IMPLEMENTATION AND INVESTIGATION OF LOW NOISE AND POLLUTANT-REDUCING PAVEMENTS

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ABSTRACT

This work is focused on the experimental investigation of an innovative low noise asphalt mixture designed within the NEMO (Noise and Emissions MOnitoring and radical mitigation) project, funded by the Horizon 2020 programme (Grant Agreement ID:860441).
The main objectives of the project concern the improvement of air quality and the reduction of noise impact through the implementation of innovative solutions in different scenarios in Europe, such as the use of remote-sensing systems and of low noise and pollutant-reducing asphalt mixtures.
In particular, this paper refers to the study of acoustic performance of an innovative low noise road pavement by means of the Close-ProXimity method (CPX, ISO 11819 2/3). The CPX method allows to evaluate the acoustic emission due to tyre/pavement interaction (rolling noise), that becomes the most important contribution of traffic noise in the mid-to-high speed range.
The pavement investigated, laid in the city of Florence, is a Very Thin Asphalt Concrete (VTAC) surface with discontinuous particle size distribution.
CPX measurements were carried out both on the existing old pavement and on the prototype pavement in order to assess the efficiency and the acoustic benefits related to new installation.

Keywords: *rolling noise, cpx method, acoustic performance*

1. INTRODUCTION

Prolonged exposure to high levels of noise can cause many different negative aspects of human health. Hearing loss, annoyance, sleep disturbance with awakening, cognitive impairment, physiological stress reactions, endocrine imbalance, and cardiovascular disorders have been demonstrated to be correlated to high noise levels [1]. Road traffic is the most widespread noise source in urban context. In most European countries, more than 50 % of inhabitants within urban areas are exposed to day-evening-night road noise levels (L_{den}) equal to or greater than 55 dB or higher [2].
Rolling noise is one of the most important noise pollution sources for traffic noise. Considering a light vehicle, the speed threshold at which tyre-road noise (TRN) begins to be a considerable source when it is superior than 30-35 km/h [3-4]. However, with the advent of electric mobility, which could lower this speed threshold and render TRN the principal noise source in an urban context, new low-noise pavement mixture design will play a fundamental role [5].
Additionally, this mixture design must also consider the air pollution of travelling vehicles. In fact, predictions on the

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number of electric cars seem to show that these will not be able to substitute sufficiently the Ignition Control Additive (ICA) vehicles in the next years [6]. Currently, cars with internal combustion engine are responsible for around 12 % of total EU emission of carbon dioxide (CO2). Light vehicles have a great impact on the greenhouse gases production, especially of nitrogen oxides (NO_x) and carbon monoxide (CO), into the low atmosphere [7-8]. This gaseous pollutant, and the high emission of hydrocarbons (HCs) have serious impacts on human health and accelerate the photochemical production of tropospheric ozone (O_3) which is extremely dangerous to creatures' respiratory systems [9].

In this context the NEMO project, funded by the Horizon 2020 programme (Grant Agreement ID:860441), is researching new solutions to reduce both noise and air pollution. The main objectives of the project concern the improvement of air quality and the reduction of noise impact through the implementation of innovative solutions in different scenarios in Europe, such as the use of remote-sensing systems applied to assess low-noise and pollutant-reducing asphalt mixtures. Within the project, two different kinds of low-noise and pollutant-reducing pavement mixtures have been developed by the M+P raadgevende ingenieurs BV and the University of Cantabria: an urban road pavement with liquid photocatalytic material sprayed on surface to remove nitric oxide, and a peri-urban road pavement with the capacity to storage microplastics produced by the tyre-pavement interaction.

In this scenario, the Close-ProXimity (CPX) method, defined by the ISO 11819-2 [10] standard, plays a fundamental role in the acoustical performance evaluation of new laid pavements, comparison between different pavements, and their durability [11-12]. Moreover, urban road traffic noise assessment can be done with Controlled -Pass-By (CPB) measurements [13] which has been shown to be coherent with CPX levels [14-16].

