Development of low emission asphalt mixtures for urban and peri-urban roads

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ABSTRACT*

The application of low noise road surfaces has proven an effective mitigation measure and has the potential to lower the level of road traffic noise significantly. In the EU Horizon 2020 research and innovation project NEMO new asphalt mixtures have been developed to mitigate the road/vehicle related emissions, for both urban and peri-urban driving circumstances. Apart from the ability to reduce traffic noise, the asphalt also exhibits capabilities for suppressing the concentration of NOx from the vehicle exhaust.

The paper presents the process of drafting a functional description, designing the low noise asphalt mixtures and performing laboratory tests, to finally result in two low emission asphalt types, for urban and peri-urban roads. The greatest challenge is to answer the targets for noise reduction and suppression of exhaust NOx without jeopardizing the durability of the road surface. The behavior of the asphalt under real traffic conditions is simulated with an accelerated pavement test device. This test makes it possible to evaluate the long-term (up to 20 years of heavy traffic or 10^6 loads) durability in a few months.

Keywords: *low noise road surface, EU horizon 2020, low emission asphalt, modelling*

1. INTRODUCTION

The European Unions research and innovation program Horizon 2020 is funding an initiative by a consortium of 18 partners from 11 different EU-member states to develop enhanced autonomous remote sensing technologies to identify noisy and polluting vehicles in traffic. Such technologies can be applied when enforcing Low Emission Zones in cities and to detect manipulation with silencing and air cleaning systems. Also innovative infrastructure-based solutions are developed to mitigate noise and emissions of passing vehicles.

The project is titled Noise and Emissions MOnitoring and Radical Mitigation with the acronym NEMO, and the project has received funding from the European Union's Horizon 2020 research and innovation program (No 860441).

This paper focusses on the development of pavement types that not only mitigate noise but exhibit capabilities to reduce the NOx emitted by internal combustion engines of passing vehicles. A further target is that the pavement shall have a rolling resistance equal or better than a smooth dense asphalt concrete pavement. Due to the different properties and technical requirements in urban and peri-urban roads, two innovative asphalt mixtures were developed.

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2. SPECIFICATION OF TARGETS

2.1 Specification of performance targets

For noise suppression and rolling resistance explicit performance targets were formulated (see table 1). The noise reduction and rolling resistance are defined relative to an AC surf-11 pavement since that is the reference pavement in the present EU-CNOSSOS noise calculation scheme and as such serves as an international acknowledged standard.

The typical conditions for urban and peri-urban roads traffic require a separate specification of the targets. Urban areas include metropolitan cores and adjacent zones, which are often characterized by dense traffic and/or limited driving speeds. Peri-urban areas are located on the outskirts of metropolitan areas and have a wide variety of roads, speed limits, and significant commuter traffic.

Although porous pavement types are very efficient in suppressing vehicle noise, urban traffic shall result in quick aging of the pavement. Therefore, the target for noise reduction is specified more modest for urban type than for the peri-urban type where application of porous pavement is considered feasible. Although peri-urban or regional roads would carry in general also a fraction of heavy vehicles, the noise reduction is only specified for cars. From our experience the porous pavements anticipated for this type will have a similar effect for heavy vehicles as for cars (ref [2].

Table 1*: Performance targets for the urban and peri-urban pavement.*

Performance type	Target value	Reference condition
Noise reduction urban	-2,0 dB	Passenger cars, 50 km/h, AC surf-11
Noise reduction peri-urban	-3,5 dB	Passenger cars, 80 km/h, AC surf-11
Rolling resistance	± 0%	at 80 km/h relative to AC surf-11

2.2 Specification of intrinsic targets

The noise related performance of a road surface is defined by its surface characteristics such as texture, flow resistivity, porosity and acoustic absorption. Rolling resistance can be related to the texture magnitude. From earlier work on performance characteristics of pavements (ref. [1]) we were able to interpret the target performances in terms of measurable surface characteristics. With these figures, development on a laboratory scale is feasible, since direct evaluation of the mixtures on base of small slabs and Marshall cores is possible.

The resulting target specifications are given in table 2 and in more detail for the texture spectrum of the urban and the peri-urban pavement type in figure 2 and 3.

