sciendo

DOI: 10.2478/rjti-2022-0013

ROMANIAN JOURNAL
OF TRANSPORT INFRASTRUCTURE

LIFE E-VIA: PROTOTYPAL LOW-NOISE ROAD SURFACE FOR THE REDUCTION OF ELECTRIC VEHICLE ROLLING NOISE IN URBAN AREA

Marie-Agnès Pallas, Researcher, PhD, UMRAE, Univ Gustave Eiffel, IFSTTAR, CEREMA, Univ Lyon, F-69675 Lyon, France, marie-agnes.pallas@univ-eiffel.fr
Julien Cesbron, Researcher, PhD, UMRAE, Univ Gustave Eiffel, IFSTTAR, CEREMA, F-44344 Bouguenais, France, julien.cesbron@univ-eiffel.fr
Simon Bianchetti, Eng, UMRAE, Univ Gustave Eiffel, IFSTTAR, CEREMA, Univ Lyon, F-69675 Lyon, France, simon.bianchetti@univ-eiffel.fr
Philippe Klein, Researcher, Eng, UMRAE, Univ Gustave Eiffel, IFSTTAR, CEREMA, Univ Lyon, F-69675 Lyon, France, philippe.klein@univ-eiffel.fr
Véronique Cerezo, Researcher, PhD, AME-EASE, Univ Gustave Eiffel, IFSTTAR, F-44344 Bouguenais, France, veronique.cerezo@univ-eiffel.fr
Pierre Augris, Tech, AME-EASE, Univ Gustave Eiffel, IFSTTAR, F-44344 Bouguenais, France, pierre.augris@univ-eiffel.fr
Christophe Ropert, Tech, AME-EASE, Univ Gustave Eiffel, IFSTTAR, F-44344 Bouguenais, France, christophe.ropert@univ-eiffel.fr
Filippo G. Praticò, Professor, PhD, DIIES Department, University Mediterranea of Reggio Calabria, Reggio Calabria, Italy, filippo.pratico@unirc.it
Francesco Bianco, Researcher, IPOOL S.r.l., 56121 Pisa, Italy, francesco.bianco@i-pool.it

Abstract

In both the current and foreseen context of significant development of the electric vehicle (EV) fleet, a future increasing ratio of EVs in the urban traffic is expected, still enhanced in low-emission zones involving bans or restricted access to other vehicles. EVs are known to be quieter than conventional vehicles at low speed because of a low motor noise emission, resulting in a higher prevalence of rolling noise in the environmental noise. EVs differ from conventional vehicles in several parameters that can influence tyre/road noise, like weight and torque. The LIFE E-VIA project objectives consist in developing, implementing and assessing a low-noise road surface for light EV traffic in urban conditions, optimised from an acoustical and life cycle perspective. In parallel, an optimisation of EV tyres is investigated.

Prior to forthcoming layout in Florence (Italy) for assessment under real traffic conditions, a prototypal road surface has been implemented and evaluated on a test track in Nantes (France). Preliminary tests carried out with different EVs on several road surfaces highlighted the variability of noise emission over vehicle types and pavements, leading to specific ranking. Two prototype versions of a low-noise road surface have been laid out in Nantes, respectively without and with crumb rubber. Both of them have been acoustically assessed with on-board microphones (CPX method) and at roadside (CPB method and microphone array). Constant speed, acceleration and deceleration conditions were considered for pass-by tests. Other acoustical or physical parameters have been measured: acoustic

absorption, 3D-texture, mechanical impedance and skid resistance properties (BPN and MPD). In comparison with a reference DAC 0/10 road surface, very usual in France, a roadside noise reduction up to 4 dB(A) was found at steady pass-by speed 50 km/h. Grip values are very high and macrotexture levels moderate. Lastly, mixtures durability is analysed with laboratory tests.

Keywords: electric vehicle, road surface, tyre/road noise, urban road traffic noise, friction

1. INTRODUCTION

Past years have brought changes in climate conditions with already dramatic evidence on citizens' safety or life quality in many parts of the world. Consequently, the states' willingness as well as the population's toward energy transition growingly asserts, including the electrification of road transportation, the former through clear objectives for reducing or stopping the production of fossil fuelled vehicles within the very next decades (by 2035 for European Union [1]) and the latter by an increasing interest in acquiring electric vehicles. Indeed, the part of battery-electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) in the market share is rapidly growing and still represented 14.3% of European sales of passenger cars (resp. 2.1% for light commercial vehicles) in the first part of 2021 according to EAFO [2].

Beyond the reduction of atmospheric emissions and air quality improvement, electric vehicles (EVs) contribute to mitigate environmental noise in urban areas, due to their low propulsion noise contribution. Therefore, rolling noise – originating from the tyre/road contact – becomes the principal contribution and plays a key role in electric vehicle noise emission as from low speeds. Further noise reduction for EVs in urban situations requires investigating and operating on tyre/road noise, taking account of the specific characteristics (weight, torque) and needs (reduced rolling resistance for increasing mileage) of EVs [3] [4]. The European project LIFE E-VIA aims at combining the knowledge of road optimization and tyre development to test an optimized solution for reducing noise in urban areas and Life Cycle Cost with respect to actual best practices, in the future perspective of a consistent portion of electrically driven vehicles within the traffic flow [5].

