A quiet poroelastic road surface manufactured in a normal asphalt mixing plant

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A poroelastic road surface for low tyre/road noise emission has been developed. It is manufactured using conventional asphalt mixing plants and conventional paving machines. Crumb rubber was added to the mix to attain the desired elastic characteristics of the surface. .

The crumb rubber was subject to a long term pre-treatment before feeding it to the plant mixer. This ensures both long term durability and excellent adhesion to the binder. The crumb rubber grain size and amount in the mix has also been carefully tuned to the aggregate grain size. By pre-treatment, the fraction of the crumb rubber in the mix can be freely selected since it is not locked to the amount of binder compared to if the rubber is added to the hot bitumen before adding it to the plant mixer.

A single layer poroelastic test road surface has been paved in Gothenburg. The achieved noise reduction relative to a SMA16 was found to be 4-6 dB(A) depending on the vehicle speed and amount of crumb rubber. The surface is almost unaffected by wear after 6 months winter traffic with studded tyres. We expect to reach additional increase in noise reduction by further tuning the recipe. The optimization work continues.
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1 Introduction

Tyre/road noise is the dominating source for passenger cars for constant speeds as low as 35-40 km/h. Therefore tyre/road noise reduction is an urgent task in efforts to reduce road traffic noise. Reduction of tyre/road noise is of vital importance in order to utilize the low drive-line noise from modern car designs and is absolutely a must for hybrid electric cars or entirely electric driven vehicles. The objective of this paper is therefore to give a status report on the development work for a poroelastic road surface with high crumb rubber content but yet manufactured at conventional asphalt mixing plants and using conventional paving machines.

A poroelastic road surface comprise both pores or voids at the same as it displays a substantial increase of the compliance (lower dynamical stiffness)

A test section 80 m long at Tagenevägen in Gothenburg has been paved with the poroelastic road surface. The purpose was both to test new production techniques as well as quantifying the achieved noise reduction.

2 Development of the poroelastic asphalt surface.

2.1 Selecting grain and binder quantities - basic design principles.

The basic design concept is to find a stone ballast size distribution, bitumen binder and crumb rubber content that will ensure:

- A void content of the mix of 15-20 % or more
- A dynamic stiffness of the surface that should be about 10-15 dB lower compared to standard road surfaces e.g. of type SMA16.

2.2 Optimizing parameters for the poroelastic asphalt

The balance between the void content, sound absorption, wear life and surface roughness is delicate. Therefore these characteristics have to be tuned in by laboratory tests as part of the design optimization process.

For tests road surfaces in Sweden we also have to account for the extra wear caused by studded winter tyres. This is limiting the maximum stone aggregate size to 8 mm. This is a compromise between the noise reduction effect, which would improve with a smaller size, and wear resistance, which would improve with a bigger aggregate size

The used optimization tools were mainly based on acoustical and mechanical tests on lab. plates.

2.3 Rubber granulate sizes

The poroelastic low-noise asphalt has been studied by aid of FEM models in order to enable parameter optimization so that it can resist the severe dynamic traffic loads that are applied to it.

If the rubber grain sizes are too big then the tyre/road adhesion tends to loosen rubber grains from the surface with resulting degradation of the top layer of the surface.

Too big rubber grains also tend to weaken the binding of aggregate in the mix since it has been found an optimal relation between grain size and percentage binder to achieve maximum wear resistance. Cantabro tests performed at the NCC Road Lab reveal that the wear rate can increase by 20-30 % per doubling of the typical rubber grain size. It was then decided that the typical grain size should not exceed 2 mm in order to get an acceptable wear rate.

Decreasing the rubber granulate maximum size thus seems to give a better wear resistance, but on the other hand smaller rubber grain size will also decrease the void content, which can heavily diminish the sound absorption and thereby the noise reduction effect.

2.4 Wetting/pre-treating the crumb rubber with bitumen before plant mixing

It has been found that rubber can absorb large quantities of bitumen. This process is very slow at normal outdoor temperatures, but will be clearly visible after some months. The amount of binder left "free" in the mix is then not enough to provide the necessary strength with catastrophic effect on the wear life of the surface.

