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Article

Ultra Low Noise Poroelastic Road Surfaces

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Abstract: Noise is one of the most important environmental problems related to road traffic. During the last decades, the noise emitted by the engines and powertrains of vehicles was greatly reduced and tires became a clearly dominant noise source. The article describes the concept of low noise poroelastic road surfaces that are composed of mineral and rubber aggregate bound by polyurethane resin. Those surfaces have a porous structure and are much more flexible than standard asphalt or cement concrete pavements due to high content of rubber aggregate and elastic binder. Measurements performed in several European countries indicate that such surfaces decrease tire/road noise between 7 dB and 12 dB with respect to reference surfaces such as dense asphalt concrete or stone matrix asphalt. Furthermore, poroelastic road surfaces ascertain the rolling resistance of car tires, which is comparable to classic pavements. One of the unforeseen properties of the poroelastic road surfaces is their ability to decrease the risks related to car fires with fuel spills. The article presents the road and laboratory results of noise, rolling resistance, and fire tests performed on a few types of poroelastic road surfaces.

Keywords: poroelastic road surface; tire/road noise; rolling resistance; road pavement; fire risk

1. Introduction

Tire/road noise is the dominant noise source for cars that are already at low speeds (typically as low as 30–40 km/h). Abating traffic noise is hence mainly about reducing tire/road noise. One can (and should) work on the tire properties to reduce noise, but also on the pavement. To reduce the tire/road noise, one can only "turn on three buttons": the pavement texture (minimum of megatexture and maximum of macrotexture), the absorption by the pavement (high accessible void content and a proper shape and length of the "channels" formed by the voids) and the elasticity of the pavement. Low noise pavements based on an optimized texture or a high void content do exist and are even widespread in some countries, such as the Netherlands. However, the third possibility to reduce noise, making the pavement elastic, has hardly been exploited so far in commercially available pavements. Some extra noise reduction is gained in some countries by adding rubber to bituminous pavements, but these pavements are still quite "hard" and the gain is limited, typically 1 up to 2 dB(A). One can suppress tire/road noise much more by making the pavement much more elastic, and this idea is exploited with poroelastic road surfaces (PERS). This article presents some of the research work related to PERS that was carried out by the Technical University of Gdansk and is based on a RAR 2015 conference paper presented by these authors [1].

PERS was invented and patented at the end of the 1970s by Nils-Åke Nilsson, at that time working for an acoustic consultantcy company in Stockholm, Sweden. It was soon discovered that this pavement has huge noise reduction potential. During the 1980s it was found that noise reduction of up to 10 dB(A) is possible with PERS [2]. All early test fields in Sweden failed very quickly, however, typically within a few weeks, due to major deterioration of the pavement.

In 1989, a trial was conducted with a 130 m-long test track built in the Oslo area, reducing car noise by 7–9 dB(A). However, this test track was accidentally destroyed by a snow plough after a few months.

By the mid 1990s, Dr. Seishi Meiarashi at the Public Works Research Institute (PWRI) in Japan started to work on PERS by attempting to obtain PERS with a reasonable lifetime. Several PERS types were tested on the straight and circular test track of PWRI in Tsukuba City between 1996 and 2002 [3]. Between 2002 and 2004, several test tracks were built on highways near the Japanese cities of Mie and Akita, which failed after a few months and up to one year.

In a street in the Stockholm area in Sweden, the Swedish National Road and Transport Research Institute (VTI) built three test tracks (one PERS with an *in situ* mix and two with prefabricated panels (1 m × 1 m) in the frame of the EU-funded project SILENCE. Unfortunately, this experiment failed very soon due to problems in the underlayer, however, huge noise reductions of up to 12 dB(A) were measured.

In the meantime, from 2006, the Japanese built some new test tracks in built-up areas, namely in Zama and Yokohama, with a higher stone content and yielding noise reductions of about 10 dB(A). The Zama test section, built in 2008, resisted wear quite well (only some slight local raveling was observed), but was contractually removed after three years in 2011. The Yokohama test track, built in 2009, was also removed in 2011, mainly due to severe local raveling at a lorry exit and loosening from the sublayer. The Zama test track, which lived for about three years, was the longest surviving PERS so far, feeding the hope that a reasonable lifetime for PERS is feasible.

The Dutch have been experimenting with PERS since 2007 and have made some test tracks on an untrafficked road in Kloosterzande, and two test tracks on a road at a parking lot along the A8 highway near Arnhem. The latter had problems with the initial skid resistance and the test track failed within a few months. For a more comprehensive overview of the history of PERS, see [4].

By 2008, some European road research institutes took the initiative to draft a proposal for an Seventh Framework Programme call of the European Commission. A consortium of 12 partners from eight countries was formed, comprising six road research institutes, two contractors, two universities and two specialist partners with some special know-how. The proposal was approved and, in September 2009, the six-year project PERSUADE started. PERSUADE is an acronym for PoroElastic Road Surface for Avoiding Damage to the Environment. The aim of the PERSUADE project was to develop PERS from an as yet experimental concept into a usable noise abatement measure.

The problems to be solved and questions to be answered about PERS at the beginning of the project-as is shown by the long series of failures with PERS until then-were numerous: how to produce a mix which would yield a durable, highly noise-reducing pavement with a sufficient skid resistance? How to avoid the PERS raveling or loosening from the sublayer? What to do in the case of a fuel spill? Or in the case of an accidental vehicle fire on a PERS section? How should PERS be built without increasing rolling resistance? Which precautions should be taken to protect road workers and people living around from hazardous fumes? What to do with PERS at the end of its lifetime? What about economic aspects?

