

**EUROPEAN COMMISSION
DG RESEARCH**

SIXTH FRAMEWORK PROGRAMME

PRIORITY 6

SUSTAINABLE DEVELOPMENT, GLOBAL CHANGE & ECOSYSTEMS

INTEGRATED PROJECT – CONTRACT N. 516288



Report of promising new road surfaces for testing

Deliverable no.	F.D4
Dissemination level	Public
Work Package	WP F.2 New production technologies for surfaces on urban main roads
Author(s)	Oliver Ripke, Bent Andersen, Hans Bendtsen, Ulf Sandberg
Co-author(s)	---
Status (F: final, D: draft)	F1_18.08.2005
File Name	SILENCE_F.D4_180805_BASt.doc
Project Start Date and Duration	01 February 2005, 36 months

TABLE OF CONTENTS

1	Introduction	4
1.1	Description and goals of SILENCE	4
1.2	Potentials for noise reduction	5
1.3	Relevant parameters	6
2	Investigation of existing road surfaces	6
2.1	Reference surface	6
2.2	Dense surfaces	6
2.3	Porous surfaces	11
3	Investigation of new road surfaces	11
3.1	Combination Gussasphalt	11
3.2	Dense asphalt with high content of polymer-modified binder	12
3.3	Poroelastic road surfaces	16
4	Surfaces for further testing	20
4.1	Comprehensive approach	20
4.2	Existing road surfaces	20
4.3	New road surfaces	22
4.4	Overview	23
5	Sources	24

TABLES

Table 1: SPB-Noise levels (ISO 11819-1) test sections Stone Mastic Asphalt Burg/Germany, Cars 60 km/h.	8
Table 2: CPX-Noise levels, GA-Sections Motorway A3, (Ripke, O., 2004).	9
Table 3: SPB-Noise levels (ISO 11819-1) test sections Gussasphalt B56 Düren, Cars 100 km/h.	9

FIGURES

Figure 1: Texture of a Stone Mastix Asphalt surface	7
Figure 2: Texture amplitude spectra, Gussasphalt sections Motorway A3 (Ripke, O., 2004).	10
Figure 3: Principle of Combination Gussasphalt	12
Figure 4: The raw rubber material used in Asphalt Rubber surfaces produced by Arizona DoT. The rubber granules are 0.5-2.0 mm in diameter, the square mesh is 6 mm (1/4 inch).	13

Figure 5: A typical bore core of an Asphalt Rubber Friction Course (ARFC) produced by Arizona DoT.	13
Figure 6: View of the surface texture of an Asphalt Rubber Friction Course (ARFC). Location: Freeway in Phoenix, Arizona. The coin is a quarter dollar (about 25 mm diameter).	14
Figure 7: Results of noise measurements made with a method resembling the CPX method. From [Donavan, 2005]. Legend: DLPA = double-layer porous asphalt, PA = single-layer porous asphalt, PCC = porous cement concrete, LA138 OGAC = porous asphalt, LA138 RAC = unknown type of asphalt rubber, ARFC = Asphalt Rubber Friction course.	15
Figure 8: The surfaces of the three tested PERS materials. The white coin has a diameter of 25 mm.	16
Figure 9: The test site when production was completed in early September 2004 (edge markings added later). The asphalt used as a reference is in the right lane.	17
Figure 10: Results of CPX (left) and CPB measurements (right) on the test sections, at a test speed of 50 km/h.	18
Figure 11: Frequency spectra of the CPX measurements on the test sections, using the four CPX tyres and calculating the mean spectrum of these, at 50 km/h.	19
Figure 12: Two types of PERS mounted on interlocking blocks, as tested in Japan. The left one has some recycled plastic particles included, potentially to increase friction.	19

1 Introduction

1.1 Description and goals of SILENCE

SILENCE aims at developing an integrated system of methodologies and technologies for an efficient control of urban traffic noise. “Integrated system” means the combined consideration of city authorities, individual traffic (on road) and mass transport (on rail and road) with a holistic treatment of all traffic noise facets: urban noise scenarios, individual noise sources (vehicles), traffic management, noise perception and annoyance.