A ***patented*** method has therefore been developed to wet the crumb rubber grains with bitumen in order to saturate the rubber grains. In this way the crumb rubber grains would be prevented to soak up the binder in the asphalt mix

Doubling of the amount impregnation bitumen has, in lab. tests, been found to increase the wear life by up to 60 %. This underlines the importance of the process of saturating the rubber grains with bitumen. This is also shown in Table 3 below, where the only difference between test plate 8 and 10, is the amount of bitumen used in the wetting pre-process of the rubber granulate,.

Plate	Total binder content in the rubber %	Cantabro test – Wear cm^3	
		Dry	Wet
8	7	12,0	17,2
10	15	7,5	14,3

Table 1 Influence of bitumen content in pre-treatment on wear resistance

High bitumen content in the wetting pre-treatment process was found to give problems with dissolving it to powder again. This problem was solved by shredding the pre-treated crumb rubber with an ALLU-loader, see Fig. 1.

Fig. 1. To the left: bitumen wetted rubber blocks in the ALLU. To the right: rubber/bitumen mix as powder after dissolving the block in the ALLU.

2.5 Binder content

The binder content has a great influence on the durability and wear resistance of the pavement. A comparison for wear resistance, the Cantabro test, between a mix with the 7,8 % of binder and a mix with slightly lower binder content 7,4 %, (everything else the same), results in data presented Table 4.

Plate	Binder content %	Cantabro test – Wear cm^3	
		Dry	Wet
10	7,8	7,5	14,3
11	7,4	16,7	39,6

Table 2 Influence of binder content on wear resistance

This shows clearly the importance in using high bitumen content in the mix to achieve the desired wear rate. However, too high binder content in the mix could make the mix soft and sticky as well as reducing the void content.

Note: The bitumen added to the rubber in the wetting/pre-treatment process is not included in the binder content in the final asphalt mix mentioned above.

2.6 Aggregate grading

Changing to smaller rubber grain size will reduce the void content of the compacted mix, with a loss in the noise reduction effect. Since the aim is to still obtain a void content of about 20 %[1] the aggregate grading will have to be adjusted to compensate for added fine grain rubber.

Results from Cantabro tests presented in Table 3 below reveal that opening up the void content too much (plate 18) will have a negative effect on the wear resistance.

The tests e.g. on plates #16 and #18 reveal that increasing the void content by 3% (from 18.5 to 21.5%) could reduce the wear rate down to 44%. So the mix is found to be extremely sensitive to the void content.

Test plate	Aggregate %		Void content % EN 12697-29	Cantabro test Wear cm^3	
	0/4 mm	4/8 mm		Dry	Wet
16	3,5	81,5	18,5	7,1	12,8
18	1,8	83,1	21,5	16,1	28,5

Table 3 Influence of aggregate grading and void content on wear resistance

3 Field testing the poroelastic asphalt

3.1 Test site

The tests have been performed in Göteborg at Tagenevägen in the Kärra region in the northern part of the city. Tagenevägen is situated in an industrial area with about 20 % of heavy traffic. The average daily traffic is 4 200 vehicles/24h (1999). Speed limit is 50 km/h. The studied poroelastic asphalt surface was applied on an 80 m long road section, (see Fig. 2).

Fig. 2 Poroelastic asphalt pavement at Tagenevägen in Gothenburg.

3.2 Test vehicle and test tyres

The test vehicle has been a Volvo V70 Bi-fuel manufactured in 2003 and belongs to the class "medium sized passenger cars". Close-Proximity (CPX) measurements performed with on-board carried microphones mounted in front and rear of the left rear tyre

[1] Void content according to EN 12697-29: *Determination of the dimensions of a bituminous specimen*

of the car. Simultaneously were also performed pass-by tests with constant speed and engine on.