In this paper, the acoustic performance of an innovative low-noise pavement by means of the CPX method is studied. The pavement under analysis, laid in the city of Florence, is a Very Thin Asphalt Concrete (VTAC) surface with discontinuous particle size distribution. CPX levels of the whole pavement and single section values are compared with the recent European criterion [17] defined by the Green Public Procurement (GPP) in the field of road maintenance, construction, and design of low-noise pavements.

2. NEMO PAVEMENT MIXTURE DESIGN

This work focuses on the acoustical performance of a Very Thin Asphalt Concrete (VTAC) which has the following mixture design properties:

- 20 mm thickness;
- 16.2 % voids in mixture;
- Most size distribution aggregate, 74.6 % in weight, between 2 and 4 mm.

3. EXPERIMENTAL PLAN AND METHODS

In the first phase and before the prototype installation, the study foresees measurements with the CPX method on a pre-existing pavement, characterized by severe surface distresses, here in after called the Ante-Operam (AO). Subsequentially, CPX measurement have been carried out on the experimental prototype, the VTAC pavement substituting the AO. At the same time, CPX levels had to be measured over a Standard Pavement (SP) with VTAC's same age laid in Florence. The SP pavement has been used in this study as a reference to assess the VTAC acoustic performances by means of a differential criterion. Fig.1 shows the VTAC and SP geographical disposition in Foggini street located in the south-west part of Florence. For completeness, the texture of all three pavements were measured in accordance with the standard ISO 13473-1 [18]. Fig. 2 shows a zoom of the VTAC an SP pavements surfaces.

Figure 1: Geographic position of the VTAC and SP pavements

Figure 2: Zoom of the investigated pavements: VTAC (left) and SP (right)

3.1 CPX method

Noise levels were acquired using two microphones placed close to the right-back wheel of the mobile laboratory vehicle. Class 1 prepolarized free-field microphones with their diaphragms at 10 cm above the ground. The acquisition system comprehends a module with a frequency sample equals to 51.2 kHz. The vehicle used for the CPX measurement is a Mercedes-Benz-VITO and a Standard Reference Test Tyre (SRTT) [18].
Fig. 3 shows the scheme of the microphones mounted on the SRTT.

Figure 3: Schematic representation of the CPX measurement system

A rotatory encoder positioned on the rear-left tyre, produce squared signals to measure the travelling distance and speed. Noise level measurements are repeated on the same track at different speeds to evaluate the parameter models. Section length for the CPX method is equal to 20 m as suggested by the mentioned standard. Broadband and one-third octave levels in the frequency spectrum band between 315 and 5000 Hz were standardized respect to a reference temperature of 20 °C and with a reference tyre hardness of 66 shore. Eqn. (1) reports the equation to standardize the CPX level over each 20-meter segment at a reference speed v_{ref}:

$$L_{cpx} = L'_{CPX} - \gamma \cdot (T - T_{ref}) - \beta \cdot (H_A - H_{ref}) \quad (1)$$

In the above equation, L'_{CPX} is the energetic mean level measured by the two microphones, γ the slope of the temperature correction, T the air temperature at the road segment, T_{ref} the reference air temperature, β the slope of the hardness correction, H_A the tyre hardness, and H_{ref} the tyre hardness reference values.

3.2 GPP requirements

To establish the CPX levels adequacy, noise levels per section road and the overall mean pavement noise level were compared with the noise limits defined by GPP.

These limits are determined for assessing the conformity production of new laid pavements and the durability of existing pavements. For this case, the v_{ref} = 50 km/h, and the L_{GPP} limits are:

- L_{GPP} = 90 dB(A), (conformity production, after 4-12 week of the road opening date);
- L_{GPP} = 93 dB(A) (durability assessment, in the time interval of 5 years after the first proof of conformity).

The compliance to the GPP requirements is verified when no single level per section is higher than L_{GPP} + 2 dB(A), and the average spatial CPX value is lower than L_{GPP} + 1 dB(A).

