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Tire/road noise and tire rolling resistance on the prototype PERS surface

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Abstract. Poroelastic road surfaces are characterized by low noise of tires running on them. Road pavements of this type are promising solution to problems related to traffic noise in cities and on rural roads. Some technical problems still have to be solved, in particular regarding durability and skid resistance on wet surface. Ongoing and planned works are to contribute to to create a quiet, durable and safe road surface, which will become an alternative to acoustic screens and vehicle speed reduction as an efficient noise reduction measure. The paper presents the results of laboratory and road tests of tire/road noise and rolling resistance on the prototype poroelastic surface (PERS) compared to the surfaces selected as a reference.

1. Introduction

Currently, three main types of surfaces are commonly used: dense pavements, porous pavements and surface dressing. In dense pavements, the mixture of stone aggregate and sand is combined with a binder (usually bitumen or Portland cement). When asphalt bitumen is used, the surface is considered as flexible, and when cement is used, it is considered to be igid. Substancial deformations of bituminous surfaces are generally irreversible. A pavement is considered as porous when it has drainage properties – allows water to penetrate at least the top layer. Surface dressing is a completely different type of surface, because the underlying base surface is sprayed with adhesive and then covered with a layer of small stones. The concept of poroelastic road surface (PERS) was invented in Sweden about 40 years ago. PERS is a wearing course that contains air voids (it is porous), and at the same time is elastic due to rubber particles. It deflects significantly when loaded by a tire, and returns to its original shape when the load decreases (elastic behaviour). Those types of wearing courses are presented in Fig. 1.

2. Poroelastic road surface production methods

The poroelastic road surface may be produced in a similar way as a porous asphalt concrete, but the mixture contains, together with a hard aggregate (stones and sand), a large percentage of rubber particles. The binder is polyurethane instead of bitumen. The content of air voids after the final compaction in the laying process is about 20-30 %. The structures of three different poroelastic pavements tested at the Gdańsk University of Technology (TUG) are shown in Fig. 2. The PERS material presented in the middle of Fig. 2 has no mineral aggregate and contains only rubber particles and polyurethane. This material was used 10 years ago to test the tire/road noise, but due to its low skid resistance this concept was rejected. PERS shown on the left side of Fig. 2, marked as PERS-

ARNAKKE, contains mineral aggregate, rubber granules and one-component polyurethane resin. It has narrow pores, because the rubber aggregate has dimensions from 2 to 5 mm. PERS shown on the right side of Fig. 2 is PERS-HET manufactured in a form of plates by the German company HET [2].

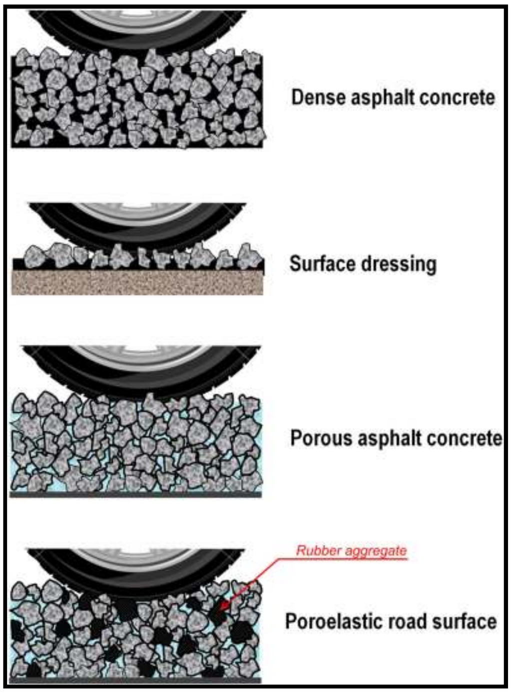

Figure 1. Road surface types: dense asphalt concrete, surface dressing, porous asphalt concrete and poroelastic road surface [1].

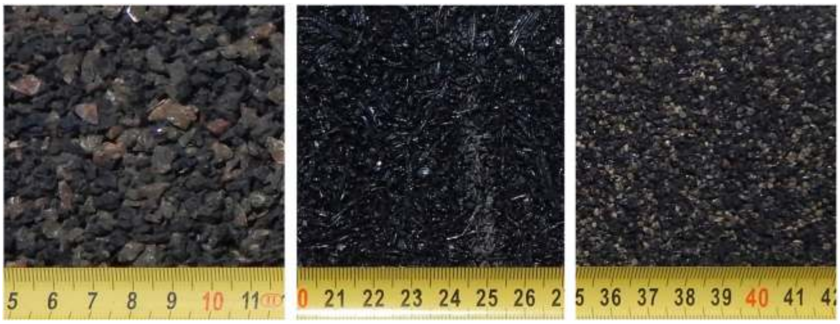

Figure 2. PERS materials tested in TUG - from the left: PERS-ARNAKKE produced by VTI, Sweden; PERS without mineral aggregates made in Japan; PERS-HET produced by the HET company, Germany [2].