Fig. 3 Test vehicle Volvo V70 Bi-fuel used for both Pass-by and CPX-tests. The reference test tyre was of type Goodyear Hydragrip 195/65R15.

The test tyres has been Goodyear Hydragrip, see Fig 3. The test tyre type and dimensions are **195/65R15** i.e. 195 mm wide; the height of the side rubber is 65 % of the width (127 mm). The rim diameter is 15" and total tyre diameter 635 mm. The reference test tyre has been selected in cooperation with the Acoustics Department at Goodyear in Luxembourg, solely for the use as reference tyre for road surface characterization.. Hydragrip 195/65R15 can be viewed as average noisy out of a current tyre population.

4 Measurements and results

Along with the measurements of the new poroelastic road surface at Gothenburg/Tagenevägen there were also measurements performed on a reference road surface of type SMA11. This reference surface was situated just adjacent to the poroelastic road surface.

The tyre/road noise has been measured with two different techniques, the Pass-by method and the Close-Proximity method.

In addition to the Pass-by and CPX tests of the studied road surface some stationary tests were also performed. The aim of these tests was to characterize the poroelastic asphalt surface in relation to the standard road surface with respect to tyre/road noise emission. Studied parameters are:

- The dynamic stiffness measured with aid of a special impedance head with in-line mounting of force transducer and accelerometer.
- Impedance tube measurement of sound absorption at 90 degree incidence

The used measurement equipment is presented in Table 2.

Equipment	Brand	Type
7-channel signal analysis system	Brüel & Kjaer	Portable PULSE
12-channel signal analysis system	Brüel & Kjaer	Portable PULSE
Microphones	Brüel & Kjaer	4189 A21
Microphone wind shields	Brüel & Kjaer	
Sound level calibrator	Norsonic	
GPS speed and position logging system	Race Technology	DL1
Weather monitoring system	Vaisala	

Table 1 Used equipment for the tyre/road noise measurements.

4.1 Pass-By measurements of tyre/road noise

The Pass-by method described in the standard ISO 7188:1994 has to applicable extent, been used for characterization of the poroelastic asphalt surface. The Pass-by method includes the test vehicle to be driven at constant speed along a test road section, at least 20 m long Engine shall be turned on and at an appropriate gear. The microphones were mounted 7.5 m from the middle of the vehicle path and 1.2 m above ground. Speed was monitored with aid of a GPS-system that uses flash-memory-storing of parameters like speed, position etc. together with a time code. The precision of the measured speed is ±0.2 km/h. Sampling rate: 100 Hz..

In Fig. 4 below, the measured data points for the A-weighted sound level are presented for both the poroelastic and reference road surface. Least square curve fits are also shown for the two surfaces. These reveal the expected straight line when sound level is plotted vs. speed in logarithmic scale.

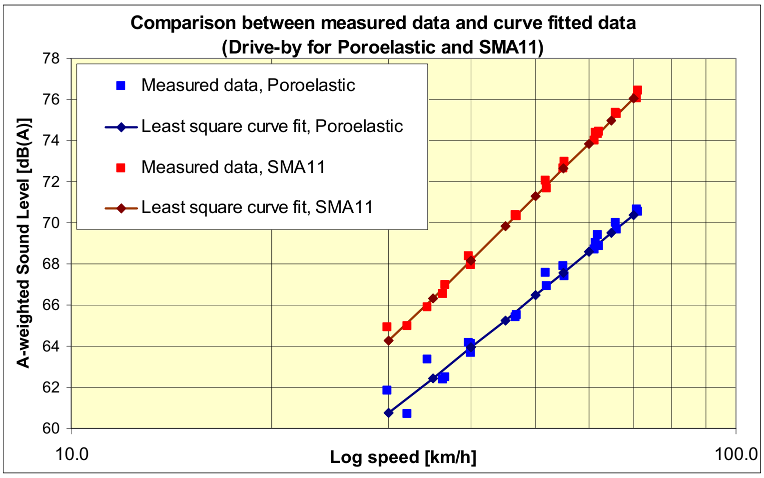

Fig. 4 Tyre/road Pass-by noise presented as broad band A-weighted sound levels according to ISO 7188:1994. **Note** that all square symbols are actual data for sound level vs. GPS-measured vehicle speed.