The SILENCE approach starts with three steps: the assessment of urban noise situations based on data from European cities, also in co-operation with the in parallel running IP QCITY, the definition of two urban noise scenarios as reference basis for the whole project, the identification of the related noise abatement priorities and noise reduction potentials. On this basis, the RTD activities are developed and integrated to an unique system of noise abatement technologies and tools and methodologies for noise reduction and policies. Thereby, the essential categories of urban traffic vehicles are considered like cars, light duty trucks, buses, trams, trains etc. One key element of this RTD approach is the global modelling for the prediction of noise effects on urban scenarios. Based on models for individual traffic elements developed in previous EU projects (like VISPeR, ROTRANOMO, STAIRRS), the global model predicts the overall noise emission of complex traffic situations and allows the prediction of noise immission by a source model coherent with the models used in HARMONOISE. This global model is used to apply the noise abatement technologies developed to the two reference noise scenarios, to predict their noise reduction effects and to validate the noise reduction potentials.

Thus, the key results and deliverables of SILENCE are first a noise abatement technology platform for road and rail vehicles, urban transport infrastructure and traffic flow aspects, and second tools, methodologies and input data for decision support systems, urban action plans and future noise scenarios.

Main Objective and Innovation of Sub-Project F Road Surface

This sub-project considers the integral design and maintenance of lower noise road surfaces in urban areas. Particular attention is given to surfacing technologies that are appropriate for use in congested streets containing road features such as inspection covers or suffer from frequent interventions due to sub-surface street works. Also new surface types will be developed for use on roads for medium to high speed traffic with speeds of 50 to 100 km/h, which are typical for city ring roads and city arterial roads carrying heavy traffic close to often populated living areas. The sub-project also includes developing technologies for ensuring that low noise surfaces maintain their cost/effective acoustic performance through their lifetime. Equipment and procedures for determining and classifying the influence of road surface noise in the urban environment is important to optimise the use of low-noise pavements in an asset management evaluation of urban road networks and therefore play an important part in the sub-project. As the materials technology is advancing around Europe, it is important the issue of novel materials are considered in the sub-project to further promote the development and use of new and innovative materials for low-noise roads.

The innovative part of sub-project F is to develop, monitor, classifying and maintain pavements to be used in urban areas, which in their whole lifetime provide an optimised cost/effective reduction of the tyre/road noise in urban areas.

Objectives of workpackage F2

At this moment all research activities in the field of construction technology for quiet roads concentrate on existing surfaces like the normal rolled asphalt pavements. In urban areas porous asphalt surfaces have (up to now) drainage and maintenance problems. The objectives are to develop new surfaces for use on roads for medium to high speed traffic (50 – 100 km/h). This may also consider surfaces for use on bridges. This has strong links with work package F5 in SILENCE subproject F (Road surfaces) and SILENCE subproject C and will consider the outputs of that work (modelling) in the design of new surfacing systems.

Tasks WP F2

- Optimisation of existing construction techniques to reach the appropriate noise reduction level for surfaces on main roads.
- Development of new technologies for the novel road surfacing materials.

1.2 Potentials for noise reduction

A number of mechanisms are responsible for the generation of noise from vehicles passing by on a road surface (Sandberg, U.; Ejsmont, J. A., 2002). One noise source is the engine and transmission system where the most important frequencies typically are smaller than 1000 Hz. This noise propagates from the vehicle directly and as reflected noise from the road surface. The surface structure is therefore important for the propagation and reflection. If the surface is absorbing to some degree the total noise may be reduced.

The second main source is the tyre/road interaction noise, which can be subdivided and described by different mechanisms:

- The aerodynamic noise generated by air pumping, when air is forced out (and sucked in) between the rubber blocks of the tyre and the road surface as the tyre rolls by. This source is typically most important in the frequency range between 1000 and 3000 Hz. If the road surface is porous with a high built-in air void, the air can be pumped down into the pavement structure, and the noise generated from air pumping will be reduced. If the pavement has an open but not porous surface structure the air pumping noise will also be reduced to some extent.
- Noise from vibrations of the tyre surface. The aggregate at the top layer of the pavement forms the pavement texture. When the rubber blocks of the tyre hit these stones, vibration is generated in the tyre structure. These vibrations generate noise typically dominated by the frequency range between 300 and 2000 Hz. With a smoother pavement structure, the generation of vibrations and noise is reduced. The vibration generated noise can also be reduced if the pavement is elastic.
- In the driving direction, the pavement surface and the curved structure of the tyre forms an acoustical horn which amplifies the noise generated by the tyre/road interaction. If the pavement side of this horn is noise absorbing, the amplification by the horn is reduced.