In order to find an answer to all relevant questions a comprehensive research program was drafted, consisting of eight work packages. The Technical University of Gdańsk (TUG) has been actively contributing to the project, mainly concerning the assessment of the performances of mixtures in the laboratory (WP2), on the road (WP5) and also concerning safety and environmental concerns (WP6).

2. Materials and Methods

2.1. Test Pavements

During the project several mixtures were considered with following specifications: 20%–85% of rubber granulate (by weight); 0%–70% of mineral aggregate; 10%–15% of polyurethane resin, aggregate size of 3–5 mm, layer thickness of 21–42 mm. The typical void content obtained with the mixtures was 20%–30%. The extensive work in the laboratory has resulted in two PERS mixtures compositions which performed well on durability tests. In this paper they have the code names mix #1 and mix #2 (for more ample information about their composition, see, e.g., [5]; mix #1 is the composition used for PERS-DK1, and mix #2 is the one used for PERS-SE2-HET2, see Table 1). Each of the mixes contains rubber granulates, stone aggregates, polyurethane as binder and some additional ingredients with specific functions. The difference between mix #1 and mix #2 is that mix #2 contains much more rubber aggregates at the expense of the stone aggregates. Both contain the same amount of binder. There are three ways of application which were tested in the PERSUADE project:

1. By mixing the ingredients on the spot and spreading the wet mix manually or with an asphalt finisher. This is called the *in situ* application.
2. The mix is made in the factory and put in moulds, given the time to cure resulting in slabs of 0, 5 m × 1 m. These slabs are then glued to the sublayer on the test area.
3. Smaller slabs are produced like in point 2 above and are glued on cement concrete blocks in the factory, which are then laid on the test area in the classical way.

Table 1. Description of test sections.

Code	Country	Mix	Application Method
PERS-B	Belgium	#1	*In situ*, classic asphalt finisher
PERS-DK	Denmark	#1	*In situ*, gussasphalt finisher
PERS-SE2-HET2	Sweden	#2	1 m × 1 m slabs, HET company produced
PERS-SE2-HET3	Sweden	#2	1 m × 1 m slabs, HET produced
PERS-SE2-VTI	Sweden	#2	*In situ*, manual application
PERS-Sl	Slovenia	#2	Small slabs, HET produced, on concrete blocks
PERS-Pl	Poland	#1	*In situ*, classic asphalt finisher

During the execution of the PERSUADE project, several test tracks were constructed in four countries: Belgium, Denmark, Sweden and Slovenia. Unfortunately, a test track in Poland has prematurely failed; its composition was basically the same as the Belgian and Danish test tracks but with local aggregates. Nevertheless, it was possible to carry out some measurements on it. The reason of the failure was not enough adhesion of PERS (poroelastic road surfaces) to the existing base layer. Table 1 summarizes the mix type and application method used for the test tracks. At the time of drafting (February 2016), the PERS-SE2-HET2 was already 18 months old and doing just as well as the 6-six-months-old PERS-SE2-HET3. Except for the Slovenian, the other test tracks were removed due to serious damages (raveling and/or debonding).

2.2. Test Tires

During the project, several passenger car tires as well as truck tires were tested in the laboratory and on the road. The tires are presented in Table 2. The tire set contained both reference tires according to [6], commercial passenger car tires typical for European roads, tires designed for electric vehicles and truck tires included retreaded tires. All tires were new or nearly new (that is used for less than 2000 km).

Table 2. Description of the tires.

Code	Manufacturer and Model	Size	Remarks
T1063	Avon AV4	195R14C	Reference tire according to ISO/CD 11819-3 [6]
T1077	Uniroyal TIGER PAW	P225/60R16	Reference tire according to ISO/CD 11819-3
T1064/68	Michelin PRIMACY HP	225/60R16	Informal reference tire at TUG
T1075/76	Continental BLUECO	195/50R18	Tire designed for electric vehicles
T1113	Bridgestone ECOPIA EP500	155/70R19	Tire designed for electric vehicles
T1066	Wanli S-1200	196/60R15	Summer tire
T1067	Continental ECOCONTACT 5	195/60R15	Summer tire
T1073	Avon ZV5	195/65R15	Summer tire
T1078	Goodyear EFFICIENT GRIP	195/65R15	Summer tire
T1079	Bridgestone ECOPIA EP001S	195/65R15	Summer tire
T1080	Michelin ENERGY SAVER X GREEN	215/55R17	Summer tire
T1081	Dunlop SPORT BLURESPONSE	195/65R15	Summer tire
T1082	Michelin ENERGY SAVER X GREEN	195/55R15	Summer tire
T1071	Vredestein QUATRAC 3	195/50R15	Winter tire
T1072	Yokohama WDRIVE	195/50R15	Winter tire
T1070	Vredestein WINTRAC EXTREME	205/55R16	Winter tire
T1114	Sava CIT U3	275/70R22.5	Truck tire, retreaded
T1115	Giti GT867	275/70R22.5	Truck tire, retreaded
T1116	Dunlop SP372 CITY	275/70R22.5	Truck tire
T1117	Michelin M758	275/70R22.5	Truck tire, retreaded
T1118	Bridgestone M758	275/70R22.5	Truck tire, retreaded
T1119	Dunlop SP372 CITY	275/70R22.5	Truck tire, retreaded

2.3. *Tire/Road Noise Measuring Methods*

Tire/road noise was measured on the road according to ISO 11819-2 standard (close proximity method of tire/road noise measurements (CPX) method) [7] using test trailer Tiresonic Mk. 4 owned by TUG [8]. In the laboratory, tire/road noise was measured on the roadwheel facilities with drums of 1.5, 1.7 and 2.0 m diameter equipped with replica road surfaces [9] described in Table 3.