Table 2*: Target values for intrinsic properties.*

Mixture	Urban	Peri-urban
Texture level r.m.s. [mm]	≤0,6	≤0,7
Texture wavelength spectrum	Figure 2	Figure 3
Flow resistivity [Pa s/m]	< 8000	< 4000
Acoustic absorption	None	Frequency of max. absorption between 800 and 1000 Hz Height of peak ≥ 60% Width at 30% absorption ≥ 40% of peak frequency

The targets for texture are defined in terms of a target wavelength spectrum and an allowed deviation around it. In the texture spectrum (Figure 2 and 3), a long wavelength range is distinguished where noise is less sensitive to texture and a wide variation is allowed. In the middle wavelength range, there exists a positive relation between texture and noise level, and consequently a narrow margin above the target is specified. Finally, in the short wavelength range the relation between texture and noise level is inversed and thus a narrow margin under the target curve is specified.

3. DEVELOPMENT OF MIXES

3.1 Laboratory testing

The target specifications for the two pavement types were used by the University of Cantabria to develop asphalt mixtures. The mixtures were evaluated on base of the intrinsic target properties but were also subjected to durability tests.

For the checking of the intrinsic properties slabs and Marshall cores were produced that were evaluated by M+P with the following test procedures:

- Texture with ISO 13473-4
- Air Flow resistivity with DIN EN 29053
- Acoustic absorption with ISO 10534-2
- Porosity with CT-scans

3.2 CT scans

CT (computed tomography) scanning of porous pavement cores helps to identify the voids in the material as is demonstrated in [3]. In the present project the CT scans were applied to identify the stones, binder and voids in Marshall cores and for the cores also the interconnectivity.

To extract the air void geometrical structure, a processing method is developed based on image analysis. A connected-component labelling technique was applied to separate the different voids in each slice in 2D. Then, the different voids have been reconstructed by a tree network search algorithm (i.e. starting from each void in the top slice and finding which voids in the slice below are connected, stepping downward slice by slice to find the entire channel.

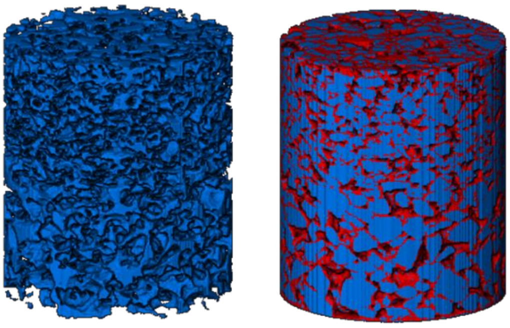


Figure 1*: Left: geometrical structure of the accessible air voids in a porous asphalt core (50 mm diameter). Right: the solid structure of the same asphalt core where the stones (blue) and bitumen (red) can be distinguished.*

From the CT-scans it can be determined which air voids are accessible from above (see Figure 1). That not only leads to a better understanding of the acoustic absorption. It also provides insight in the capacity of the mixture to collect and store microplastics from the wear of tyres. In a later stage of testing, it may be possible with this technique to determine that the air voids are partially filled with microplastics.

3.3 Selection of two mixtures

To achieve the targeted specifications, variables such as particle size distribution, maximum aggregate size, thickness, binder and void content needed to be optimized. The design of the mixtures involved the balance of different conflicting properties and different attempts were carried out. In this iterative process, the mechanical performance of the experimental mixtures was ensured before the evaluation of their intrinsic properties. The laboratory tests for the mechanical characterization depended on the type of mixture. For the urban mixture, air void content (EN 12697-8), Marshall (EN 12697-34), water sensitivity (EN 12697-12), wheel tracking (EN 12697-22) and binder drainage (EN 12697-18) tests were carried out. As for the peri-urban road, in addition to air void content, water sensitivity and binder drainage, the particle loss in dry (EN 12697-17) and wet (NLT 362/92) conditions were done. The targets for the mechanical performance were based on the highest traffic category and the threshold values established by the Spanish General Technical Specifications for Road and Bridge construction (PG-3) technical requirements.

Based on the results of the mechanical and intrinsic properties, two designs were selected which complied with all targeted specifications. The two designs included a polymer modified bitumen and good quality aggregates (ophitic). Table 3 presents the main design properties of the experimental mixtures.