3. Passenger cars tire/road noise on PERS

Fig. 3 shows the A-weighted noise levels obtained for AVON ZV1 summer tire on the road-wheel facility with an external drum of 1.7 m diameter covered with two different replica road surfaces and PERS-HET. For all test speeds, the noise level for the poroelastic road surface is 7 to 8 dB lower than for smooth asphalt and 8 to 11 dB lower than for rough one. In the case of the off-road tire, GOODREACH Mud Terrain, with a very aggressive tread pattern, the decrease of noise levels is not so impressive. The noise reduction is from 0.3 to 4.2 dB for smooth asphalt and from -0.6 to 2.1 dB for rough surfaces (see Fig. 4). The sound spectra indicate that the noise reduction for PERS compared to smooth asphalt concrete is obtained mainly for frequencies above 500 Hz, while the reduction when compared to the rough surface is observed in the frequency range of 125-2000 Hz.

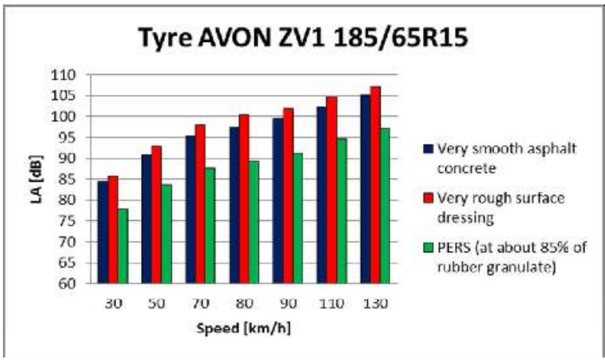

Figure 3. A-weighted sound levels for summer tires running on two conventional road surfaces and on PERS [3].

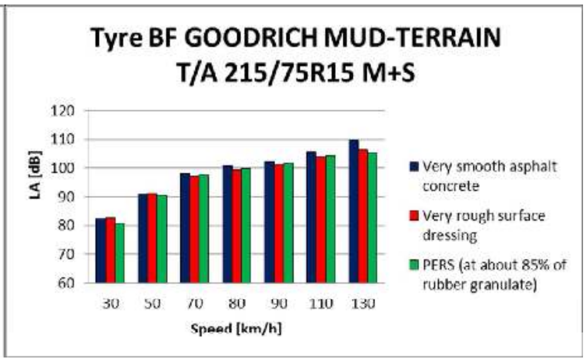

Figure 4. A-weighted sound levels for an off-road tire rolling on two conventional road surfaces and on PERS [3].

In the preliminary study of tire/road noise on the PERS pavement, also selected winter tires, including studded ones, have been tested. The aim was to prove the hypothesis that PERS surface can significantly reduce noise generated by studded tires, which are very popular in Scandinavia. Unfortunately studded tires should not be tested on rigid replicas of road surfaces mounted on the facility drum due to technical reasons (rapid wear of the replicas). Thus the tests were performed in real road conditions using the CPX method on dense pavements while tests on PERS were done on the drum facility . The obtained test results indicate a very positive effect of this type of surface on tire/road noise. Poroelastic road surface reduces the noise of studded tires by 5 - 7 dB.

4. Truck tire noise on PERS

Seven truck tires have been tested on the road-wheel facility with a drum of 2.0 m diameter. Tires used in the experiment are shown in Tab. 1. Noise measurements for truck tires were carried out on the PERS-HET (designated PERSr20 in this case) and on two other replicas of dense surfaces, DAC16r20 and ISOr20 (see Tab. 3). The measurement results for the speed of 80 km/h are shown in Fig. 5. A very smooth ISOr20 was the loudest surface for all tested truck tires. Depending on the tire, the difference between PERSr20 and ISOr20 was within the range from 4.9 dB to 12.8 dB regardless of the test speed. For the DAC16r20 the difference was from 3.3 dB to 9.7 dB. An example of frequency spectra for the T-1114 truck tire measured at speed of 80 km/h is shown in Fig. 6. The noise reduction on PERS surface can be observed in the entire frequency range. The spectra for the other tires look similar.

Table 1. Truck tires parameters tested on the 2.0 m diameter drum

TIRE	MANUFACTURER	MODEL	SIZE	DATE CODE	DESCRIPTION
T-1084	DUNLOP	SP242	385/65R22.5 160K	2108	-
T-1085	BRIDGESTONE	R168	385/65R22.5 160K	1109	-
T-1114	SAVA	CIT U3	275/70R22.5 148/145J	4208/0314	retreaded
T-1116	DUNLOP	SP3 72 CITY	275/70R22.5 148/145J	4309	-
T-1117	MICHELIN	XDU	275/70R22.5 148/145J	1210	retreaded
T-1118	BRIDGESTONE	M758	275/70R22.5 148/145J	3807/3114	retreaded