Table 3. Description of replica road surfaces fitted to the drums.

Code	Description	Placement	Mean Profile Depth (MPD) [mm]
ECEr15	Replica of dense asphalt concrete with 11 mm aggregate made as an epoxy laminate	Drum 1.5 m	0.67
APS4r17	Replica of surface dressing 8/10 mm aggregate. Mineral chippings connected to the polyurethane base layer by the polyurethane resin	Drum 1.7 m	4.75
PERSr17	Poroelastic road surface (mineral and rubber aggregate glued by polyurethane resin), 4 mm chipping size	Drum 1.7 m	1.53
DAC16r20	Replica of dense asphalt concrete with 16 mm aggregate made as an epoxy laminate	Drum 2.0 m	1.33
ISOr20	Replica of ISO reference road surface made as an epoxy laminate	Drum 2.0 m	1.06
PERSr20	Poroelastic road surface (mineral and rubber aggregate glued by polyurethane resin), 4 mm chipping size	Drum 2.0 m	1.53

During the measurements, the tires were loaded to 3200 N and the capped inflation pressure was 200 kPa.

2.4. *Rolling Resistance Measuring Methods*

There is no standardized method of measuring tire rolling resistance on the road. To perform rolling resistance tests, test methodology developed in TUG was used together with the test trailer R^2 Mk.2 [8]. The tire load during road measurements was adjusted to 4000 N and regulated inflation pressure to 210 kPa.

During laboratory measurements TUG's roadwheel facilities with drums 1.7 and 2.0 m were used. The roadwheel facilities are designed to test the rolling resistance by means of the torque method [10,11]. Load and inflation pressure for the passenger car tires were set according to ISO 28580 [12]: the load equal to 80% of the maximum load stated by the Load Index and a capped inflation pressure of 210 kPa. For truck tires of size 275/70R22.5, the load was 2,4800 N and the capped inflation pressure was 700 kPa.

3. Results

3.1. Tire/Road Noise Reduction by PERS

The main reason to develop PERS was its potential for reduction of tire/road noise, which is one of the main environmental problems related to road traffic. PERS has a positive influence on the aerodynamic related tire/road noise generating mechanisms (due to its porosity) and on the vibration related mechanisms (due to its elasticity). The noise properties of PERS were tested both in laboratory on roadwheel facilities with drums covered by PERS slabs manufactured by the company and PERSUADE partner HET, and on the road on test sections paved with different types of PERS.

3.1.1. Laboratory Measurements of Tire/Road Noise on PERS

During the test campaign, several tires were tested on different replica road surfaces and on slabs produced by HET (indicated with "PERS-HET"). In Figure 1, the results obtained for three tires on two replica road surfaces and PERS-HET are presented (for the names, see Table 3). A comparison of A-weighted levels shows that for all speeds the tire/road noise on PERS-HET surface is considerably lower than on other road surfaces. The noise reduction provided by PERS-HET increases with speed and, for example, in comparison to dense asphalt concrete it is 7.8 dB for 50 km/h, 10.5 dB for 80 km/h and 12.6 dB for 100 km/h. In comparison to a surface dressing it is 6.9 dB, 9.2 dB and 11.6 dB, respectively.

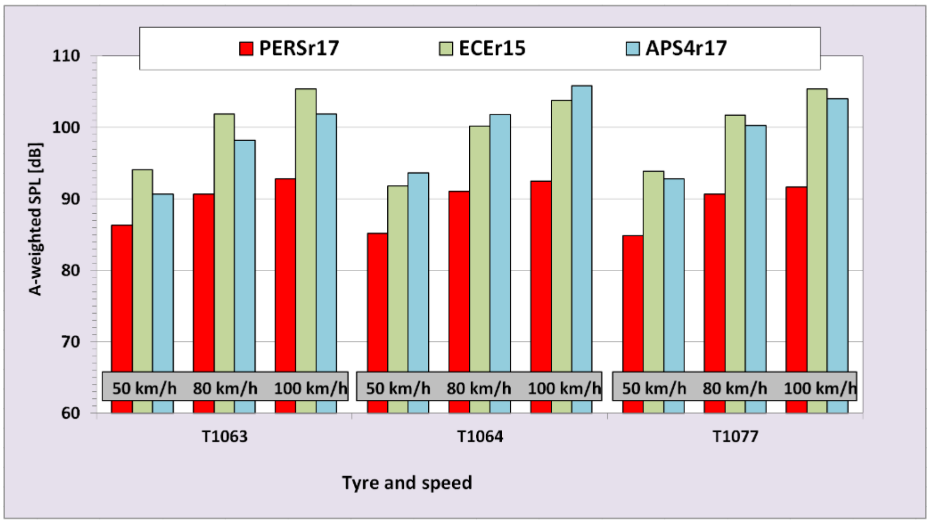


Figure 1. A-weighted sound pressure level (SPL) for passenger car tire.