Table 3*: Design properties of the experimental mixes.*

	Urban	**Peri-urban**	
	-	**Top layer**	**Bottom layer**
Max aggr. size (mm)	4	4	8
Binder / mixture (%)	4,8	6,5	6
Voids in mixture (%)	16,2	22,2	23,1
Thickness (mm)	20	20	20
Density (g/cm3)	2,14	1,95	1,94

Concerning the functional properties, both mixtures achieved the requirements with a low flow resistance (around 5200 Pa s/m in case of urban and 800 Pa s/m for the peri-urban pavement), with the textures presented in figure 2 and 3 and for the target for the acoustic absorption of the peri-urban design with a frequency at the peak at 850 Hz and a peak absorption coefficient > 70%.

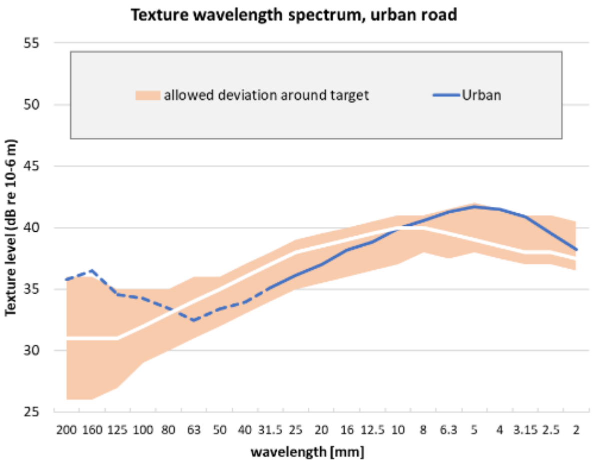


Figure 2: *Target wavelength spectrum and result for the experimental mix for the urban pavement*

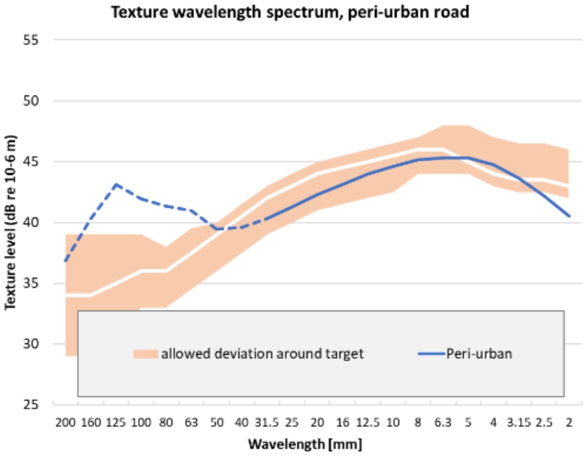


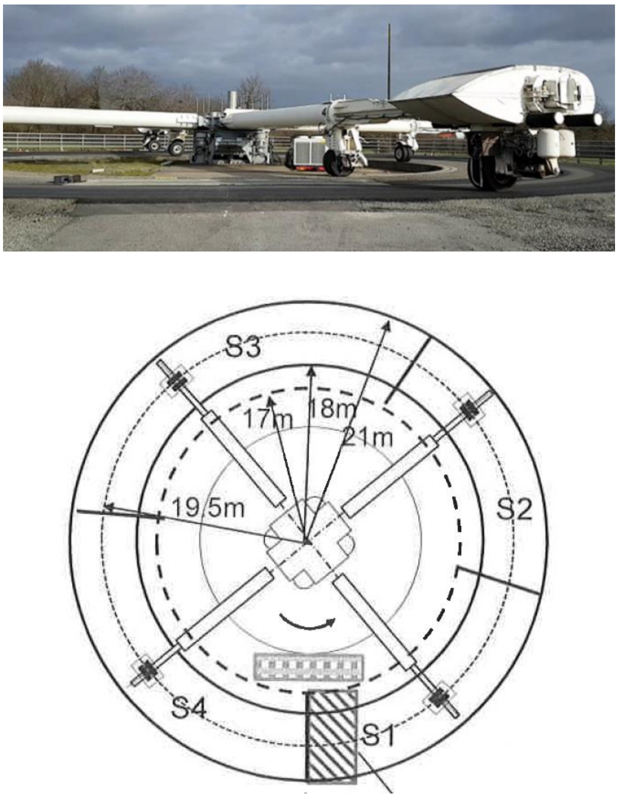
Figure 3: *Target wavelength spectrum and result for the experimental mix for the peri-urban pavement. The deviations at long wavelengths are caused by the limited size of the sample*

4. PROVING GROUND TESTING

4.1 Fatigue carrousel

To investigate the durability of the developed mixtures, the final asphalt mixtures were subjected to a test on the Fatigue Carousel of Eiffel university in Nantes.