Note that the difference in A-weighted sound level is 6 dB(A) at 70 km/h, but only 3.5 dB(A) at 30 km/h. The reduced effect at lower speeds depends on the background

noise emitted from the engine/driveline.
This conclusion is confirmed more in detail by the CPX-measurements presented in the next section 4.2.

4.2 Tyre/road noise measured with the Close-Proximity method (CPX)

Parallel to the Pass-By method, the Close Proximity (CPX)-method was also used, performed according to the standard proposal, ISO CD 11819-2 (to applicable extent). The CPX-method includes test tyre microphones at the leading and trailing contact edge (see Fig 5). Length of the tested road shall be at least 20 m.
Speed was monitored using the GPS-system described in section 4.1.
Data from the two microphones, in front and rear of the test tyre, were averaged. The average sound pressure levels was evaluated for each car passage including least square fit to each third octave band from which the overall A-weighted sound levels were calculated. In Fig 6 below is presented the measured and evaluated data for the A-weighted sound level vs. speed in log scale.

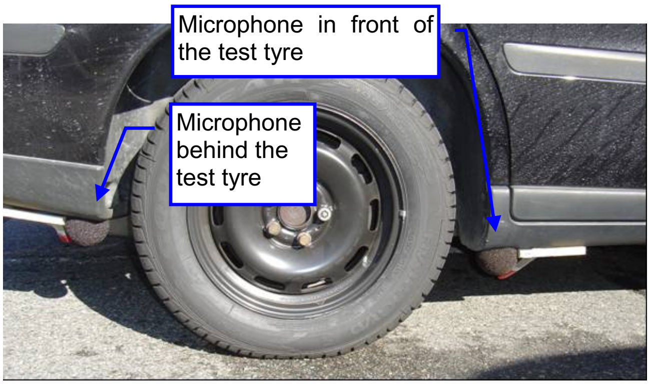

Fig. 5 Microphone positions in front of and rear of the test tyre. Selected microphone positions will minimize the aerodynamic self-noise in the low to mid-frequency range and will also offer high stability by firm microphone carrier.

.It can be seen in Fig. 6 that the measurement data points very well fit the least square curve fit and that it forms a straight line when the sound level is plotted as a function of speed in logarithmic scale. This indicates good quality of the test data. Note that with the CPX-method the difference between the reference and the poroelastic road surface is the same for low as for higher velocities.

From Fig. 6 it can also be seen that the poroelastic road surface has **5.6** to **5.9 dB(A)** less tyre/road noise compared to the reference road surface. Note that a comparison to a SMA16 would give 1.4 dB(A) increased reduction resulting in an overall noise reduction of 7.3 dB(A)-units.

Below in Fig. 7 is presented the curve fitted (separate curve-fitting for each 1/3-octave band) A-weighted Sound Pressure Level data for the poroelastic asphalt surface as compared to the reference road surface AC11 at 70 km/h

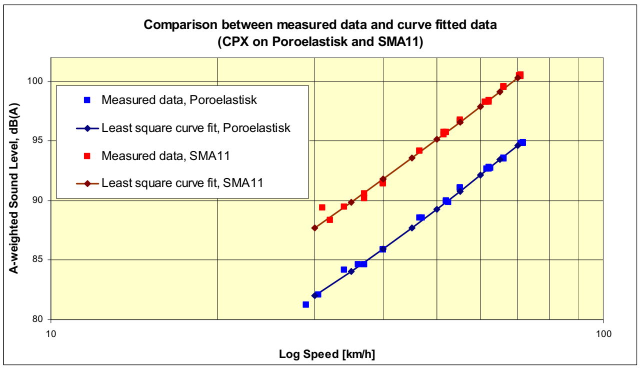

Fig. 6 The CPX-measured and curve fitted A-weighted Sound Levels as a function of speed. The speed axis is presented in logarithmic scale.

