/road noise levels, without strictly referring to CPX indexes, but for the sake of simplicity they are hereafter referred as L_{CPX} values. Mainly, the set-up is based on the measurement system described in several papers (17, 18, 19, 20) in which microphones are mounted on a self-powered vehicle. During the measurement session, acquisitions over the tested surface are repeated several times varying the vehicle speed, typically between 35 and 90 km/h.

In the post-processing step, data analysis is based on the spatial resolution of 5.84 m (this basic space is called a “section”, defined as three times the tire circumference, i.e. just about 5.84 m for the tire used). The sound pressure level $L_p(i)$ associated to the i-th segment at the reference speed is estimated by fitting $L_p(i)(j)$ level vs. speed both at this segment, by the well-known relationship related v_0:

$$L_p(i) = A(i) + B(i)\log\left(\frac{v(i)(j)}{v_0}\right) \tag{1}$$

where $A(i)$ is the pressure level at v_0 reference speed, $B(i)$ is the speed coefficient, $v(i)(j)$ is the actual speed at the i-th section and j-th repetition. The fit is calculated for each section, for levels if each third octave band, from pressure data obtained as the energy-based averages of the two microphones, in the frequency range from 315 to 5000 Hz. Then, the overall A-weighted equivalent sound pressure level, at the reference speed, associated to the i-th segment, $L_{CPX}(i)$, is obtained through the A-weighted energy-based sum of the third octave band estimated levels, as required by the ISO 11819-2:2011 document.

Finally, the variability in the emission characteristics along the road surface test stretch (homogeneity) is evaluated plotting the $L_{CPX}(i)$ levels versus distance, named L_{CPX} in the following, with its type A uncertainty. The spatial averaged spectrum is computed too.

The adapted procedure prescribes that, in order to minimize the influence of the variability of the results due to measurement conditions, the data acquisition has to be extended during the same survey session over a second road surface, typically one of the types DAC 0/12 or SMA 0/12 as prescribed in (21), close to the test one as much as possible. The chosen surface then become the “reference” because it is a long aged surface presumably acoustically stable in time, or it is a stretch surface as equal as possible to the pre-existing one or at least equal aged.

Thus, the comparison between the two surfaces has to be done to evaluate the acoustical performances of the test one relative to the reference one, this is called "*the differential criterion*" (16).

Moreover, the *normalized* third octave bands spectrum is calculated (4),(16) and it is used to compare the spectral shape of the noise emission between surveyed surfaces in different contexts and/or different measurement sessions.

3.2 Statistical Pass By method (SPB)

Statistical Pass By methodology is applied to study the influence of the surface on the whole road traffic noise, averaged on a relevant amount of passages.

The procedure applied by ARPAT within the LEOPOLDO project combines the technical international standard with the guidelines provided by HARMONOISE project (21), introducing a second measurement position and the use of the sound exposure level (SEL (22)) being more representative of the pass-by than the simple maximum level. The procedure uses a second microphone positioned at 3.0 m height in order to avoid bias due to local context, because of the ground just outside the road carriage, which can change with the location, influences significantly the sound pressure level at 1.2 m height. Both microphones are placed at 7.5 m far from the central line of the measured lane. Thus, the applied procedure consists in measuring the SEL of the various isolated vehicles passing at different speeds. During the post processing analysis the statistical sample, composed by many single passages, constitutes the data for the following logarithmic regression between the measured speed and the SEL. From this regression the SEL at the reference speed (50 km/h) (or any other speed) is estimated for each microphone and frequency band:

$$\mathrm{SEL} = A + B \log\left(\frac{v}{v_0}\right) \tag{2}$$

where A is the SEL at reference speed and B is a speed-related correction.

In this work results are presented only for the light vehicles category (i.e. the L_1 SPB index) because other vehicle categories (23) were not enough populated.

4. RESULTS

Results are presented for four different rubberized surfaces in Tuscany: one of them is the experimental one laid in the framework of the LEOPOLDO project and monitored for a long time to assess maintenance and acoustical characteristics over time, the others are surfaces used as mitigation action in Tuscany. In this case comparison is carried out only through CPX results referred to 1 year after the installation. At that time surfaces have completed to set down structurally and acoustically (24), process that is ongoing in the early months after the laying. In table 1 surfaces and installation details are reported. All the surfaces have depth between 3 and 5 cm and they were laid on urban or extra-urban roads, exposed at high traffic density. What is more, they are in different kind of Italian weather and climatic areas (plain, hill and mountain ground, next or far from the sea, sunny or shady, with narrow or wide air temperature range etc).