3.3 Pavement texture measuring procedure

The road texture of the three analysed pavements was measured through a laser-triangulation device, mounted on the right-rear tyre traveling trail.
A monoaxial accelerometer installed above the laser encasing is used to exclude the vehicle vibrations during the measurements. 30 km/h was the speed for the profile measurement.
Next, texture values are reported, in the range between 2 to 500 mm wavelengths, corresponding to a part of the macrotexture and to the megatexture of the road. The rotatory encoder ensures that the measured sections are the same of the measured CPX levels.

4. RESULTS

This section reports CPX and texture results.

4.1 CPX results

Noise levels near the Tyre-Pavement contact zone were measured both in broadband and in one-third octave band in the range from 315 Hz to 5 kHz. A differential criterion on the broadband CPX levels allowed to compare the acoustic performance between the different pavements. Table 1 reports the average broadband CPX levels of the AO, VTAC and SP pavements at 50 km/h. Indeed, L_{CPX} values are A-weighted and normalized to tire hardness and air temperature reference values.

Table 2 reports the obtained differential criterion values. Fig.4 and Fig.5 report the L_{CPX} spatial trend per road section for the SP and VTAC pavements. In each figure, the green dashed and solid line represent respectively the upper limit for the CPX level within a single section and for the average CPX level of the whole installation. In addition, the averages of spatial L_{CPX} values are also represented in light blue lines with their uncertainties correspondingly. Fig.6 reports the one-third spectrum values in flat frequency response of the whole three pavements.

Table 1: CPX levels of the different pavements

Pavement	L_{CPX} $[dB(A)]$
AO	95.1 ± 0.9
VTAC	84.1 ± 1.0
SP	87.4 ± 1.1

Table 2: Acoustic performance comparison

Differential criterion	
$L_{CPX,AO} - L_{CPX,VTAC}$	11.0 ± 1.4 dB(A)
$L_{CPX,AO} - L_{CPX,SP}$	7.7 ± 1.4 dB(A)
$L_{CPX,SP} - L_{CPX,VTAC}$	3.3 ± 1.5 dB(A)

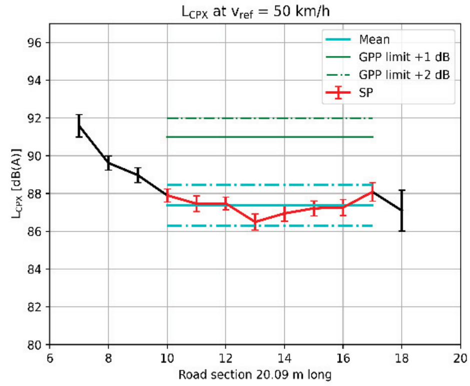

Figure 4: L_{CPX} spatial trend of SP pavement at 50 km/h

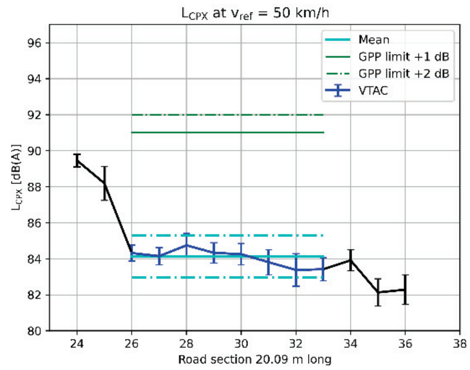

Figure 5: L_{CPX} spatial trend of VTAC pavement at 50 km/h

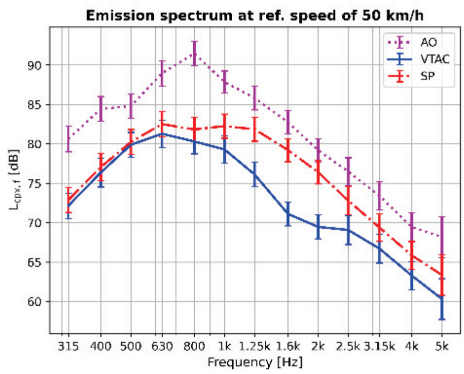

Figure 6: One-third octave spectrum of Z-weighted CPX levels of analysed pavements

4.2 Texture results

Results of each of the three pavements are expressed in terms of the parameter Mean Profile Depth (MPD), as shown in Table 3. At the same time, spectral values are expressed in the range between 2 to 500 mm wavelengths, as depicted in Fig 7.