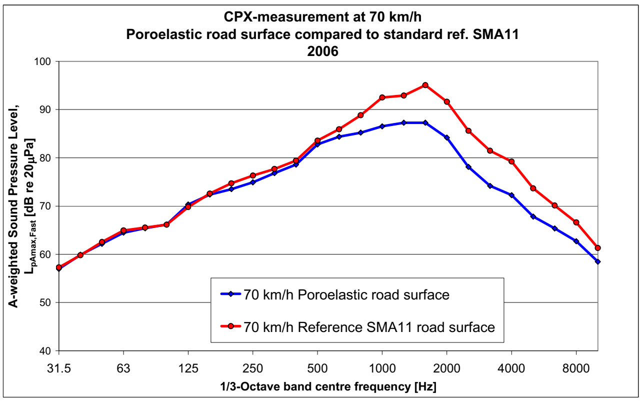

Fig. 7 A-weighted Sound Pressure Level for the poroelastic road surface and the reference road surface SMA11 measured with the CPX-method at 70 km/h.

4.3 Dynamic stiffness of the road surface

Laboratory manufactured road surface test plates was also studied. These studies included measurements of dynamic stiffness and sound absorption as well as standard strength, durability and stability road lab. testing.

The dynamic stiffness of a structure is the ratio of the force divided by the responding vibration displacement (vibration acceleration integrated twice), when the test object is excited with a force from e.g. a hammer impact. The dynamic stiffness has been analysed as a function of frequency (in the continuation called Frequency Response Function, FRF). Normally it is distinguished between point and transfer FRF.

The mechanisms involved in the sound generation at the tire/road interface are mostly due to local deformation and occur close to the leading and trailing contact edge. Therefore measurements have been focused on the point FRFs in order to as closely as possible deliver results relevant for the excitation process.

The measurements have been performed with aid of a technique utilizing the impedance head concept. The impedance head for measurement of the Dynamic Stiffness of road surfaces was developed by ACL and was first presented at the ICSV conference in 2003. It was developed to measure the point FRF on elastic road surfaces thereby as closely as possible resembling the excitation process when a tyre tread element hits the road surface. Fig. 8 below shows the impedance head developed by ACL.

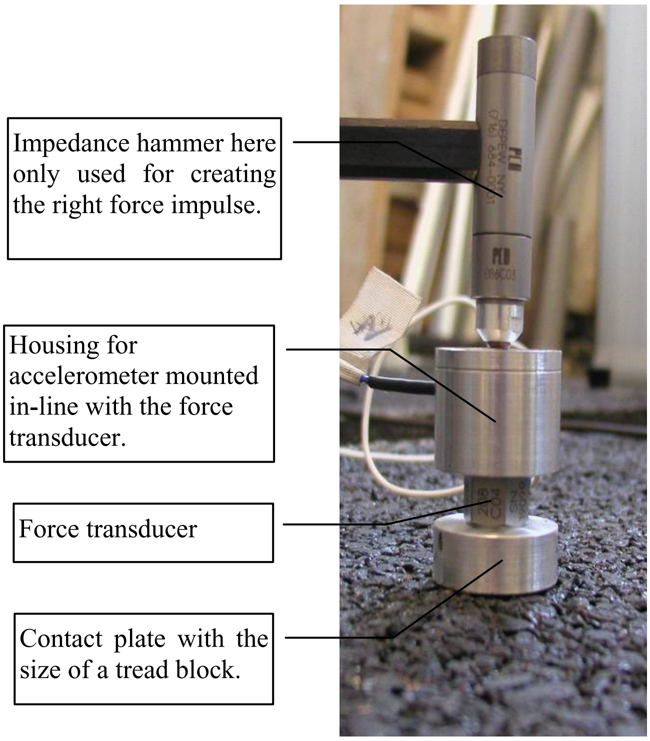

Fig. 8 Impedance head for measurement of the dynamic stiffness of poroelastic road surfaces. The contact plate diameter is tuned to give relevant data for the dynamic process of a tire tread block in the contact patch.