A comparison of noise spectra obtained at 80 km/h for tire T1064 indicates that a positive influence of PERS is visible for all frequencies; see Figure 2. In comparison to dense asphalt concrete, the noise reduction has the highest values for frequencies over 800 Hz and, in comparison to rough surface dressing, the reduction is the highest for frequencies below 800 Hz. The noise reduction for higher frequencies can be explained by the suppression of the air pumping by the high porosity of the PERS. An important and unique reduction of the noise levels between about 800 and 2000 Hz is obtained by the elasticity, *i.e.*, by suppressing tire vibrations. The very low megatexture of the PERS is responsible for the low noise emission below 800 Hz. The effect of the absorption is not visible in this spectrum, except maybe the shallow absorption dip around 1200 Hz. Results for other tires and speeds were very similar.

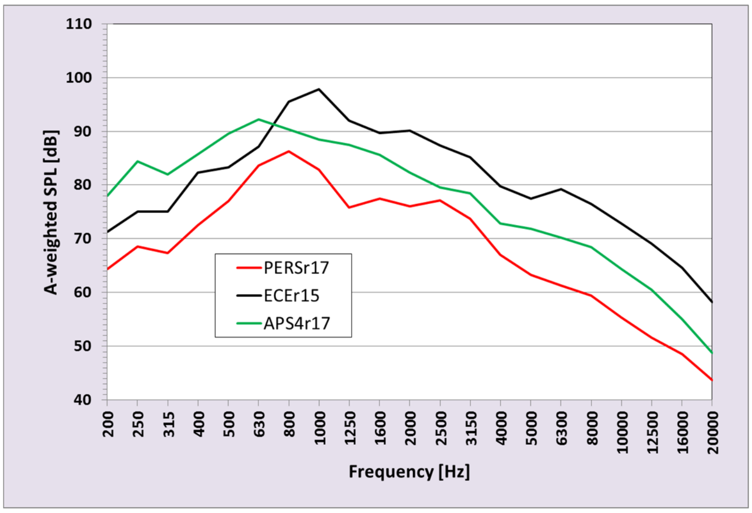


Figure 2. Comparison of spectra for tire T1064 at speed 80 km/h (PERS is the PERS-HET-type (slabs produced by HET)).

A roadwheel facility with a 2.0 m drum was used for testing the noise of truck tires as well. Five tires were tested on PERSr20, ISOr20 and DAC16r20, and the results are presented in Figure 3. In all cases, the noise emitted on poroelastic road surface is much lower than on other road surfaces that were tested. The difference is from 7 dB up to 13 dB. Also, in the case of truck tires, the noise reduction is visible for a broad range of frequencies, from very low to very high; see Figure 4.

Drum measurements clearly indicate that the noise emitted on poroelastic road surfaces is much lower than the noise emitted on dense and stiff road surfaces. Generally, noise reduction increases for high speeds reaching over 10 dB for certain tires. A similar noise reduction is obtained for passenger car tires and truck tires.

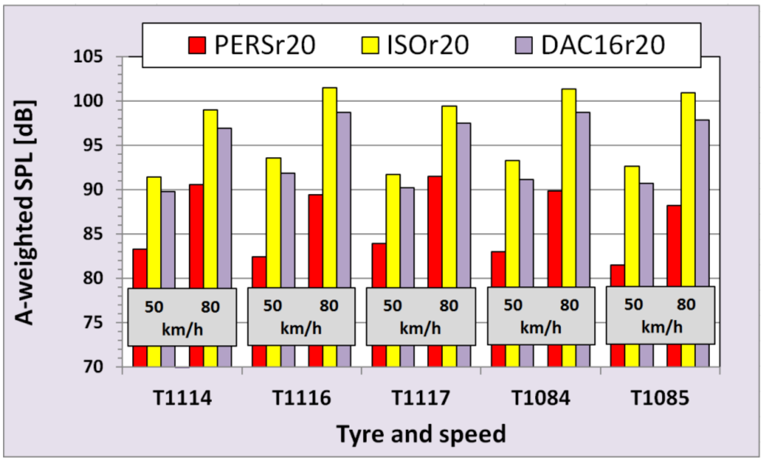


Figure 3. A-weighted SPL for truck tires (PERS is the PERS-HET-type).

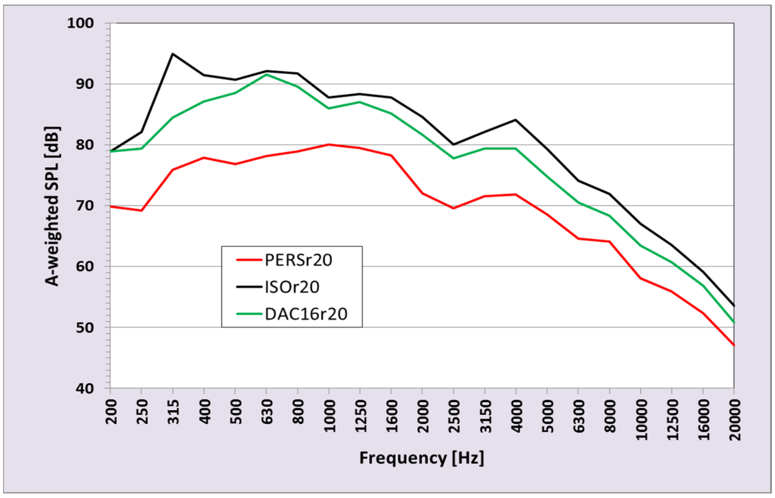


Figure 4. Comparison of spectra for truck tire T1085 at speed 80 km/h (PERS is the PERS-HET-type).

3.1.2. Road Measurements of Tire/Road Noise on PERS

TUG measured tire/road noise by the CPX method (ISO 11819-2) [7] on several test sections paved with PERS material, however, in this article only the results obtained on the test sections constructed in Poland and in Denmark are reported.