After assessing current EV noise emission on a set of actual road surfaces [6] and a preliminary study of low-noise road surfaces [7], an optimised prototypal road surface has been designed and implemented on the reference track of Université Gustave Eiffel in Nantes (France). Then, an extensive assessment of its performance, focusing on acoustical and grip properties, has been achieved and it is presented in this paper.

First, the design and the construction of the prototype road surface is presented (section 2). The next part reports the results on road surface properties, including the ones influencing noise emission (section 3.1) and those essential for friction/adhesion (section 3.2). Finally, the road surfaces are acoustically assessed through onboard CPX tests and roadside pass-by measurements with EVs at constant speed and under acceleration (section 4). Finally, conclusions are drawn in the perspective of the subsequent implementation of the road surface under real traffic in Florence (Italy).

2. DESIGN AND CONSTRUCTION OF THE PROTOTYPE

A holistic optimization has been performed by Mediterranea University of Reggio Calabria (UNIRC, Italy) to specify an optimized road surface mix. Based on a comprehensive literature analysis [7], the selection considered acoustic response, expected life, permeability, friction and Expected pass-by Noise level Difference from Texture level variation (ENDT) [8]. Consequently, a very thin asphalt concrete mixture with Nominal Maximum Aggregate of 6 mm (VTAC 0/6) has been selected by UNIRC, with two options according to the use of crumb rubber or not in the mix composition. In this paper, the prototype with crumb rubber is named PCR (resp. P without crumb rubber).

A section of size 4 m width by 57 m long, respectively for each road surface option, has been implemented on the reference test track of Université Gustave Eiffel in Nantes (France) (Figure 1). Each compacted mixture has a thickness of 25 mm. The detailed composition is given in Table 1.

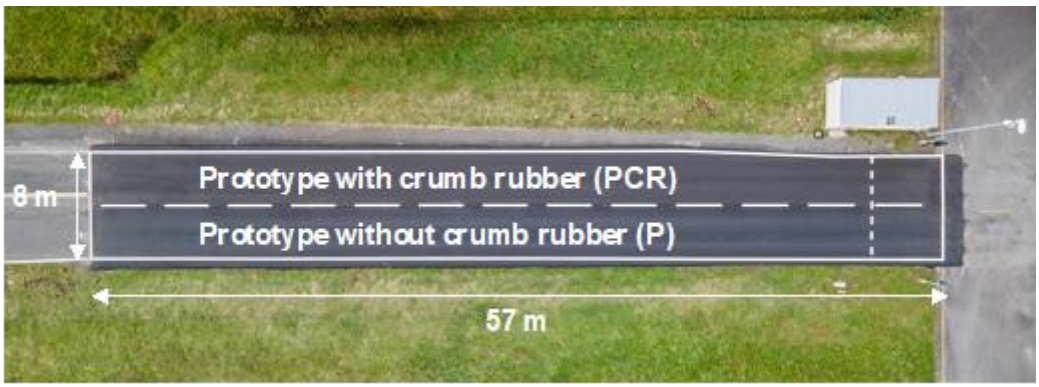


Figure 1. Topview of the prototype road section

Table 1. Mix composition of the two options of prototype VTAC 0/6

Fraction (mm)	Mix P	Mix PCR
4/6.3	7.0%	7.0%
2/4	33.0%	33.0%
0/2	52.0%	51.0%
0/1 (CR)	-	1.9%
Fines	1.6%	1.0%
Filler bitumen	-	6.1%
Total bitumen	6.4%	6.4%

The prototype road surfaces performance is then assessed comparatively to a dense asphalt concrete 0/10 (DAC, here named E1), which is very common to the French road network. A close-up view of the pavements is given in Figure 2, pointing out the finer grading and the flattening of aggregates existing in the prototypes.



Figure 2. Detailed view of the prototype road surfaces P (left) and PCR (middle), and of the reference road surface E1 (right)

3. ASSESSMENT OF THE PHYSICAL PROPERTIES OF THE PROTOTYPE SURFACES

Several physical parameters of the prototype road surfaces have been looked into, some of them playing a role in the noise generation or radiation, while others are central for friction capacity.

3.1. Properties influencing tyre/road noise

The 3D road texture, characterizing the surface geometry, the sound absorption and the mechanical impedance have been studied for each road surface to be compared.

3D road texture

The 3D texture describes the geometrical characteristics of the road surface, as the vertical surface profile according to the longitudinal and transverse positions on the track. It is provided by a 3D profilometer, which uses a laser beam scanning the surface transversely on 0.35 m and longitudinally over 1.5 m, with a sampling interval of 0.1 mm in both directions (Figure 3, left). Four consecutive scans were performed on the wheel path on the side of the pass-by microphone position (see section 4.2) and two consecutive scans on the opposite wheel path, providing final complete texture scan lengths of about 5.80 m and 2.94 m respectively.

The Mean Profile Depth (MPD) and the texture spectra have been calculated using longitudinal profiles extracted from the 3D texture scans, in accordance with ISO 13473-1 and ISO 13473-4 respectively. The average MPD amounts to 0.39 mm for the P test section (resp. 0.30 mm for PCR test section), quite lower than the value 0.82 mm available for the reference road surface E1.