The carousel is an outdoor road traffic simulator designed to study the behaviour of real scale pavements under accelerated heavy traffic. The fatigue carousel has a diameter of 40 m and four loading arms, which can each carry loads up to thirteen tons, at a maximum loading speed of 100 km/h (Fig. 4). Two months of testing can represent up to 20 years of heavy traffic undergone by a moderate traffic pavement (150 heavy trucks/day). During loading, a lateral wandering of the loads can be applied to simulate the lateral distribution of loads of real traffic (see pictures below).



S1: Porous Asphalt Reference (not discussed further)
S2: Peri-urban mixture
S3: Urban mixture
S4: Reference

Figure 4: *Picture and scheme of the fatigue carousel at the Gustav Eiffel University in Nantes with the geometries of the test sections*

The tests were carried out by using an average carousel radius of 19.5 m (between 18.8 m and 20.3 m) and a mean perimeter of approximately 122.5 m. Four sections of road (two experimental and two reference), each 3 m wide, are constructed. For the four sections, the base course was a layer of GB (Gravel Bitumen, or grave bitumen, in French). The performances of the different sections were evaluated simultaneously. A picture of the carousel and the geometry of the test sections is given in figure 4.

All the asphalt mixes were prepared at a local Colas asphalt mixing plant. The reference sections included a conventional asphalt concrete BBSG pavement, namely S4, and a porous asphalt BBDr pavement, namely S1. The experimental peri-urban section (namely S2) is approximately 25 m long, and the experimental urban section (namely S3) is 35 m long.

Following construction and qualification of the sections, accelerated durability testing was conducted in two phases. A first phase corresponded to urban conditions (200,000 load cycles), followed by a second phase relating to peri-urban conditions (800,000 load cycles). The main differences between the two are the speed and the number of cycles applied: *i.e.*, 50 and 70 km/h with transverse wandering of 26 and 52 cm, respectively. A same load (dual wheels, loaded at 65 kN) was applied in both cases.

The number of test cycles are derived from the French design standard NF P98-086 [4] that stipulates that the mechanical design of the pavement is to be based on the cumulative heavy goods vehicle traffic over the entire design period of 20 years.

In addition to mechanical durability, the accelerated pavement evaluation included dust and noise monitoring as well as texture evolution studies.

4.2 Properties of the test sections

In total 4 test sections were laid at the carrousel (see figure 4). Three of the sections were part of the test program:

- S2: Peri-urban mixture
- S3: Urban mixture
- S4: Reference.

From each of the sections the following surface properties were determined:

- r.m.s. texture level
- texture wavelength spectrum
- flow resistance
- acoustic absorption and porosity (from cores taken from the section, outside the wheel track).

4.2.1 Initial results for texture and flow resistance

The properties were determined at three moments during the testing:

- at the start of the testing
- after 200.000 load cycles
- after 1.000.000 load cycles.

At this moment the testing has just started and only initial values are available. They are given below.

Table 4: *Results for the overall texture level [mm r.m.s.]*

Mixture	Target	Fatigue carrousel
Urban	< 0,6	0,61
Peri-urban	< 0,7	0,65
Reference	-	0,52

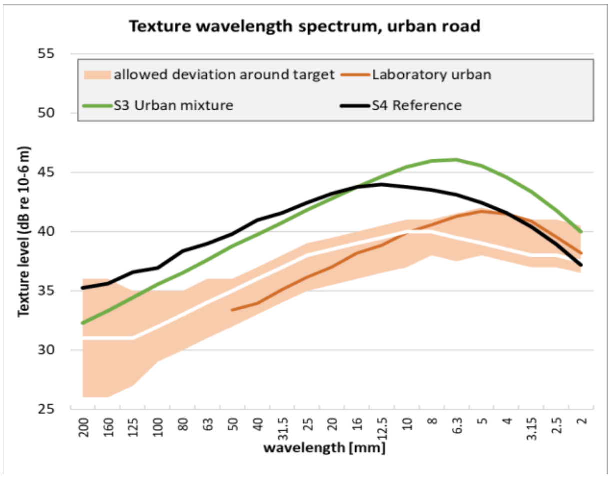


Figure 5: *texture spectrum for the urban design. Pictured is the target spectrum, the laboratory mixture and the mixture laid at the carousel (S3). As comparison the reference is given (S4)*