Other mechanisms are also described in the literature (Sandberg, U.; Ejsmont, J. A., 2002). It is the current opinion by the authors that the mechanisms mentioned above are the most important for the generation of tyre/road noise. The understanding of the mechanisms for noise generation is the background for the acoustical design of the noise reducing porous drainage asphalt pavements.

1.3 Relevant parameters

The following parameters in recipes can be changed and adjusted in order to optimise the noise reduction:

- Maximum aggregate size.
- The shape of the aggregate (cubic, flat, round etc.).
- The distribution of the size of aggregate and filler.
- The percentage of bitumen and modifier applied.
- The built-in air void.
- The thickness of porous pavement layers.
- The amount of rubber or other elastic material.

Also the process of laying pavements on roads is important in relation to achieve lower noise generation. Good craftsmanship and accuracy in the laying process are important to achieve the best results. The compaction has also influence on the final surface texture as it can ensure a smooth surface where flat sides of the aggregate are “facing” upwards. Suggestions for an optimum surface texture spectrum are given in the literature (e.g. Sandberg, U.; Ejsmont, J. A., 2002). Such texture spectra might be realised by using different recipes or laying techniques.

The relevant speed interval for urban main roads is 50 to 100 km/h. This includes lower speeds where engine noise is also of some importance for heavy vehicles or for accelerating passenger cars.

2 Investigation of existing road surfaces

2.1 Reference surface

When working with noise-reducing pavements, it is very important to have a common reference pavement in relation to noise, as this has a significant influence on stated noise reduction. In Denmark, a dense asphalt concrete surface with an aggregate size of 8 - 11 mm of the same age as the tested surface is generally used. Since tyre/road noise generation changes with the age of the pavement, it is important to construct reference sections along with test sections. In this way, the influence of ageing on the noise reduction can be eliminated.

2.2 Dense surfaces

2.2.1 Stone Mastic Asphalt

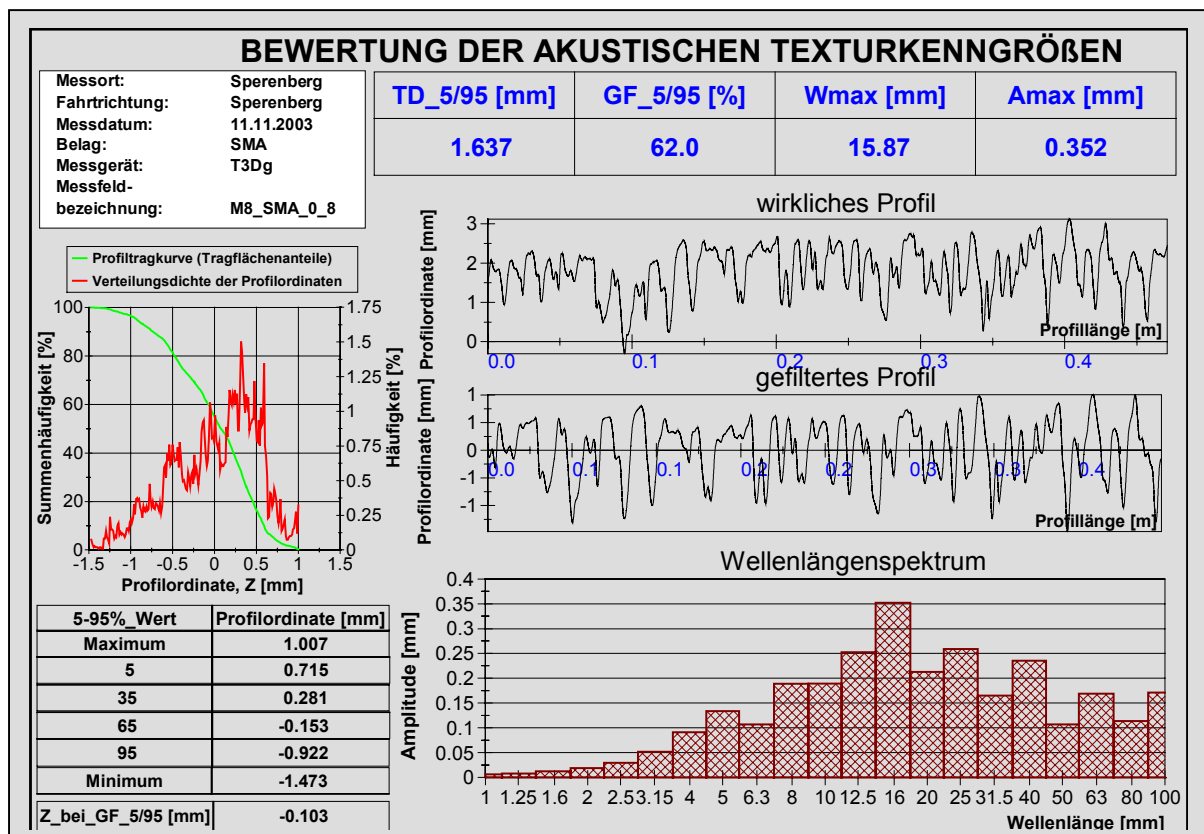
This surface was initially developed in Germany in the mid 1960's to create a road surface which has a high resistance to studded tyres. After the use of these tyres ended in the 1970's, it was found that these asphalt mixture has also a good resistance to rutting. In a third step it showed that it is a quiet surface compared to other surfaces which were in use at this time.