One-third octave band texture spectra have been computed, averaged over the left and right wheel tracks of each prototypal test sections P and PCR (Figure 3, right). The texture spectrum of E1 is also plotted for comparison. At wavelengths lower than 125 mm, the texture levels of section P are up to 3 dB larger than those of section PCR, indicating a rougher surface in this wavelength range. The opposite situation occurs at large wavelengths, greater than 250 mm. An untypical peak at wavelength 160 mm is observed for PCR test section. Both prototype test sections have much lower texture levels than the reference E1. In particular, wavelengths higher than 16 mm exhibit a difference of about 6 dB for P (resp. 9 dB for PCR), highlighting the relatively smooth nature of the prototype surfaces.

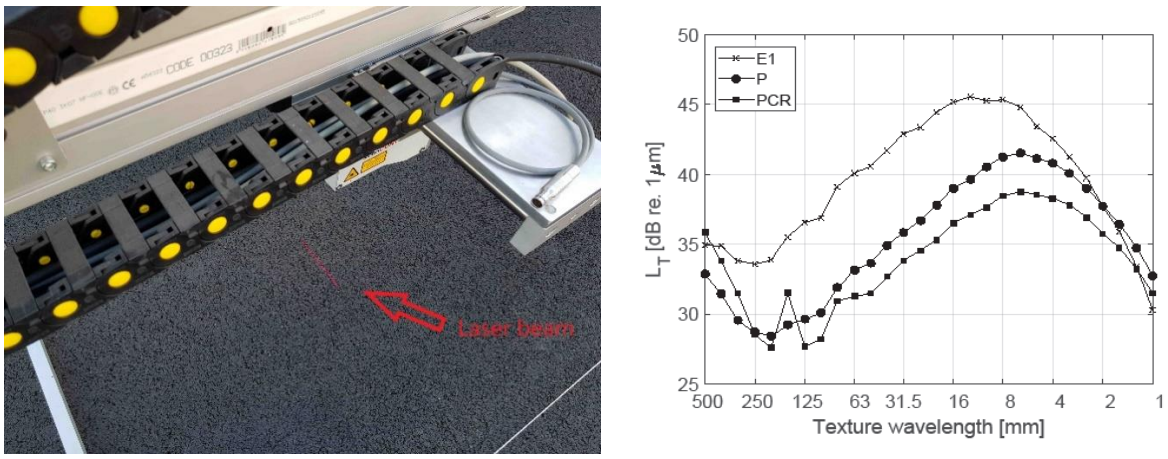


Figure 3. 3D road texture reading by laser beam (left) and texture road spectra of the three road sections (right)

Sound absorption

Sound absorption by the road surface influences tyre/road noise emission, but may also have an effect on propulsion noise radiation. The absorption coefficients of the prototype surfaces P and PCR have been measured with a system conforming ISO 13472-1 (Figure 4, left). This was carried out in the centre of the track at five spots located approximately in front of the pass-by microphone used below in section 4.2. After narrow-band frequency averaging, the sound absorption coefficient was computed in one-third octave bands (Figure 4, right).

On both road surfaces, this parameter is not significant at most frequencies, except in the range 2000-3150 Hz with a maximum value of 0.27 at 2500 Hz for road surface P (resp. 0.17 for road surface PCR), suggesting that the prototypes are acoustically poorly absorbing. It was not measured for the dense surface E1, which essentially reflects sound without absorption properties.

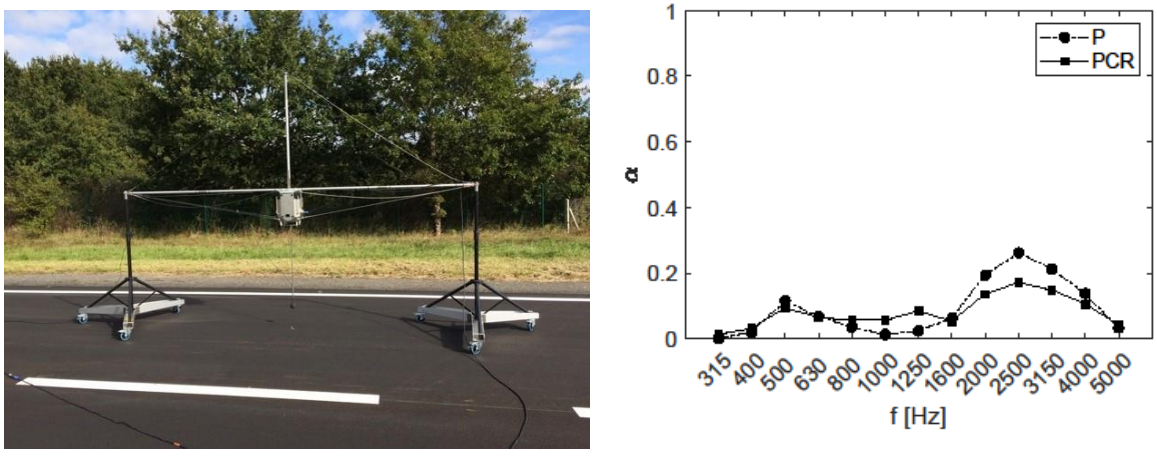


Figure 4. Measurement of sound absorption (left) and sound absorption coefficients of the two prototype sections (right)

Mechanical impedance

Mechanical impedance (or dynamic stiffness) is a factor influencing tyre-road noise generation, a softer road surface being expected to reduce this noise production. The dynamic stiffness of the prototype road surfaces has been measured *in situ*, using an impact hammer and an impedance head (Figure 5, left). This gives the direct force and acceleration at the impact spot to provide the

frequency transfer function between these quantities. The experiment was carried out at five spots near each track centre, as for sound absorption described above.