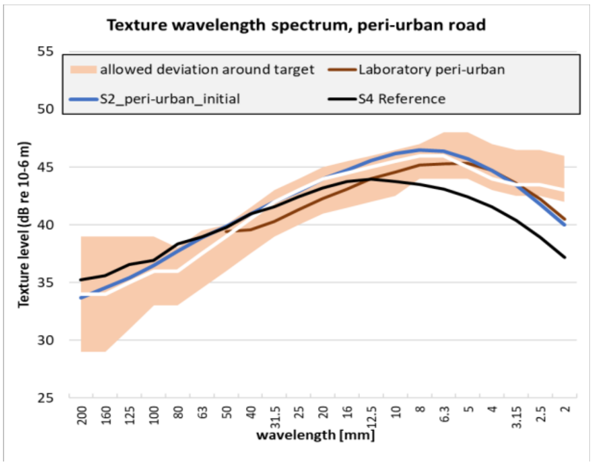


Figure 6: *texture spectrum for the peri-urban design. Pictured is the target spectrum, the laboratory mixture*

and the mixture laid at the carousel (S2). As comparison the reference is given (S4)

Table 5: *Results for the flow resistance [Pa m/s]*

Mixture	Target	Laboratory	Fatigue carrousel
Urban	< 8000	5179	1449
Peri-urban	< 4000	820	1333
Reference	-	-	30671

4.2.2 Results from bore cores; acoustic absorption and porosity

From the urban section and from the peri-urban section under test three cores were taken outside the wheel track. From each of the cores the acoustic absorption spectrum was determined in an impedance tube. The results are presented in figures 7 and 8.

After that the cores were investigated with a CT scanner to analyse the 3D geometry inside the mixture and to determine the porosity. Only voids accessible from the top are effective in the noise suppression and the particle buffering. These results are given in figure 9.

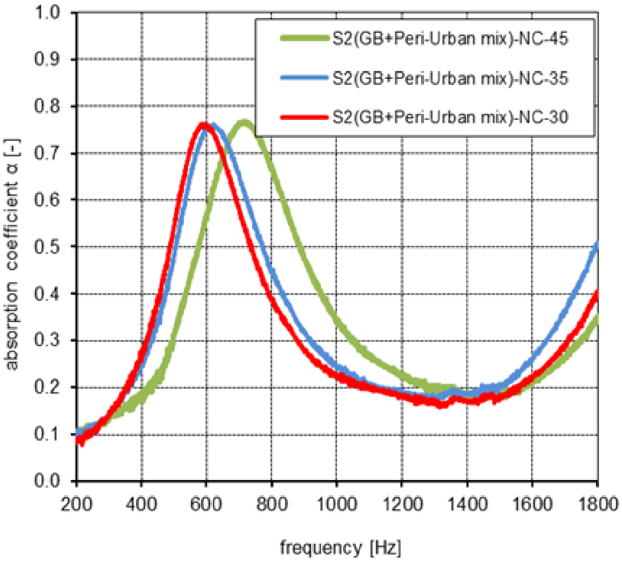


Figure 7: *acoustic absorption spectra from each of the three cores taken from the Peri-urban section S2*