A first explanation for the positive acoustic behaviour of Stone Mastic Asphalt delivered a large research project which was commissioned by the Federal Highway Research Institute of Germany, known as the “Sperenberg” project. One result was, that the surface of a road should resemble “plateaus with ravines” after the road has been constructed (Beckenbauer et al. 2002). Small plateaus of the same height are located irregularly next to one another, so

that interim spaces (ravines) are left, allowing the tyre profile to release a certain amount of air. This reduces the air-pumping. The resultant surface is also smooth which means that the tyre vibration excitement is as low as possible for small aggregate sizes. Rolled asphalts with a dense surface, i.e. stone mastic asphalt and asphalt concrete, are close to this surface design, i.e. tend to have a surface structure with favourable acoustic properties which is also reflected in noise measurements.

The SMA surface has a very characteristic texture wavelength spectrum, Figure 1 shows an example of this. There are the larger amplitudes in the macrotexture range with wavelengths of up to approximately 20 mm (twice the maximum aggregate size, 8 mm in Figure1), which is desired for the releasing of the air in the tyre profile, and the decreasing amplitudes in the megatexture. Large amplitudes in the megatexture with wavelengths of up to approximately 200 mm have proved to have a negative effect on noise generation (Philips, S., Nelson, P., 1997), (Köllmann, A., Steven, H., Haberkorn, U., 1999). This study showed also, that in general, wavelengths of over 200 mm only play a small role in noise generation.

Figure 1: Texture of a Stone Mastix Asphalt surface



It is difficult to optimise the acoustic properties of rolled asphalts as mixture design, above all for SMA, and the surface which is formed during placement and compaction is fixed for the most part.

It is, however, thought that there are possibilities for optimising this construction method in the placement. The megatexture (wavelengths of 50 to 500 mm) of Stone Mastic Asphalt may be able to be improved.

An analysis of the placement and compaction process was carried out in the project "Quiet traffic – reduced tyre-roadway noise" (Federal Highway Research Institute, 2004). The research work was carried out under normal conditions of a construction site and ran into problems:

- The technical guidelines give only small room for variations of the asphalt mixture and the durability of the surface layer has to be guaranteed by the contractor. E.g. the demanded degree of compaction has to be achieved.
- A high number of possible variations on the screed of the paver and the rollers.
- Measuring the surface texture directly on the hot surface behind the paver and the rollers in a short period of time.

A variation of the compaction process was carried out on a road near Burg/Germany which connects two federal trunk roads. The differences in the noise levels of the three test sections measured with the Statistical Pass By Method (ISO 11819-1) were approximately 1 dB(A), which is within the inaccuracy of the measurement (Table 1).