The Polish test section was constructed on the road paved with SMA11 (Stone Mastic Asphalt), so this type of pavement was considered as the reference. In Figure 5, the A-weighted sound pressure levels are compared for four passenger car tires. In all cases PERS provides noise reductions of about 10 dB in comparison with SMA11.

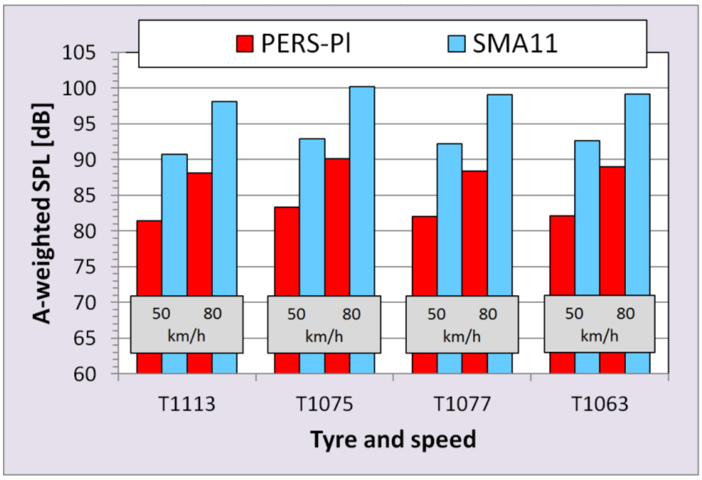


Figure 5. A-weighted SPL for passenger car tires measured by close proximity method of tire/road noise measurements (CPX) method.

In Figure 6, spectra obtained on PERS and SMA11 are compared. In contrast to drum measurements, the spectra seem to indicate that the noise reduction is concentrated in the frequency range of 500 up to 12,500 Hz. In the opinion of the authors, the reason for this apparently low noise reduction in the low frequency range is related to the test trailer construction. To be practical, the test trailer is rather small and the protective chamber cannot provide perfect noise screening for very low and very high frequencies. For conventional road surfaces this is not a problem, as noise generated by the tire is rather high, but in the case of tires rolling on poroelastic road surfaces, the background noise at low and high frequencies may influence the results.

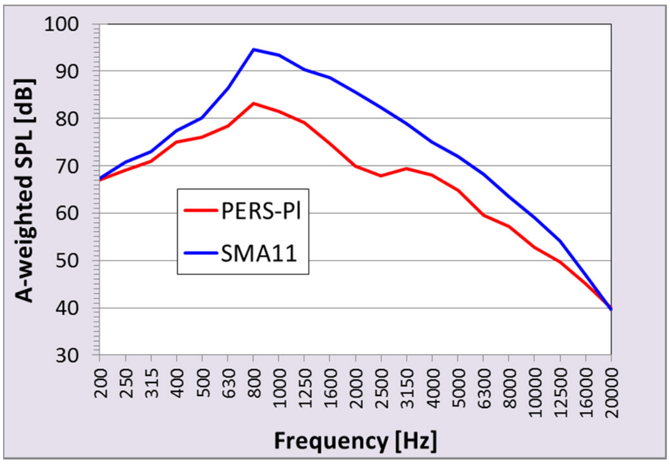


Figure 6. A-weighted spectra for passenger car tires measured by CPX method.

In Figure 7, results obtained on the PERS surface designed and manufactured in Denmark are presented. The measured noise reduction on this test section, in comparison with dense Asphalt Concrete DAC 8, was 6–7 dB.

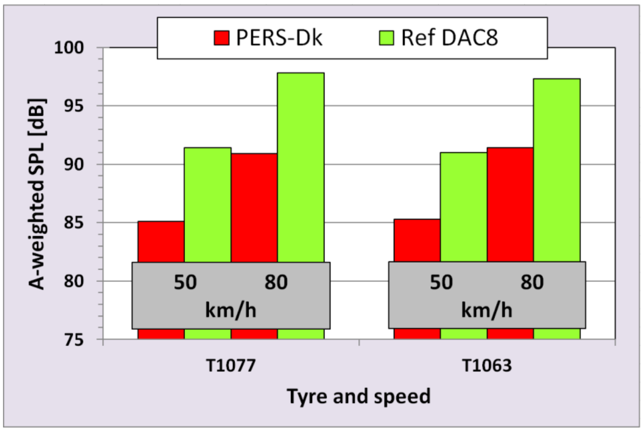


Figure 7. A-weighted SPL measured by the CPX method on test sections in Denmark.

For comparison: a noise reduction of 6 dB is about the noise reduction yielded by a noise screen with a height of 3 m and, for a noise reduction of 8 dB, the height of the screen has to be 4 m. To reduce the noise with 10 dB, one needs a height of about 6 m and, for 12 dB, even 8 m. The noise reductions measured on the PERS developed in the PERSUADE project are hence substantial and PERS can be thought of being capable of replacing noise screens if they could meet certain minimum criteria regarding durability.

3.2. Tire Rolling Resistance on PERS

Rolling resistance of tires is one of the most important factors controlling energy consumption of road vehicles. Influence of rolling resistance on energy consumption is especially important for constant medium speeds. Usually, at low speeds, most of the energy is consumed for the acceleration, *i.e.*, to overcome inertia forces on vehicles (congested traffic), at moderate speeds (50–90 km/h) it is consumed to overcome rolling resistance, and for high speeds to overcome the aerodynamic drag force. The tire rolling resistance may be assessed in the laboratory by using roadwheel facilities or on the road using coast down or trailer methods. Laboratory methods are internationally standardized [11,12] but the road methods are performed according to methodologies developed by performing organizations.