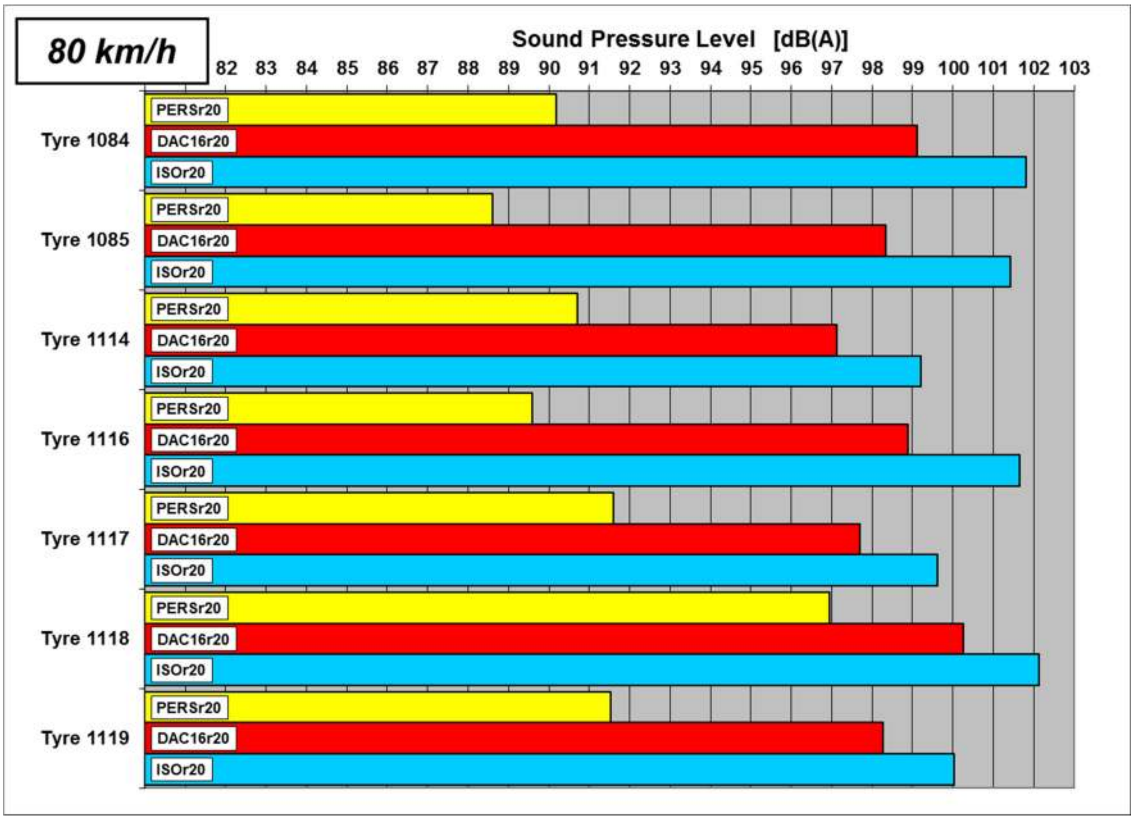

Figure 5. A-weighted sound pressure levels for truck tires at 80 km/h [3]