Fig. 9 presents the measured Dynamic Stiffness of the poroelastic road surface at Tagenevägen in Gothenburg compared to a reference road surface of the type SMA11. It can be seen that the poroelastic road surface has approximately 10 dB lower Dynamic Stiffness (i.e. at least 3 times more flexible).

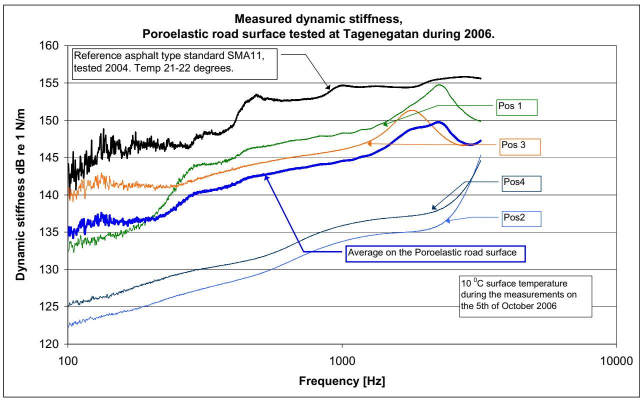

Fig. 9 Dynamic Stiffness for poroelastic road surface samples from at Tagenevägen in Göteborg (
Blue curve: Average of poroelastic asphalt surfaces.
Black curve: Reference road surface SMA11
Note: Spread in impedance data at different surface spots.

4.4 Sound absorption

Sound absorption for perpendicular incidence of the sound field has been measured on samples drilled from the test surface at Tagenevägen. In Fig 10 below is shown a measurement setup at ACL during the measurement with aid of the two channel impedance tube. Figure 11 below presents the sound absorption data from the drilled samples. Though the absorption factor is just around 10% at the frequency range of interest, its effect for the propagation angles from the tyre/road interface will be largely increased.

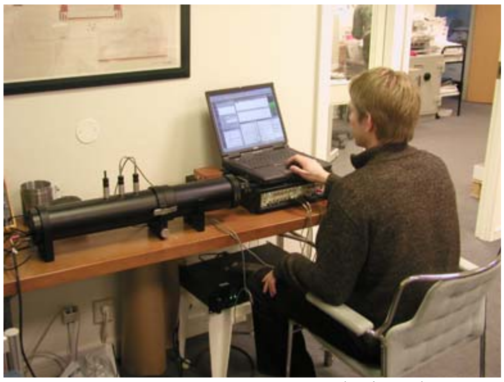

Fig. 10 Measurement setup at ACL during the measurement with aid of the two channel impedance tube.

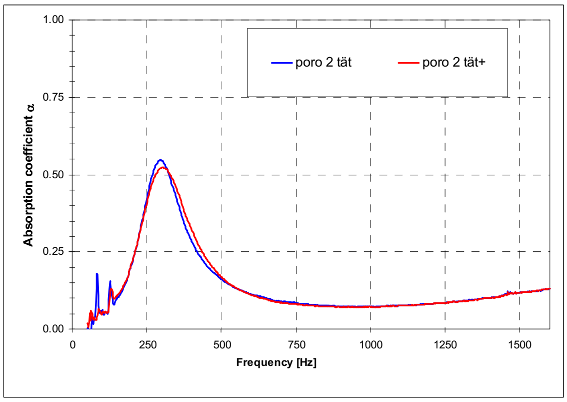

Fig. 11 Impedance tube measurements of the sound absorption from road surface samples at Tagenevägen.

5 Conclusions

Testing a newly designed single layer poroelastic road surface was found to give 6 dB(A) units less noise than the adjacent newly paved AC11 (11 mm max stone size) and 7 dB(A) units less noise compared to a SMA16 (16 mm max stone size). Pre-treated crumb rubber was added, causing the surface to be about 3 times more flexible than AC11.

Acknowledgments

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This support is gratefully acknowledged. [3]

References

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