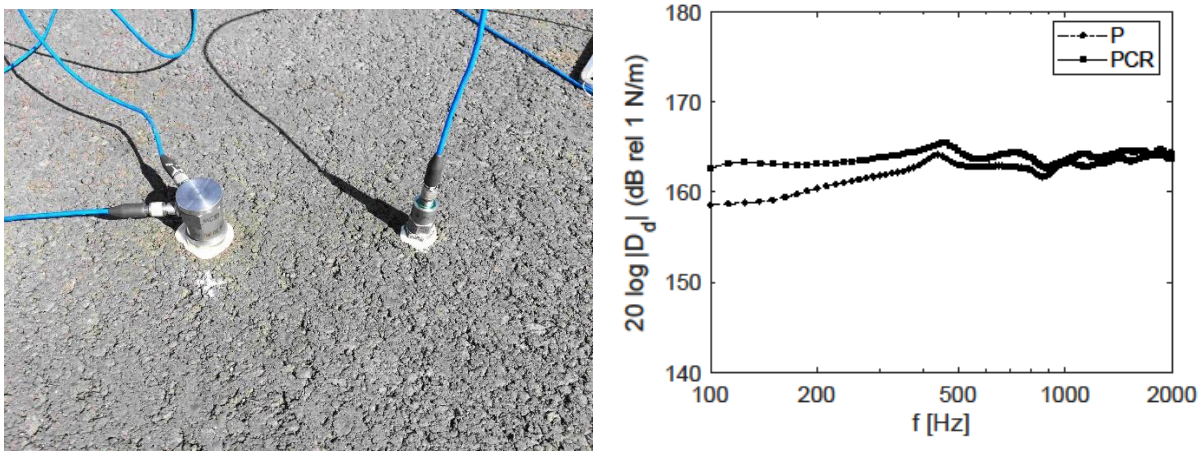


Figure 5. Measurement of the dynamic stiffness (left) and dynamic stiffness spectra of the two prototype sections (right)

The dynamic stiffness turns out to remain almost constant over the frequency range 100 Hz – 2000 Hz, indicating a behaviour of the prototypes close to an ideal spring (Figure 5, right). Despite the addition of crumb rubber, the PCR prototype is stiffer than the P road section, the stiffness difference reaching 5 dB below 400 Hz and being about 2 dB above 400 Hz.

3.2. Skid resistance and texture

The skid resistance properties of the reference section and prototype have been characterized through standard tests of friction and macrotexture. The devices used and the measurements results obtained are detailed below. In parallel, two samples have been tested in laboratory with the Wehner and Schulze machine, to reproduce the evolution of surface friction with traffic (i.e. polishing) and to assess long term performance.

MPD measurements

Macrotexture has been measured with an Elatextur device. The device is composed of a laser sensor mounted on a rotating arm which provides a circular 2D profile with a diameter of 400 mm. The 2D profile is analyzed according to ISO EN 13473-1 to calculate MPD (Mean Profile Depth) value. This static measurement provides a punctual assessment of the macrotexture of the pavement

surface. This is the reason why the measurements were repeated every ten meter on the prototype to obtain a global view of the macrotexture level. Six locations are defined along the longitudinal direction (i.e. rolling direction) of the road sections. The MPD values are used to calculate ETD (Estimated Texture Depth) which is the indicator currently used for road acceptance. The following relationship is applied: $\mathrm{ETD} = 0.8 * \mathrm{MPD} + 0.2$

The average value of ETD is higher on section P compared to section PCR (Table 2). Moreover, ETD values are weak on PCR and close to the threshold value of 0.40 mm, which is the lower limit on French roads.

Table 2. Macrotexture measurement - Estimated Texture Depth

Location (m)	Mix P	Mix PCR
10	0.49 mm	0.40 mm
20	0.47 mm	0.39 mm
30	0.48 mm	0.40 mm
40	0.47 mm	0.37 mm
50	0.51 mm	0.38 mm
60	0.52 mm	0.38 mm
Average Value	0.49 mm	0.39 mm
Standard Deviation	0.02 mm	0.01 mm

Friction measurements

Friction measurements were performed thanks to two devices. On the one hand, British pendulum provides a punctual static friction coefficient ranging between 0 (low friction) and 100 (high friction) according to standard EN 13036-4 and on the other hand, T2GO provides a continuous friction coefficient ranging between 0 and 1 all along the test section. Both are obtained at low sliding speed and on wet surface.

First of all, the average British pendulum values measured on sections with and without crumb rubber are superior to 70 (Table 3). The friction values on P road section are 10 points lower than on PCR prototype but the levels of performance remain very satisfying. Moreover, continuous friction measurements performed with T2GO on both sections confirmed these good results with average coefficients of friction around 0.80.

Table 3. Friction coefficient - British Pendulum test

Location (m)	Mix P	Mix PCR
10	71.4	83.4
20	68.4	78.6
30	68.0	81.8
40	70.8	85.2
50	68.8	84.0
60	74.8	81.8
Average Value	70.4	82.5
Standard Deviation	2.5	2.3

Polishing tests

The Wehner and Schulze machine is composed of a polishing station simulating the action of traffic and of a friction measuring station. Polishing is done by rolling three rubber cones on the surface of the sample, where a mixture of water and silica flour (abrasives) is continuously spread. The tests are carried out according to EN 12697-49 standard. The measurements led to a curve giving the evolution of friction coefficient with polishing stages, expressed in number of passes of the rollers.