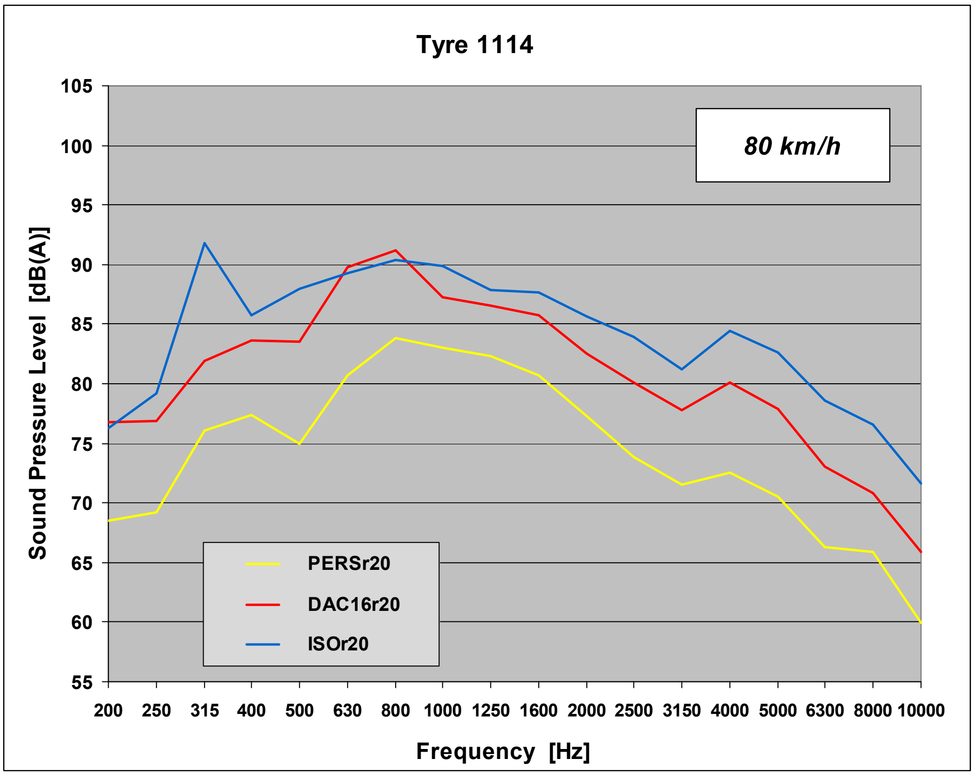

Figure 6. Sound spectrum for the T-1114 truck tire on three surfaces at 80 km/h [3]

5. Rolling resistance measurements on PERS

5.1 Laboratory results

Measurements were performed on the road-wheel facility. 16 different passenger car tires listed in Tab. 2 were tested on PERS-HET surface and on three replicas of road surfaces described in Tab. 3. The basic tests were carried out in accordance with ISO 18164. The tire load was 80% of the max. load and capped inflation pressure was 210 kPa. Instead of the steel surface of the drum, appropriate replicas of road surfaces were used (Table 3). Tests were carried out at speeds of 30, 50, 80 and 100 km/h. The set of tested tires included three tires considered to be "informal reference tires" for rolling resistance, i.e. Michelin PRIMACY HP 225/60R16 tires, Uniroyal TIGER PAW (SRTT) P225/60R16 and Avon SUPERVAN AV4 195R14C. The results of measurements are shown in Fig. 7 and 8. It is clearly visible that the rolling resistance of passenger cars tires on PERS-HET surface is about 15 % higher than on smooth surfaces with a medium road surface texture (DAC16r20 and ISOr20). Passenger car tire rolling resistance on PERS-HET is about 20 % lower than on surface dressing but at about 10 % higher than on dense asphalt concrete and SMA16.

Table. 2. Selected passenger car tires

TYRE	MANUFACTURER	MODEL	SIZE
T-1068	MICHELIN	PRIMACY HP	225/60R16 98V
T-1077	UNIROYAL	TIGER PAW	P225/60R16 97S M+S
T-1063	AVON	SUPERVAN AV4	195R14C 106/104N
T-1067	CONTINENTAL	CONTIECONTACT5	195/60R15 88H
T-1071	VREDESTEIN	QUATRAC 3	195/60R15 88V M+S
T-1066	WANLI	S-1200	195/60R15 88H M+S
T-1072	YOKOHAMA	Wdrive	195/50R15 88T M+S
T-1070	VREDENSTEIN	WINTRAC NEXTREME	205/55R16 94V
T-1064	MICHELIN	PRIMACY HP	225/60R16 98V
T-1069	VREDESTEIN	SLICK	235/45R17 94W
T-1073	AVON	ZV5	195/65R15 91V
T-1078	GOODYEAR	EFFICIENT GRIP	195/65R15 91H
T-1079	BRIDGESTONE	ECOPIA EP001S	195/65R15 91H
T-1080	MICHELIN	ENERGY SAVER X GREEN	215/55R17 94H
T-1081	DUNLOP	SPORT BLURESPONSE	195/65R15 91H
T-1082	MICHELIN	ENERGY SAVER X GREEN	195/65R15 95T
T-1073	AVON	ZV5	195/65R15 91V

The selected 6 truck tires tested on a 2.0 m diameter drum on the ISOr20 and DACr20 replica surfaces described in Tab. 2 are presented in Tab. 4. Replica road surfaces are manufactured in such a way that they replicate pavement texture but at the same time follow the curvature of the drum and are strong enough to withstand centrifugal force. Tests were performed at 50 and 80 km/h only. The measurement results are shown in Fig. 9 and 10. In the case of truck tires, the rolling resistance on PERS-HET surface was significantly higher (40-50 %) than the rolling resistance on other medium or low texture replicas. To investigate the cause of the significant increase of rolling resistance of truck tires running on PERS-HET surface, thermal images for the surface and tire combination have been taken. They allow finding the cause of the energy loss. Thermograms of rolling truck tire on the DAC16r20 and PERS-HET are shown in Fig. 11.