Table 1 – One year old special surfaces: installation details. The first is the LEOPOLDO project experimental surface.

ID	Surface	Area	Length	Temperature
1	WET (0/8)	Mountain	150 m	23 °C
2	WET (0/12.5)	Plain	800 m	22 °C
3	DRY (0/6)	Hill	950 m	17 °C
4	WET (0/12)	Plain	450 m	35 °C

4.1 Comparison of 1 year old rubberized surfaces

The analysis of the surfaces is performed in terms of differential values between the rubberized surface and the reference one chosen in accordance with the EU projects HARMONOISE/IMAGINE (see (23)). In particular reference surfaces are all DAC 0/12 usually used in Italy (in Tuscany at least), with installation close to the tested rubberized surface and older than 4–5 year, without apparent damages and discontinuities as crack or patches. They have been surveyed at the same time as the tested rubberized surfaces in order to minimize the measurement condition influence. Nevertheless,the absolute L_{CPX} values of reference surfaces are not all comparable because of different wear due to meteorological conditions and/or potential different traffic density and because of the influences of the measurement condition. In table 2 spatially averaged L_{CPX} at 50 km/h are reported, in terms of differential values, with related associated uncertainties (only the statistical one).

Results are obtained as arithmetic mean of both lanes. The main part of the uncertainty associated to the spatial average values arises from data spatial variability within and between lanes.

Surface 1 and 2 have a sound emission lowering of respectively 4.7 dB(A) and 6.2 dB(A), and these results are clearly better than those obtained for the other surfaces, which show differential values lower than 3 dB(A) (usually the expected minimum gain for a mitigation action). Same conclusions can be drawn from results obtained at 80 km/h. By the end, analyzing results in terms of differential values means concluding that in case of surface 3 site, the real benefit of having used the rubberized surface as mitigation action is an emission

Table 2 – L_{CPX} differential values between special rubberized and reference surface results at 50 km/h

L_{CPX} @ 50 km/h	Differential
1	-4.7 ± 0.5 dB(A)
2	-6.2 ± 1.8 dB(A)
3	-1.2 ± 0.6 dB(A)
4	-1.8 ± 1.0 dB(A)

level of 1.2 dB(A) lower than the reference DAC 0/12. In case of surface 2 site the real benefit is more than 6.0 dB(A) and it is surely more effective.

The wide spread of differential values cannot be completely associated to the different rubberized asphalt techniques, because no clear pattern can be found among these and L_{CPX} levels (see tables 1 and 2). The most reliable explanation is that the variability is also due to the quality of the pavement installation, which depends on the ability of the installer, on the materials used and on the adherence to the technical construction notes for the special pavement.

The last way to compare the four surfaces is by the frequency analysis. In figure 1 the *normalized spectra* are shown.

This type of spectrum has the total energetic sum set to 0 dB and it allows to compare the different energetic spectra in order to identify the different frequency behaviors showing the relative sound pressure levels of each 1/3 octave band.

All surfaces have the spectral peak at 1000 Hz and with the same relative intensity. The only shape details noteworthy are the secondary spectral peak at 2000 Hz shown by surfaces 1 and 2, and the low frequency levels (500–630 Hz) of surface 2 being higher than other surfaces. The secondary spectral peak of surface 1 and 2 have no remarkable effect on the L_{CPX} values because levels at 2000 Hz are 4 dB(A) lower than the 1000 Hz ones and it has a little weight in the overall level.

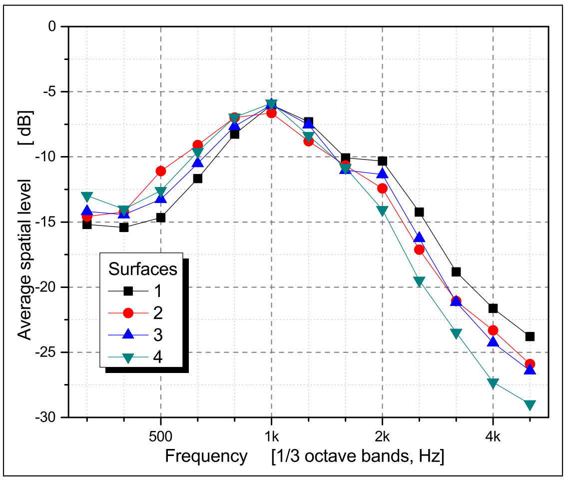

Figure 1 – Spatial mean spectra of the measured rubberized surfaces

On the contrary, a shifting energy towards low frequencies produces a significantly lower overall level, through to the A-weighing. Surely, this is one of the reasons for the good performance of surface 2.