Before starting the tests, the characteristics of the two samples were determined with Elatextur and British pendulum devices (Table 4). We obtained friction coefficients with the same order of magnitude but reversed with respect to those on the test sections and higher macrotexture values. These discrepancies may probably be due to differences in the compaction process between real site and laboratory. The Wehner and Schulze tests led to friction curves exhibiting a classical shape with an increase of friction coefficient in a first phase (bitumen removal) and a decrease in a second phase (aggregates polishing) (Figure 6). Moreover, P road section presents a lower friction value than PCR section but friction coefficients stay always superior to 0.40 whatever the number of passes, which traduces a satisfying level of performance.

Table 4. Friction and macrotexture of the two laboratory samples

Surface property	Mix P	Mix PCR
Friction (British Pendulum)	82.4	73.9
ETD (mm)	0.71	0.61

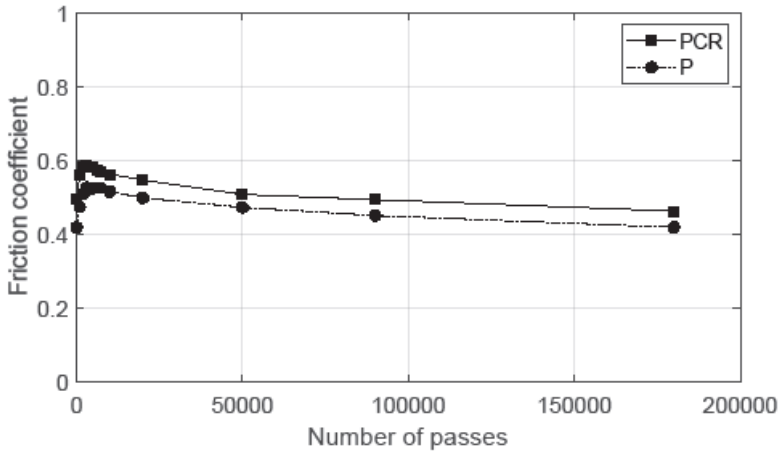


Figure 6. Wehner and Schulze test results on the two prototype sections

4. ACOUSTIC ASSESSMENT OF THE PROTOTYPE SURFACES

The acoustical behaviour of the prototype road surfaces under driving conditions is evaluated in terms of on-board CPX and roadside measurements, the latter considering pass-bys both at constant speed and under acceleration.

4.1. Close-proximity measurements

CPX is a close-proximity method described in ISO 11819-2, assessing the acoustical influence of a road surface by measuring tyre-road noise with on-board microphones fixed near the test tyre. Two distinct systems have been involved in LIFE E-VIA for the implementation of this standard, each involving a specific vehicle and reference tyres:

- a Renault Scenic equipped with tyres Michelin Energy Saver 195/60 R15 (Figure 7, left). These tyres are a commercial model, offering a good energy efficiency.
- a Mercedes Vito fitted with SRTT tyres of dimension P225/60 R16 (Figure 7, right). These correspond to the reference passenger car tyres P1 described in ISO/TS 11819-3, also used for various standardized tests[1].

On both vehicles, the on-board microphones are placed near the right rear wheel.

[1] The P1 tyres are also involved in the specification of minimum requirements for low-noise pavement design [9].



Figure 7. CPX test vehicles and tyres: Renault Scenic fitted with Michelin Energy Saver tyres (left) and Mercedes Vito fitted with SRTT tyres (right)

The experiment was repeated in a similar way on the road surfaces P, PCR and reference E1. It consisted in pass-bys at constant speed from 30 to 110 km/h in 5 km/h steps. The third-octave noise levels are energy averaged between both lateral microphones and over the test section length. Features specific to each vehicle system are:

- a frequency range of 400-4000 Hz for the Michelin tyres and a correction for removing air turbulence and vehicle engine contributions as background noise,
- a frequency range of 315-5000 Hz for the SRTT tyres.

The analysis of the results focuses on the overall noise levels and on the third-octave band content, provided by the following data processing:

- overall noise: the overall CPX noise level of each measuring system is recomposed over the available frequency range, finally corrected in temperature at 20°C in both cases and corrected in hardness for the SRTT tyre. Then, a regression based on $\log(speed)$ is calculated to get the overall CPX noise level at 50 km/h (Table 5).
- third-octave noise: no temperature correction is included. In each frequency band, a regression based on $\log(speed)$ is calculated to finally get the CPX noise level spectrum at 50 km/h (Figure 8).

With the Michelin tyre, the overall noise reduction at 50 km/h compared to the reference surface E1 is 2.8 dB(A) for P and 2.4 dB(A) for PCR. With the SRTT tyre, the noise reduction is 1.7 dB(A) for P and 2.4 dB(A) for PCR, both prototypes meeting the Core criterion of GPP for a low-noise pavement [9] and PCR even being close to the more stringent Comprehensive criterion.

For either tyre type, both prototype sections exhibit similar noise spectrum patterns. However, the tyre type affects the frequency of the spectrum maximum, around 800-1000 Hz for the Michelin tyres and around 500-800 Hz for the SRTT tyres. The noise reduction provided by the prototypes relatively to the reference

surface E1 spans most of the frequency range with the Michelin tyres, most significant over 500-2500 Hz. By contrast, the improvement mainly concerns the range 800-1600 Hz with the SRTT tyres. In both cases, the maximum noise reduction amounts to 4 dB(A) at 1000 Hz.