Table. 3. Description of the surface used on facility drums

SYMBOL	SURFACE TYPE	LOCATION	DESCRIPTION
PERSr17	Poroelastic road surface.	Roadwheel facility 1.7m	Factory produced slabs. Poroelastic surface made on the basis of mineral and rubber aggregate and polyurethane resin. Pavement suitable for road and drum use, very smooth and flexible. Still in development stage. For more details refer to [2].
PERSr20	Poroelastic road surface	Roadwheel facility 2.0 m	Factory produced slabs. Poroelastic surface made on the basis of mineral and rubber aggregate and polyurethane resin. Pavement suitable for road and drum use, very smooth and flexible. Still in development stage. For more details refer to [2].
DAC16r20	Replica of dense asphalt concrete with 16 mm aggregate	Roadwheel facility 2.0 m	Polyester laminate replica made on the basis of a typical DAC 16 mm (rather high texture)
ISOr20	Replica of ISO reference surface	Roadwheel facility 2.0 m	Polyester laminate replica made on the basis of the reference road surface according to the ISO 10844 (average texture)
APS4r17	Replica of surface dressing 8/10 mm aggregate	Roadwheel facility 1.7m	Polyurethane /mineral replica of a Surface dressing pavement

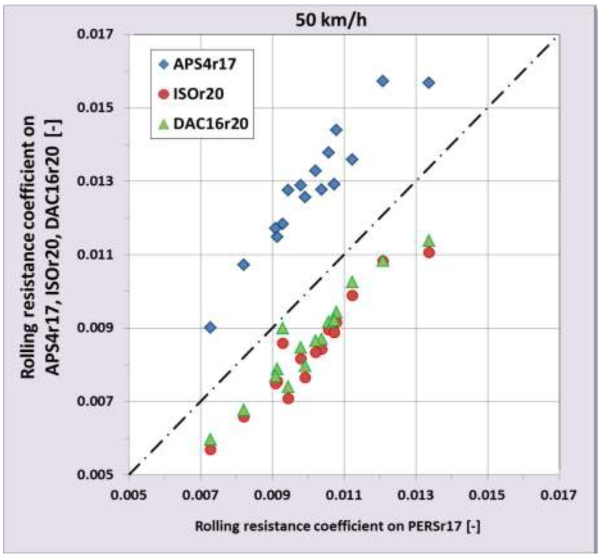

Figure 7. Relation between rolling resistance on PERS-HET surface and on other replicas surfaces at 50 km/h [3].

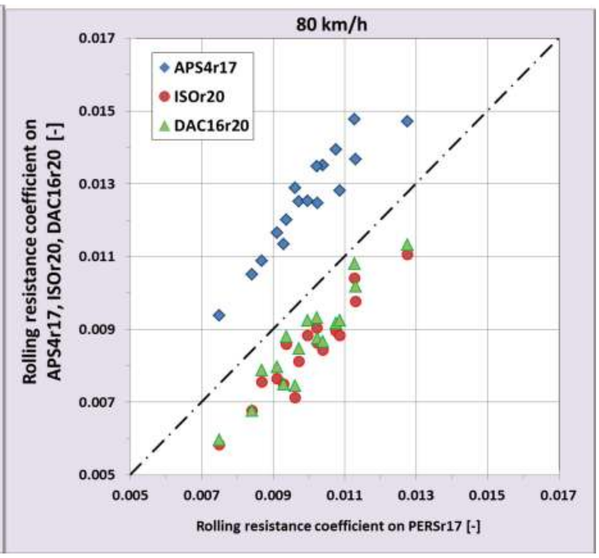

Figure 8. Relation between rolling resistance on PERS-HET surface and on other replicas surfaces at 80 km/h [3].

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Table. 4. Tires for trucks tested on the 2.0 m diameter drum

TYRE	MANUFACTURER	MODEL	SIZE
T-1114	SAVA	CIT U3	275/70R22,5 148/145J
T-1115	MADE IN CHINA	GT867	275/70R22,5 148/145J
T-1116	DUNLOP	SP372 CITY	275/70R22,5 148/145J
T-1117	MICHELIN	XDU	275/70R22,5 148/145J
T-1118	BRIDGESTON	M758	275/70R22,5 148/145J
T-1119	DUNLOP	SP372 CITY	275/70R22,5 148/145J

Analysing the thermograms in Fig. 11 it can be seen that in case of truck tires running on PERS-HET surface a lot of energy dissipates in PERS material. After tire warming-up time on DAC16r20 surface the temperature of the shoulder was 37-39 °C and the maximum temperature of the replica was 30.6 °C. Under the same conditions, when the tire was running on PERS-HET surface, the shoulder temperature increased to 41-42 ºC at a maximum PERS-HET surface temperature of 45-46 °C. The temperature of the tire shoulder increased by approximately 3 ºC while the surface temperature increased by 15 ºC. The ambient air temperature during all thermography tests was 20 °C. Truck tires have been tested in accordance to ISO conditions. However, in the case of passenger car tires the situation was completely different. After the tire was warmed-up on ISOr20 the temperature of the tire shoulder was 37-38 °C and the maximum temperature of the replica was 27 °C. Under the same conditions when the tire was rolled on PERS-HET surface, the tire shoulder temperature increased by 1 ºC, while the maximum PERS-HET surface temperature increased only by 2 ºC. The presented results indicate that the hardness of the PERS-HET surface is well suited to the pressures resulting from the contact with a passenger car tire, but is too low for truck tires. Truck tires deform the surface too much from the rolling resistance point of view.