4.2 LEOPOLDO surface

4.2.1 CPX results

As seen in table 1, the LEOPOLDO project experimental surface is a gap graded 0/8 with a bitumen mixture modified by the addiction through the wet process (25) of rubber crumb recycled from scrap tires. The CPX and SPB methods have been applied in several measurement sessions to carry out a four years long monitoring of acoustical performances. Moreover, one month after its laying, a DAC 0/12 surface have been laid next to the rubberized surface and in this paragraph CPX results will be shown using this new DAC as reference, to figure out the different time evolution. Absolute L_{CPX} spatial averages are reported in table 3 and plotted in figure 2.(a) L_{CPX} differential values are reported in the last column of the table and plotted in 2.(b).

All values are calculated at the reference speed $v_0 = 50$ km/h and corrected for the air temperature according to the standard(4). In terms of emission spectra, shown in figure , no significant shape difference can be highlighted among the two surfaces analyzed (there is just a little secondary peak at 2 kHz for the rubberized surface)

Table 3 – Absolute and differential L_{CPX} spatial average values obtained for the LEOPOLDO project surfaces.

Session	Absolute values [dB(A)]		Differential values [dB(A)]
	Rubber	DAC	Differential
1	92.3 ± 0.1	91.9 ± 0.4	0.4 ± 0.4
2	91.5 ± 0.1	92.5 ± 0.3	-1.0 ± 0.3
3	91.7 ± 0.1	93.4 ± 0.3	-1.8 ± 0.3
4	91.6 ± 0.1	93.6 ± 0.3	-2.0 ± 0.3
5	92.1 ± 0.1	94.8 ± 0.4	-2.7 ± 0.4
6	91.6 ± 0.1	94.1 ± 0.4	-2.6 ± 0.4

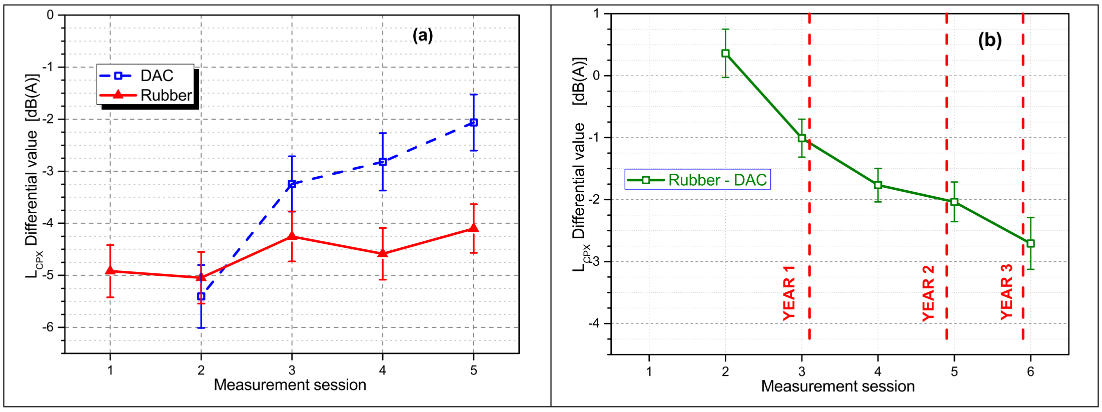

Figure 2 – a) Time evolution of L_{CPX} differential values; b) Time evolution of L_{CPX} differential values obtained as difference between rubberized surface and DAC one. The age of surfaces is indicated by vertical dotted lines.

The rubberized surface shows a good spatial homogeneity and this leads to low uncertainty values. Absolute values shows that DAC noise emission is significantly increasing in time, whereas rubberized surface shows levels quite constant.

L_{CPX} differential values are significantly increasing in time, as highlighted in the figure.

4.2.2 SPB results

Statistical Pass by campaigns have been analyzed too.

In table 4 results and sessions details are reported, all values are calculated at the reference speed v_0 = 70 km/h.

Table 4 – Comparison between L_1 SPB values obtained on rubberized surface site.