To measure rolling resistance forces on PERS, both laboratory and road methods were used by TUG. The particularities of equipment utilized during these measurements are described in [8].

3.2.1. Laboratory Measurements of Rolling Resistance on PERS

Rolling resistance measurements were performed on roadwheel facilities with diameters of 1.7 and 2.0 m owned by TUG. In Figure 8, the results obtained for passenger car tires are presented. The coefficients of rolling resistance (C_{RR}) reported in this figure are corrected for both temperature and drum curvature.

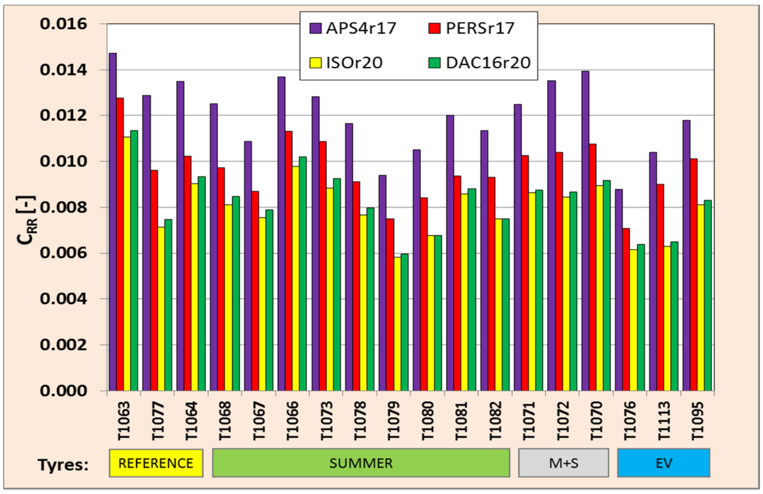


Figure 8. Results of laboratory rolling resistance measurements for passenger car tires (EV-tires designed for electric vehicles).

The coefficients of rolling resistance measured on the PERS surface are, on average, 24% lower than measured on the replica of a surface dressing (APS4r17), 17% higher than on the replica ISOr20 and 15% higher than on the replica of dense asphalt concrete with 16 mm aggregate (DAC16r20). The results indicate that PERS is positioned somewhere between existing road pavements concerning rolling resistance for passenger car tires.

It is interesting to investigate the rolling resistance of truck tires on PERS. To do so, six truck tires (of a size commonly used for busses) were tested on a roadwheel facility with a 2.0 m diameter drum. The results are presented in Figure 9. As the 2.0 m drum is not equipped with a replica of the surface dressing, the measurements were carried out only on PERSr20, ISOr20 and DAC16r20.

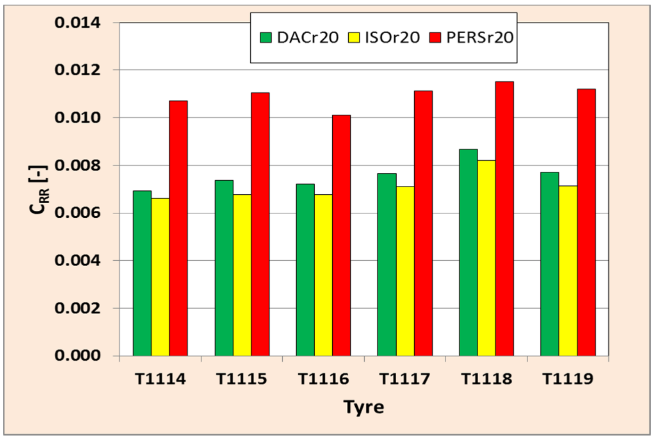
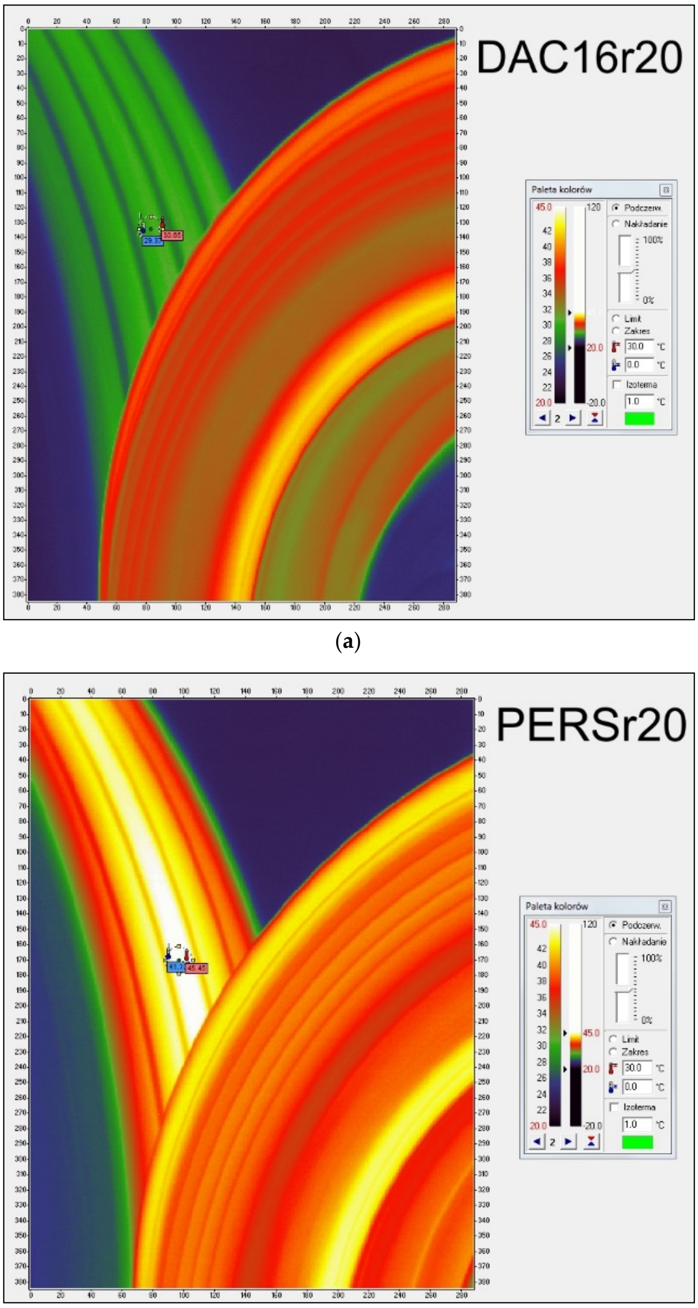