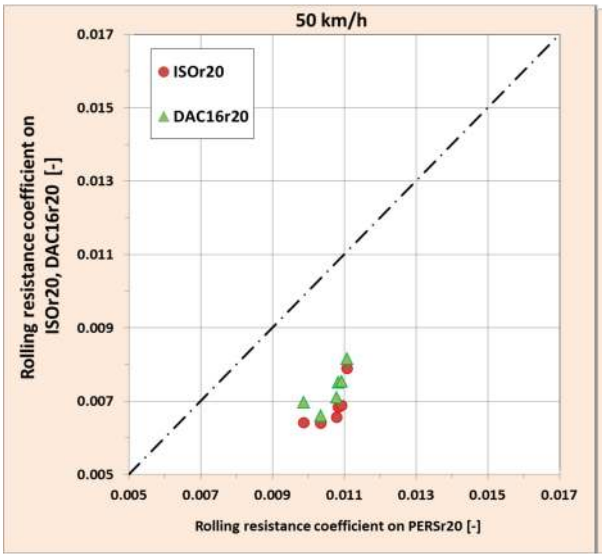

Figure 9. Rolling resistance relationship for truck tires between PERS-HET surface and on other replicas at 50 km/h [3]

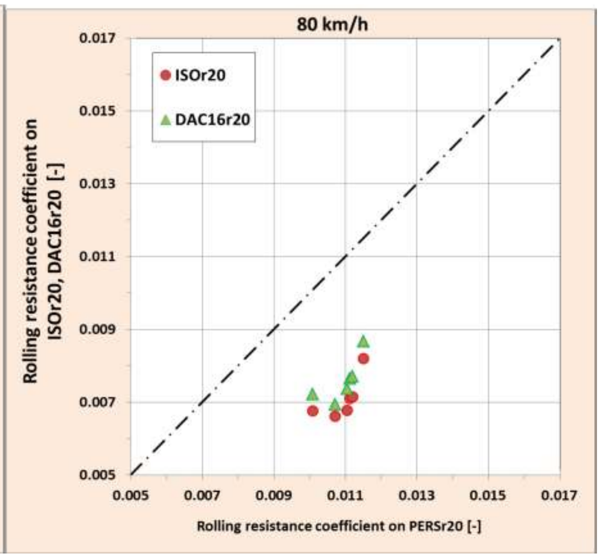

Figure. 10. Rolling resistance relationship for truck tires between PERS-HET surface and on other replicas at 80 km/h [3]

5.2 Results of road rolling resistance measurements on PERS surface variants
Rolling resistance tests were conducted on the test sections in Denmark (PERS-DK1), Sweden (PERS-SE2-VTI, PERS-SE2-HET) and in Slovenia (PERS-SL). PERS-DK1 was constructed as the mixture called PERS-ARNAAKE laid in situ. The test section was about 3.5 m wide and 75 m long (see Fig. 12).. The reference road surface in that case was DAC11. The Swedish test section (Fig. 13) was built

in two different subsections, adjacent to each other. The first subsection was made of prefabricated PERS panels produced and supplied by HET, Germany; here referred as PERS-SE2-HET. The total length of this test section was 30 m. The second subsection was constructed by hand in accordance to VTI recipe. It was 24 m long and was designated as PERS-SE2-VTI. Both sections were placed in two strips with the width of 1 m marked as LWT and RWT (Fig. 13). Regular road surface on this road was SMA 16 and it has been recognized on this PERS test site as a reference surface. The Slovenian test section PERS-SL (Fig. 14) has been paved with concrete blocks, which have been covered with glued PERS-HET material made in Germany. Regular surface on this road - AB11 has been qualified as the reference surface.

Thus, the original dense surfaces existing on roads close to the test sections have been used as reference surfaces. The tests were carried out on dry road surfaces. The rolling resistance measurement results corrected for the temperature are shown in Fig. 12, 13 and 14.