Session ID	T [°C]	Number	$L_1^{SPB}(1.2)$ [dB(A)]	$R^2(1.2)$	$L_1^{SPB}(3.0)$ [dB(A)]	$R^2(3.0)$
1	10	86	75.1 ± 0.1	0.67	74.1 ± 0.2	0.64
2	21	157	76.0 ± 0.1	0.63	75.6 ± 0.1	0.63
3	23	102	75.8 ± 0.1	0.78	76.0 ± 0.1	0.76
4	21	66	75.8 ± 0.1	0.67	75.2 ± 0.2	0.70
5	15	146	77.3 ± 0.1	0.72	76.5 ± 0.1	0.70

Typical SPB measurement data are a cloud centered around the usual road speed, in this case 70 km/h.

Sample size is different for each measurement session, as shown in table 4, and the speed distribution, shown in figure 3, can influence the SEL vs. speed regression slope.

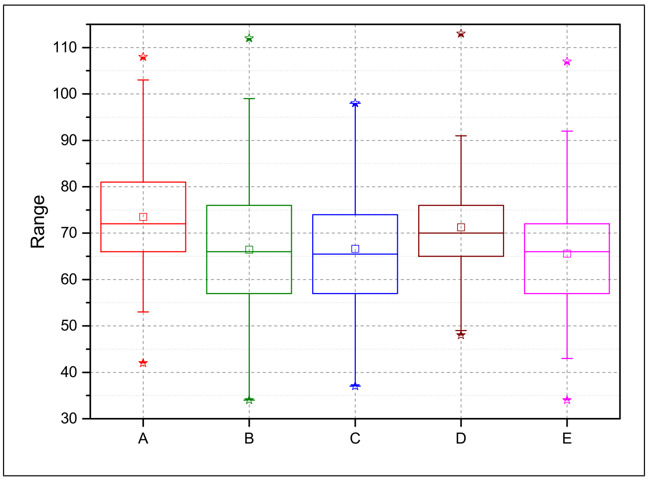

Figure 3 – The boxplots show experimental speed distributions for data collected in the five SPB measurement sessions

The SPB results time distribution does not match with CPX results shown above. Not even temperatures, detailed in table 4, might justify the SPB results and their difference with the CPX ones.

Evidently, the pass-by method suffers the variability of propagation mechanisms as much as the real physical information about the tire-road noise emission is almost hidden. Analogous conclusions have been found within the SILVIA project (26). Modified procedures in order to increase pass-by method accuracy should be matter of further research.

5. CONCLUSIONS

To date, the use of special low noise emission surfaces can be the only solution to mitigate noise for roads with high and continuous traffic flows, especially in urban or extra-urban contexts. Rubberized surface is one of the most used low emission solution spread in the world and it is going to become established also in Italy. Some rubberized surfaces have been used as experimental mitigation actions in Tuscany. It allows to survey four different installations with the CPX method and to compare the results one year after the laying. Moreover, a rubberized surface has been laid within the LEOPOLDO project (a project developed in Tuscany Region which aim is, among other things, monitoring over time some different type of road surfaces to be used to mitigate road noise emissions in future action plans for regional roads co-funded by Tuscany Regional Administration, its Provinces and thew Italian Ministry of Transportation) and it has been possible to monitor its acoustical time-stability with both CPX and SPB methods. All the surfaces here analyzed have no special absorption behavior (no open surfaces were present). Analysis has been performed both wideband or as a function of frequency.

In terms of L_{CPX} values, the LEOPOLDO project surface shows a good spatial homogeneity and a significant noise emission reduction if compared to both its respective *ante operam* and a DAC surface laid at the same time. This acoustical behavior is stable in time. On the other side, the SPB results obtained in five different measurement sessions in the same position near the LEOPOLDO surface spread over three years are not useful to accurately describe the influence of this surface on the tire/road noise emission propagated at roadside. Modified procedures are necessary in order to increase pass-by method accuracy and they are going to be matter of further research.

Besides the LEOPOLDO project experience, other three different rubberized surface installations have been analyzed through the CPX method. The comparison among themselves shows variable results, with differential values between about 1 dB(A) and 6 dB(A). It is argued that the main reason to this variability might be the quality of pavement installation. This statement is clearly shown in some spatial distribution analysis of the L_{CPX} levels.

As clearly demonstrated with two different cases analyzed, the rubberized surface solution can represent a very efficient and well adaptable mitigation action, especially in an urban context where other solutions cannot be applied (i.e. barriers, flow control or open-graded surfaces). In order to avoid action uselessness, it must be considered that the installation of this kind of surface needs care and proficiency complying with the technical specifications.

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