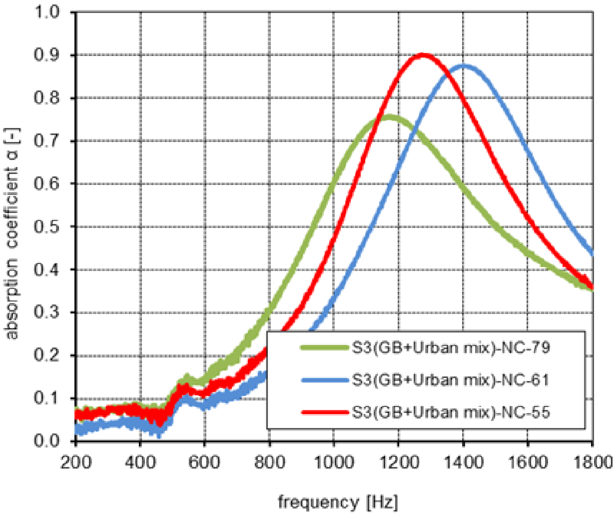


Figure 8: *acoustic absorption spectra from each of the three cores taken from the urban section S3*

Table 6: *Average porosity from the three cores per test section*

mixture	design	fatigue carousel
urban	16	18,6
peri-urban	>20	20,1
reference	4-6	1,7

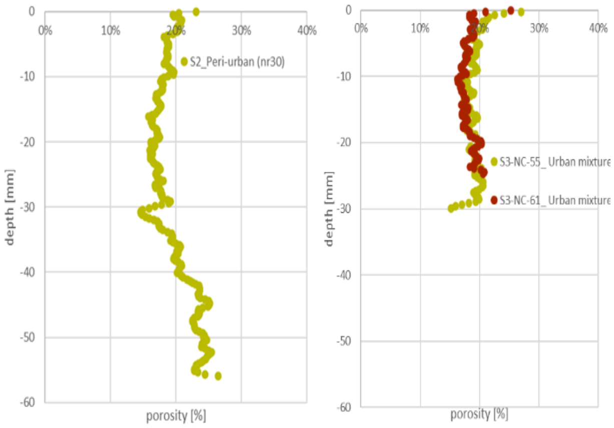


Figure 9: *Porosity as a function of depth in the cores taken from the test sections. Left the result for the peri-urban mixture, right the urban mixture.*

4.3 Sound measurements

The passing tyres at the fatigue carousel enable the assessment of the effect of the pavement on the rolling noise of the test tyres. Although the situation is not ideal and does not comply with noise measurement standards such as ISO 11819-1 [2] or ISO 11819-2 [3], it was found that a fair estimation could be made. Background level of the system was about 10 dB under the test values and rolling speeds were in the representative range.

Results of the LAmax levels at around 3,5 m from the passing tyres were determined for each of the three test sections. The noise reduction was calculated by subtracting levels at the urban and peri-urban section from those at the reference section. Results are given in table 7.

Table 7: *Noise reduction relative to the reference section (S4)*

Mixture	target [dB]	noise reduction [dB]	
		50 km/h	70 km/h
urban (S3)	-2,0 @50 km/h	2,2	4,2
peri-urban (S2)	-3,5 @80 km/h	3,4	6,4

5. CONCLUSIONS

The surface characteristics of the test sections for the urban (S3) and peri-urban (S2) mixture were determined and compared to the target specifications for overall texture level, texture spectrum, flow resistance and acoustic absorption (S2 only). For porosity no direct target was specified but is assumed that porosity is a quantity that enables the buffering of microparticles and is thus included in the study.

For the peri-urban mixture it can be concluded that the surface properties of the mixture at the fatigue carousel comply with the target specifications. The achieved noise reduction exceeds the target significantly. A goal of -3,5 dB was defined, but the measurement at the carousel tyres indicates a -6 dB reduction at 70 km/h.

For the urban mixture one must conclude that the actual mixture laid at the fatigue carousel deviates considerably from the target values in the beginning. The objective was a dense asphalt pavement with optimal surface characteristics. During the laboratory testing the design properties of the porosity were adjusted to achieve the required noise reduction. Eventually, the mixture at the carousel is clearly a porous asphalt with a porosity higher than 18%. The open nature of the mixture is reflected in the texture wavelength spectrum, that exceeds the target curve considerably. However, the higher texture did not spoil the acoustic performance, which can be explained by the acoustic absorption of nearly 80% at 1200 to 1500 Hz. Such semi-open thin layers are known to be a very efficient noise reducer.

The durability of the mixture and the noise reducing effect is of course one of the major objectives of the tests at the fatigue carousel. Repeated measurements after 200 k and 1.000k passings will show how aging affects the performance.

6. ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support by the European Union.

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