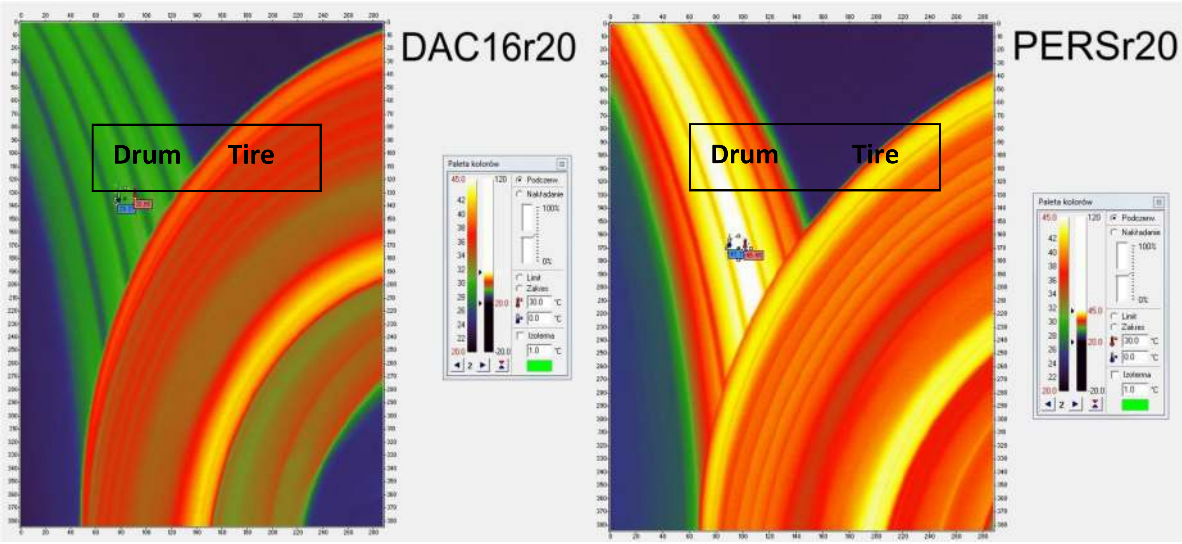

Figure 11. Thermograms of a truck tire rolling on the replica of the road surface DAC16r20 (left photo) and on PERS-HET surface (right photo) at speed of 80 km/h [3]

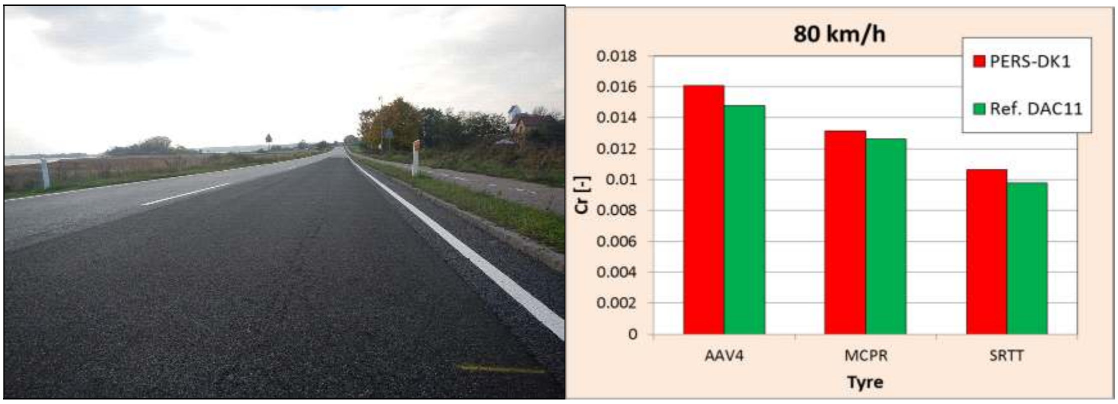

Figure 12. Danish test section with PERS-DK1 surface together with the obtained values of the rolling resistance coefficient on PERS and on the reference DAC11 at the speed of 80 km/h [3]

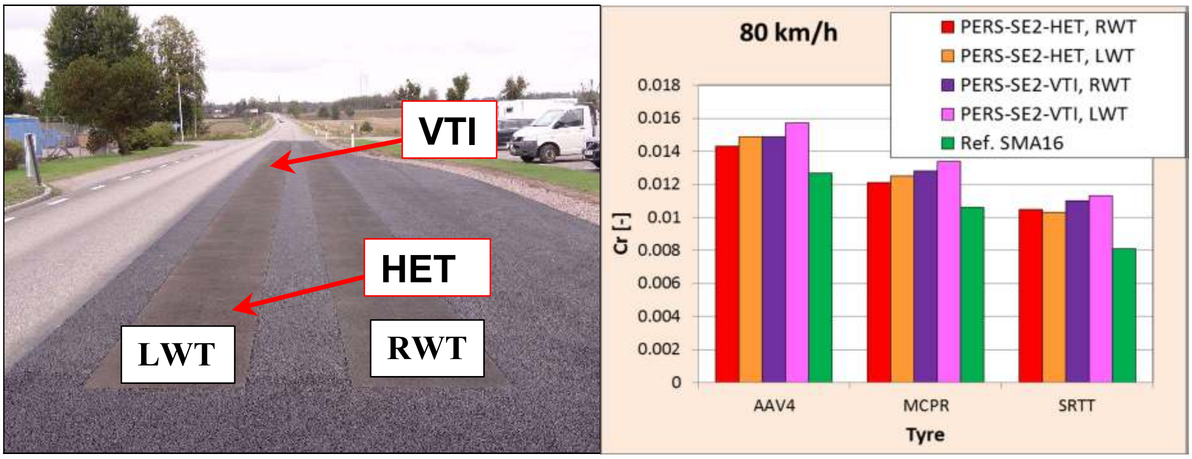

Figure 13. Swedish test section marked as PERS-SE2 together with the obtained rolling resistance coefficient values on PERS-SE2 and on the reference SMA16 at 80 km/h [3]