Figure 9. Results of laboratory rolling resistance measurements for truck tires (PERS is the PERS-HET-type).

The results indicate that the rolling resistance of truck tires on a PERS is considerably higher than on a replica of a dense asphalt concrete (DAC16r20) or of an ISO reference surface (ISOr20). Detailed investigation has shown that for truck tires, which induce considerable pressure on the surface, the PERS pavement deflects and the hysteresis of the material leads to energy losses. Considerable energy losses in the pavement lead to increase of its temperature. This phenomenon is documented in Figure 10. In this figure thermographic images of a truck tire tested on PERSr20 and DAC16r20 are compared. It is clearly visible that the pavement temperature of replica DAC16r20 is much lower (at about 30 °C) than the temperature of PERS in the area touched by the tire (at about 49 °C). One must observe that at 80 km/h, each part of the pavement is contacted by the tire 3.5 times per second, so the actual "traffic intensity" is immense and much higher than it would be possible on the road.



(**a**)

(**b**)

Figure 10. (**a**) Thermographic image of truck tire rolling on DAC16r20; and (**b**) PERSr20.

In this context it is important to keep in mind that PERS is only intended to be used on relatively short road sections, namely where there are major noise problems, such as a trunk road crossing a built up area, hence only a small fraction of the road network will be covered with PERS and the influence on the total fuel consumptions will be negligible.

3.2.2. Road Measurements of Rolling Resistance on PERS

Different variants of PERS were also tested on the road. In this paper, only results from the Swedish test tracks (PERS-SE2-VTI and PERS-SE2-HET2,) are presented. The PERS material was laid only in the wheel track areas.

The results obtained on PERS were compared with the adjacent dense asphalt concrete DAC16. The measurements were performed using standard TUG parameters, *i.e.*, a speed of 80 km/h, a load of 4002 N and a regulated inflation pressure of 210 kPa. The results of rolling resistance measurements are presented in Figure 11. As the measuring conditions were different than in the case of laboratory measurements, the results also differ to some extent. In the case of road measurements, PERS exhibits almost the same rolling resistance properties (for passenger car tires) as DAC16.

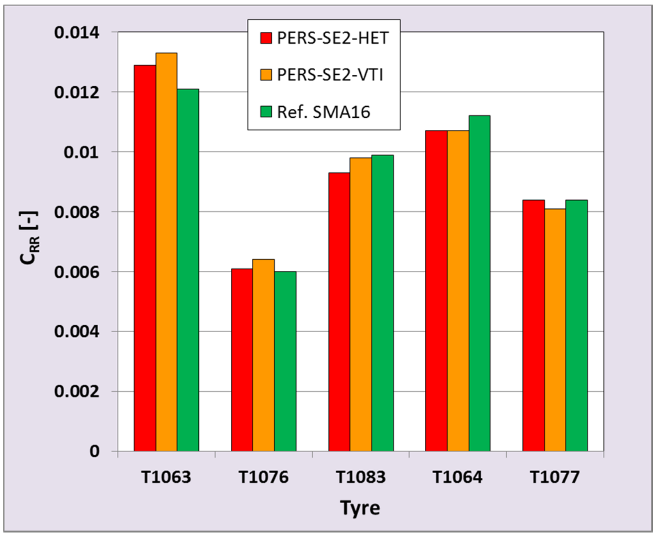


Figure 11. Rolling resistance results obtained during measurements on test section PERS-SE2.

3.3. Fire Risk on PERS

One of the major concerns that had to be addressed at the developing stage of PERS was the possibility of excessive danger in the case of an accidental car fire on poroelastic road surface containing rubber particles and polyurethane [13]. In fact, two different risk factors were considered: the rapid spread of fire due to the porosity of pavement and its rubber contain, and the risk of the emission of hazardous substances (such as hydrogen cyanide HCN and mono-nitrogen oxides NO_x). The first concern was in clear contradiction to findings of Meiarashi [14] who, over 10 years ago, established by burning a 5 m × 5 m area of PERS that regarding the spreading speed and flame height, PERS was safer than the dense asphalt concrete. In his investigation, Meiarashi used PERS without mineral aggregate (so potentially more dangerous than the material used by these authors) and diesel oil as fuel.

The PERSUADE project management decided to perform comprehensive fire tests of PERS road surface to ascertain that this surface will not create any fire hazard to the road users. This task was given to the TUG and three separate experiments were performed.