Table 3: MPD values of the three pavements

Pavement	MPD values
AO	1.45 ± 0.27 mm
VTAC	0.77 ± 0.07 mm
SP	0.64 ± 0.08 mm

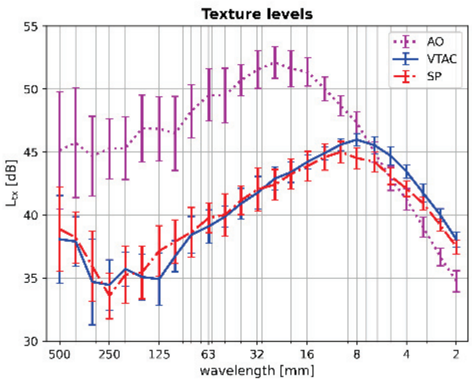

Figure 7: Texture levels of analysed pavements

5. DISCUSSION

In Tables 1 and 2, VTAC and SP pavements show a better acoustical performance with respect to the pre-existing AO pavement. In particular, based on the differential criterion, VTAC pavement offers a great noise reduction more than 10 dB(A) compared to the AO pavement.

Comparing the two new laid pavements, the VTAC continue showing an acoustic benefit of more than 3 dB(A) respect to the SP. Similar and coherent behaviour can be seen in the frequency Z-weighted spectrum. As it was expected, the road distresses identified in the pre-existed AO pavement produced higher noise level values in all the frequency bands. From Fig. 6, the spectrum emission of the SP pavement seems to have a larger bandwidth around its maximus value, while the VTAC behaves in a more concentrated spectral decomposition to the lower frequencies and a peak around 630 Hz.

The experimental prototype pavement VTAC demonstrated an exceptional acoustic performance, with an L_{CPX} value less than 6 dB(A) of the GPP requirements, as detailed in Fig. 5.

Discussing about texture analysis, the AO pavement showed the higher MPD value and texture levels. Furthermore, the presence of different and severe pavement distresses affected the measured uncertainty. For instance, higher wavelengths, above 63 mm, and the MPD standard variation might be mostly affected by this.

As illustrated in Fig 7 and looking at the level texture of the wavelength composition, VTAC pavement shows considerably higher levels for wavelengths shorter than 10mm compared to the SP, as literature suggests for the optimization of texture spectra for reducing rolling noise.

6. CONCLUSIONS

The NEMO project focused on developing and implementing novel solutions as low-noise and pollutant-reducing asphalt mixtures.

In this paper, the acoustic performance of a low emission Very Thin Asphalt Concrete (VTAC) new prototype pavement was evaluated by means of CPX method. Parallelly, CPX measurements were also carried out on the pre-existing pavement (AO), and on a new Standard Pavement (SP) in order to assess the efficiency and the acoustic benefits related to new installation.

VTAC showed an excellent acoustic performance with an L_{CPX} value 6 dB(A) lower than the GPP requirements.

Based on a differential criterion, VTAC pavement offers a significant noise reduction of more than 10 dB(A) when compared to AO pavement. When comparing the two newly laid pavements, the VTAC continues to have a noise reduction of more than 3 dB(A) compared to the SP.

Referring to the analysis texture, VTAC pavement has considerably higher levels for wavelengths in the range of 2 to 10mm compared to the SP, in accordance with literature criteria for the optimization of texture spectra for reducing rolling noise. In terms of future developments, additional measurements campaign and studies are planned to evaluate the durability over time of the acoustic performance of the VTAC prototype.

7. ACKNOWLEDGMENTS

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