Table 5. CPX overall noise levels on the road surfaces P, PCR and E1 with the two tyre types – Reference speed 50 km/h

	P	PCR	E1
Michelin Energy Saver 195/60 R15	84.2 dB(A)	84.6 dB(A)	87.0 dB(A)
SRTT P225/60 R16	88.5 dB(A)	87.8 dB(A)	90.2 dB(A)

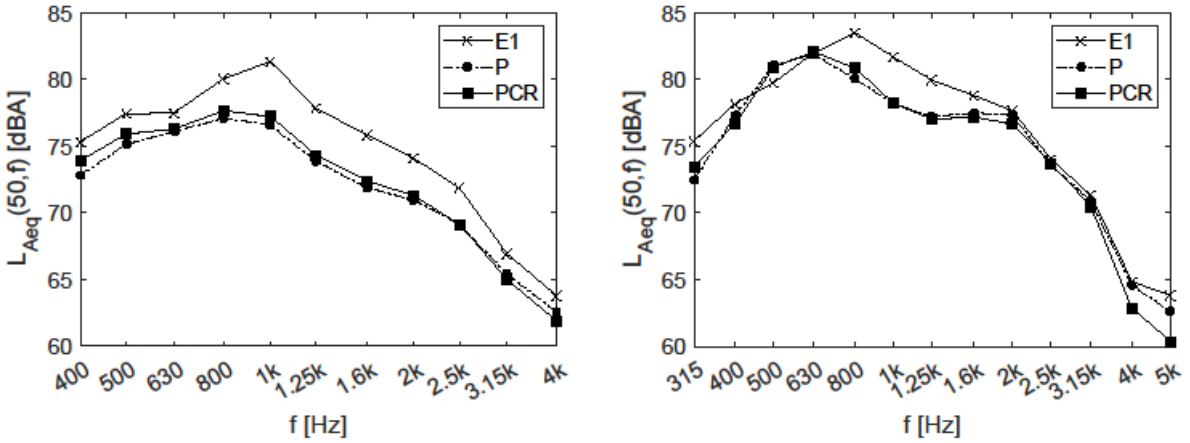


Figure 8. CPX spectra on the three road surfaces, measured with Michelin Energy Saver tyres (left) and SRTT tyres (right)

4.2. Pass-by measurements at constant speed

Controlled pass-by measurements assess the influence of the road surfaces on vehicles noise emission, evaluated at constant speed from a roadside microphone. In accordance with ISO 11819-1, the microphone is located at a distance of 7.5 m from the track centre and a height of 1.2 m. The relevant quantity used is the maximum noise level L_{Amax} at pass-by.

One light commercial and two passenger electric vehicles, all very common EV models in Europe within their category and equipped with their own commercial tyres, have been tested respectively on the three road surfaces P, PCR and E1 at constant speed from 20 to 70 km/h: Renault KANGOO ZE (Michelin Energy Saver 195/65 R15), Renault ZOE (Michelin Energy EV 185/65 R15) and Nissan LEAF (Michelin Energy Saver 205/55 R16) (Figure 9). If existing, the

alerting sound operating at low speed (AVAS) was off. Only the measurement of the Nissan LEAF on road surface E1 was not available.



Figure 9. CPB test vehicles: Renault KANGOO ZE (left), Renault ZOE (middle) and Nissan LEAF (right)

Preliminary data processing included correction from the background noise contribution, as described in [6]. Regressions on the overall CPB noise levels with log $(speed)$ have been performed to point out the main noise trend and derive the estimated level at 50 km/h for each vehicle/road configuration corrected at 20°C according to [10] (Figure 10). Similarly, regressions have been carried out in third-octave bands to get the spectrum at 50 km/h in the range 100-5000 Hz (Figure 11). No temperature correction is applied in frequency.

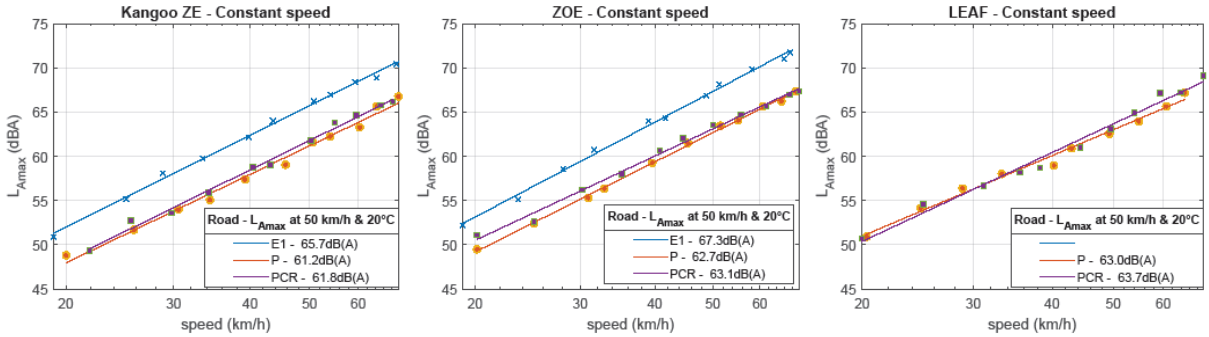


Figure 10. Overall noise levels L_{Amax} at constant speed on road surfaces E1 *(blue)*, P (*red*) and PCR (*purple*): KANGOO ZE (left), ZOE (middle) and LEAF (right) – Measures (*dots*) and regression (*lines*)