3.3.1. Emission of Toxic Fumes During PERS Fire

In order to estimate HCN + $(CN)_2$ emissions during a fire, several tests were performed at the TUG in conditions not covered by any standard but judged as equivalent to a real car fire. Determination of the quantity of HCN and $(CN)_2$ formed during PERS material combustion was performed. The lowest emission value was 0.0051 mg/g, the highest value was 0.0082 mg/g with average value for all tests being 0.0066 mg/g.

As the results of laboratory tests indicated very low emission of toxic gases from burning PERS samples, it was decided to make road test on a bigger scale using slabs of PERS material placed on cement concrete underlayer. The main reason for this test was to establish the concentration of HCN nearby burning PERS. Each sample of PERS (1.5 m × 1.5 m) was soaked with 2.5 L of 95 octane gasoline and ignited with a pyrotechnic fuse and a small charge of gunpowder wrapped in cotton wool soaked with gasoline.

During the tests, the concentration of HCN was monitored with a hand held measuring instrument “ToxiRAE” at a distance of 0.5 m and 3.0 m from the centre of the PERS sample. The HCN concentration in the air at a distance of 3 m from the source was maximum 1 ppm. According to literature [15], a concentration of hydrogen cyanide of 20–40 ppm may lead to "slight symptoms" after several hours of exposure, thus the concentration measured during the experiment must be classified as safe for a short time exposure typical for an emergency situation.

3.3.2. Fire Spread During Car Fire on PERS Pavement

The final check of the PERS behaviour during a real car fire with a fuel spill was performed within a full scale experiment. The PERS slabs were laid on a dry cement concrete surface forming a rectangle of 5 m × 4 m. The car was placed in the middle of the PERS surface and an ignition system was placed under the car floor. The PERS sample under the car was soaked with 20 L of gasoline. Most of the gasoline was retained in PERS, but after a few seconds some of the fuel (probably 2–5 L) drained in the direction of the car’s rear and right side reaching the dense surface not covered by PERS.

In the first stage of the experiment the flames under the car were hardly visible. There was no typical violent combustion despite that 20 L of fuel were just spilled under the car. After about 20 s the flames on the PERS surface were still very small. As it was mentioned above, some of the fuel has drained from the PERS on the plain concrete surface due to the limited size of the PERS sample used for experiment. After about 90 s, this fuel on the concrete pavement caught fire and started to burn intensively. The fuel fire on the dense concrete created a firewall and increased the temperature to such a level that the plastic elements on the right part of the car body started to melt and finally started to burn. According to the subjective impressions of the observers, if the PERS section was larger, there would be no flow-outs of the fuel on the dense surface and, probably, the car would not catch fire at all.

Figures 12 and 13 document the progress of the car fire on the PERS pavement. Figure 12 shows the situation after 30 s from ignition, when there is no fire of the PERS but a small spill of fuel on the concrete surface at the rear part of a car is burning. Figure 13 shows the situation after 260 s, when plastic elements of the car start to burn due to the high temperature created by the burning fuel spill on the concrete. This spill was burning violently and ignited plastic parts of the car. Ignition of plastic parts started an interior fire in the car resulting in its complete destruction.

Unfortunately it was not possible to burn a similar car on a conventional road surface, so a simplified test was performed. Twenty liters of gasoline were spilled on a dense cement concrete and ignited. In contrast to the PERS surface, the whole spill caught fire immediately after ignition and after 15 s the fire looked like it is presented in Figure 14.

Figure 12. Car fire 30 s after ignition. Observe the fuel spill at right side of a car that is still not ignited [12].

Figure 13. Car fire 260 s after ignition.

Figure 14. Fire of the 20 L gasoline on dense concrete pavement 15 s after ignition.

4. Conclusions

The TUG measurements and experiments conducted in the frame of the PERSUADE project revealed the following interesting results:

Measurements of the tire/road noise on PERS of the mix #2 type (the one with the higher rubber content) yielded high-to-extreme noise reductions (8 dB up to 12 dB) with respect to the DAC reference surface for reference car tires and surprisingly also for the common truck tires which were tested (7 dB up to 13 dB). The noise gain is over the whole relevant frequency spectrum and tends to increase with increasing speed.

CPX measurements on the Danish and Polish test tracks show noise reductions of respectively 6–7 dB and about 10 dB. For the Danish test track with respect to DAC 8 and for the Polish one in relation to SMA 11.

Rolling resistance measurements on the drum show that for car tires, the rolling resistance on PERS (mix #2) is a little bit higher than on dense asphalt concrete (DAC), but for truck tires it is typically up to 50% higher. Road measurements of the rolling resistance with car tires show similar results for PERS and DAC.

Tires designed for electric vehicles provide a low rolling resistance on PERS surfaces, so the operating range of electric vehicles is not adversely affected by using PERS.

Fire tests on PERS show that there is no particular problem with HCN concentrations, which remain low to very low during a fire. The fire spread in the case of a car accident with a gasoline spill appears to be much slower on PERS than on a conventional impervious pavement.

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Abbreviations

The following abbreviations are used in this manuscript:

CPX	Close Proximity Method of tire/road noise measurements
$(CN)_2$	Dicyanide
C_{RR}	Coefficient of rolling resistance
DAC	Dense Asphalt Concrete
EV	Electric Vehicle
HCN	Hydrogen Cyanide
MPD	Mean Profile Depth
M+S	Mud and Snow tire
PERS	Poroelastic Road Surface
SMA	Stone Matric Asphalt
SPL	Sound Pressure Level
TUG	Technical University of Gdansk

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