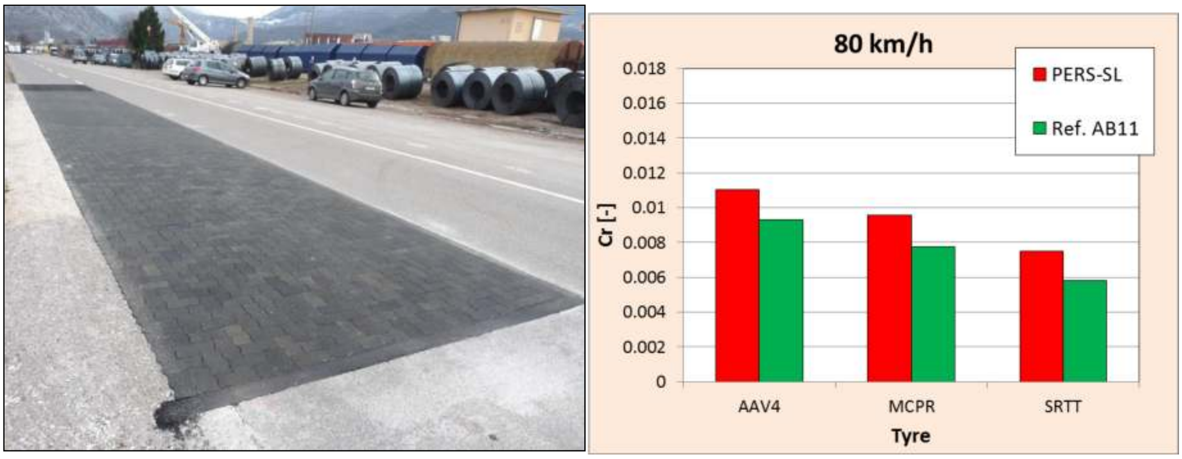

Figure 14. Slovenian test section PERS-SL together with the obtained values of the rolling resistance coefficient on PERS-SL and on the reference AB11 at 80 km/h [3]

In all cases the rolling resistance measured on PERS surface was about 10 to 20 % higher than on the reference surface. Very similar differences were noted for all tested tires. This result was influenced by random selection of the reference surfaces, which were located near the test sections with PERS.

6. Conclusions

The following conclusions can be formulated based on performed noise and rolling resistance tests on the poroelastic road surfaces.

For all test speeds, the noise levels of summer passenger car tires on PERS pavement are 7 to 8 dB lower than obtained on smooth asphalt and 8 to 11 dB lower than on rough surfaces. In the case of the tested off-road tire, GOODREACH Mud Terrain, the noise reduction on PERS is not so significant (from 0.3 to 4.2 dB for smooth pavements and from -0.6 to 2.1 dB for rough surfaces). Poroelastic surfaces reduce noise of, studded tires by 5 - 7 dB.

The results of tire/road noise measurements indicate that both types of PERS material (produced on site PERS-ARNAAKE and delivered in slabs PERS-HET) provide a significant noise reduction compared to the reference surface. However, the PERS-HET material has got better noise reduction properties than the PERS-ARNAAKE produced on site. When comparing the noise results obtained in the laboratory with results of road measurements using the CPX method, the observed differences in the noise level were up to 2.9 dB depending on the tested tire, speed and the test section.

Laboratory measurements of noise emission for truck tires can be summarized as follows:

- ISOr20 was the loudest replica of all tested drum surfaces,
- depending on the tire, the difference between PERSr20 and ISOr20 surfaces was in the range from 4.9 dB to 12.8 dB regardless of the test speed,
- for the DAC16r20 surface, the difference in comparison to PERS was from 3.3 dB to 9.7 dB.

The porous structure of PERS reduces the noise generated by aerodynamic mechanisms while elasticity reduces the mechanisms associated with vibrations due to tire tread block impacts. Collectively, according to performed laboratory and road tests PERS can reduce the vehicle noise by 8-11 dB compared to typical surface currently used,. In the PERS mixture manufacturing process a significant amount of rubber aggregate is used. The rubber can be obtain form used tires.

On the PERS-HET surface, rolling resistance of passenger car tires is about 20 % lower than on surface dressing, but higher by about 10 % than on dense asphalt concrete and SMA16. For truck tires the rolling resistance coefficient on PERS-HET is 40-50 % higher than on dense asphalt concrete. The hardness of the PERS-HET surface is well adapted to the pressures resulting from contact with a car tire, but it is too low for truck tires. Truck tires deform the surface too much causing energy losses in the surface, which increase rolling resistance considerably. The above defect requires further improvements. Several other technical problems still need to be solved, in particular regarding durability and skid resistance. Ongoing and planned works are to contribute to create a quiet, durable and safe road surface, which will become an alternative to acoustic screens and vehicle speed reduction.

The results of road and laboratory tire rolling resistance tests can be used in the construction and testing of drive train models and traction properties of vehicles [5].

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