The noise reduction introduced by the prototypes relatively to E1 is significant, around 4 dB(A) or more at 50 km/h for KANGOO ZE and ZOE. In comparison, the difference between P and PCR is weak. For the three vehicles, PCR turns out to give slightly higher overall noise levels than P on most of the tested speed range. At 50 km/h, this results in a difference between PCR and P of 0.4 dB(A) with the KANGOO ZE and respectively 0.6 and 0.7 dB(A) for the ZOE

and the LEAF. Generally speaking, KANGOO ZE is the quietest vehicle on the road surfaces tested, whereas LEAF gives the highest noise levels on the prototype road surfaces, more clearly at high speed.

KANGOO ZE and ZOE offer a similar spectrum pattern on the reference road surface E1, with a maximum at 1000 Hz. This peak is reduced by 5 dB(A) and 10 dB(A) respectively with ZOE and KANGOO ZE on both prototypes. The prototype surfaces result in a generally wider spectrum pattern, with a shifted maximum contribution around 630 Hz (KANGOO ZE and LEAF) or 800 Hz (ZOE). The prototypes also introduce a significant noise reduction at lower frequencies 250-400 Hz, where ZOE and LEAF exhibit a distinct secondary peak. However, changes at high frequencies are small. The predominance of noise levels previously observed with the three vehicles on PCR compared to P result from a smaller reduction by PCR occurring in the range 630-800 Hz.

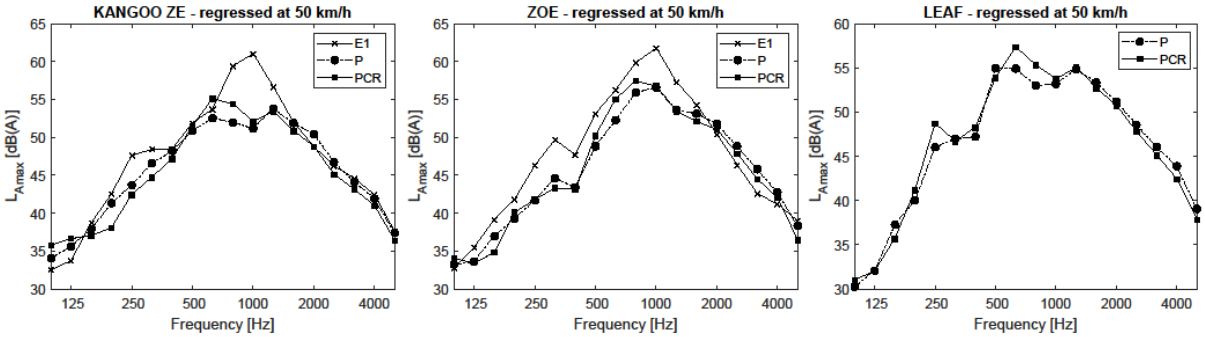


Figure 11. CPB noise spectra on road surfaces E1, P and PCR, regressed at 50 km/h: KANGOO ZE (left), ZOE (middle) and LEAF (right)

4.3. Pass-by measurements under acceleration

EVs have a high acceleration capacity due to the typical performance of electric motors, providing increased acceleration rates on a wide speed range in comparison with conventional vehicles [3]. Noise emission under acceleration relatively to constant speed,a higher motor's noise contribution and stronger efforts in the driving tyre/road contact areas result in potentially increased rolling noise levels [4]. In order to characterize the road surfaces in various driving conditions encountered in real life, the project LIFE E-VIA has also investigated pass-bys under acceleration and deceleration, which are common situations in urban traffic. Full acceleration corresponds to the harshest conditions and pass-by tests have been carried in full throttle. A microphone being located at the same position as for CPB tests (see Section 4.2), the test vehicle accelerated over a

minimum length of 10 m centred on the microphone, from various initial speeds. The average acceleration rate on the 10 m section, the instantaneous speed and the noise level (L_{AF} with time constant *Fast*) were determined when the vehicle centre is right to the microphone. These quantities are used to compare noise emission from the three previous EVs on the road surfaces E1, P and PCR, except for the LEAF on E1 unavailable (Figure 12).

The KANGOO ZE has lower full acceleration capabilities than the other two vehicles, as can be seen on the bottom graphs of Figure 12, whereas the LEAF is the best performing one. It may be checked that the acceleration rates were consistent regardless the road surface. Most often, the noise levels at speeds over 50 km/h, where the acceleration ability is weaker, are of the same order than at constant speed. Acoustical behaviour and road surface ranking under acceleration varies between vehicles. E1 provides the loudest situation of the three surfaces tested with KANGOO ZE over the speed/acceleration range, the prototypes giving a reduction of more than 1.5 dB(A) in the urban speed range. The difference between the prototypes and the reference E1 is lower with the accelerating ZOE. Considering both prototype sections, PCR is in general slightly louder than P with all vehicles. The unexpected behaviour observed with the ZOE on PCR below 50 km/h, ranking it as the noisiest road surface with this vehicle, has to be further investigated.

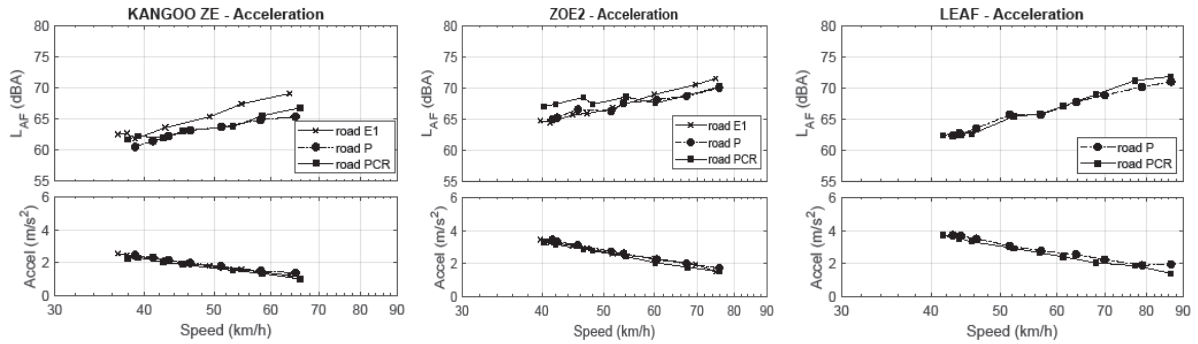


Figure 12. Electric vehicles at full acceleration on road surfaces E1, P and PCR: KANGOO ZE (left), ZOE (middle) and LEAF (right) -- Overall noise levels L_{AF} as a function of the instantaneous speed right to the microphone (top) and corresponding average acceleration rate (bottom)

5. CONCLUSION

Two prototypes of a low-noise road surface, previously designed by considering an LCA, have been tested before further implementation on a road with traffic in Florence, Italy. These are VTAC 0/6 (resp. P and PCR), the latter including 1.9% of crumb rubber. Their acoustical and grip properties have been evaluated. MPD and ETD turn out to be quite low, but both road sections offer good friction performance with a satisfactory durability. Sound absorption coefficients are low, as expected with this type of surfaces, and the mechanical impedance reflects relatively stiff surfaces, even for PCR.

On-board CPX measurements, carried out with commercial and SRTT tyres, highlight an overall rolling noise reduction from 1.7 to 2.8 dB(A) compared with a common reference DAC 0/10, the prototype ranking depending on the considered tyres. They fully fulfil the Core criterion of GPP for a low-noise pavement. Roadside CPB measurements involving three common EVs show a pass-by noise reduction of at least 4 dB(A) relatively to DAC 0/10 at 50 km/h, with a significant effect around 1000 Hz. P and PCR acoustic behaviours differ only slightly, in favour of P. The same trend is observed under acceleration.

Further reduction of the EV noise emission is investigated in the LIFE E-VIA project by an optimization of tyre design, which is currently under investigation on the prototype test sections.

Acknowledgements

The authors thank the European Commission for its financial contribution to the LIFE18 ENV/IT/000201 LIFE E-VIA project into the LIFE2018 programme.

This work used measuring equipment of the LABEX CeLyA (ANR-10-LABX-0060) of Université de Lyon, funded within the program "Investissements d'Avenir" (ANR-11-IDEX-0007) operated by the French National Research Agency (ANR).

The authors thank Sebastien Buisson and Samuel Louis from Université Gustave Eiffel for their contribution to the building of the prototype.

REFERENCES

[1]. *European Union Press Release 14 July 2021*, https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541, consulted on 17.08.2021.

[2]. European Alternative Fuels Observatory, https://www.eafo.eu/vehicles-and-fleet, consulted on 17.08.2021.

[3]. M.-A. PALLAS, J. CESBRON, S. LUZZI, L. BUSA, G. COLUCCI, R. BELLOMINI, *Review on Electric Vehicles and Their Noise Emission*, Deliverable of the LIFE project E-VIA (LIFE18 ENV/IT/000201), European Commission, **2020**.

[4]. C. HOEVER, *Review on noise relevant differences between ICEV and EV tyres*, Deliverable of the LIFE project E-VIA (LIFE18 ENV/IT/000201, European Commission, **2020**.

[5]. LIFE E-VIA Project (LIFE18 ENV/IT/000201), Available: https://life-evia.eu .

[6]. J. CESBRON, S. BIANCHETTI, M.-A. PALLAS, A. LE BELLEC, V. GARY, P. KLEIN, *Road surface influence on electric vehicle noise emission at urban speed*, Noise Mapping 8, pp. 217-227, doi:10.1515/noise-2021-0017, **2021**.

[7]. F. G. PRATICÒ, *Review on quiet pavement technologies and their performance over time*, Deliverable of the LIFE E-VIA Project (LIFE18 ENV/IT/000201, European Commission, **2020**.

[8]. J. CESBRON, S. BIANCHETTI, M.-A. PALLAS, F. G. PRATICÒ, R. FEDELE, G. PELLICANO, A. MORO, F. BIANCO, *Acoustical characterization of low-noise prototype asphalt concretes for electric vehicle*, Proc. of Euronoise2021, Madeira, Portugal, **2021**.

[9]. *EU Green Public Procurement Criteria for Road Design, Construction and Maintenance*, European Commission, **2016**.

[10]. F. ANFOSSO-LÉDÉE, Y. PICHAUD, *Temperature effect on tyre-road noise*, Applied Acoustics 68 (11), pp. 1-16, doi:10.1016/j.apacoust.2006.06.001, **2007**.