Table 1: SPB-Noise levels (ISO 11819-1) test sections Stone Mastic Asphalt Burg/Germany, Cars 60 km/h.

	Asphalt mixture	Compaction	L(60) in [dB(A)]
Section 1	SMA 0/8 S	vibration	71,2
Section 2	SMA 0/8 S	vibration	71,2
Section 3	SMA 0/8 S	static	70,0

As the table shows, the noise level for a passenger car on a Stone-Mastic-Asphalt surface is approximately 71 dB(A) at a speed of 60 km/h, which is typical for the priority road network in urban areas. Additional measurements on a different test section confirmed this value. It has to be pointed out, that the asphalt surface used in these test sections had a small aggregate size of 8 mm which is common in Germany. In other countries aggregate sizes of 10, 11, 14 or even 16 mm are used in these asphalt mixtures. As the results of the “Sperenberg” project demonstrated, there is a correlation between noise and aggregate size. The optimum for car tyres is about 3 to 5 mm (Beckenbauer et al. 2002, p. 214).

2.2.2 Gussasphalt (Mastic asphalt)

As well as the Stone Mastic Asphalt, “Gussasphalt (GA)” (mastic asphalt) is a proven surface course on the German federal motorways. It combines a high level of skid resistance with good durability. The pourable mixture is laid with surplus binder at high temperature without compaction. Immediately after distributing the hot mixture, it is absolutely necessary that the smooth surface made of mortar is covered with chippings in order to ensure skid resistance. For conventional Gussasphalt the chippings are knead into the surface with the help of rubber-tyred and steel wheel rollers. The combination of the rollers helps to incorporate large amounts of chippings and closes cavities which occur when the hot mixture is laid on a damp base course. Apart from the commonly used chippings with large aggregate size, this use of a roller is, however, the main reason for the unsatisfactory acoustic properties of these conventional Gussasphalt surface courses so far. The rubber-tyred roller leaves an uneven surface which can not be sufficiently smoothed by the following steel wheel roller. Fixing the chippings to the surface through its own weight without the use of rollers helps to solve the problem. This requires an optimal mortar level before the chippings spreader is used. A dry base is imperative, cavities and pockets of steam cannot be closed.

The results of the “Sperenberg” project concerning noise and aggregate size are exactly the same for this construction method. This means, that fine chippings, e.g. 2/4 mm, and a cubic grain-shape improves the acoustic properties of GA surfaces. Dependent on the amount of the heavy vehicle traffic, the size of the chippings could be different, i.e. 5 mm on the first lane of a motorway and 3 mm on the fast lane.

The optimisation steps mentioned above were implemented on 4 test sections on the motorway A3 south of Cologne. Half a year after the sections had been laid, the noise

properties were recorded using the close-proximity method (CPX) in a noise measurement trailer (Table 2).

Table 2: CPX-Noise levels, GA-Sections Motorway A3, (Ripke, O., 2004).

Section	GA 0/8S without rolling chippings 2/4 mm	GA 0/8S rolled surface chippings 2/4 mm	GA 0/5S rolled surface chippings 2/4 mm	GA 0/11S rolled surface chippings 5/8 mm (reference)
Average noise level CPX 120 km/h [dB(A)]	102,4	104,2	105,3	106,5

The ranking is clear, ranging from the quietest non-rolled section to the loudest section of rolled conventional Gussasphalt (reference) with chippings of 5/8 mm.

The size of the chippings and the use / non-use of rollers are also shown in the ranges of texture wavelengths. Fig. 2 shows that the non-rolled GA 0/8 has the smallest amplitudes in the wavelengths which are important for noise generation (Ripke, O., 2004).

An additional test was carried out 2002 within the scope of the project “Quiet traffic – reduced tyre-roadway noise” (Federal Highway Research Institute, 2004). On the federal trunk road B56 south of Düren (between Aachen and Cologne) two test section with a maximum size of the chippings of 3 mm were constructed apart from other surfaces. The sections differed in the maximum aggregate size of the asphalt mixture of 5 and 8 mm respectively. The noise level were recorded with the Statistical Pass By Method (ISO 11819-1) (Table 3).

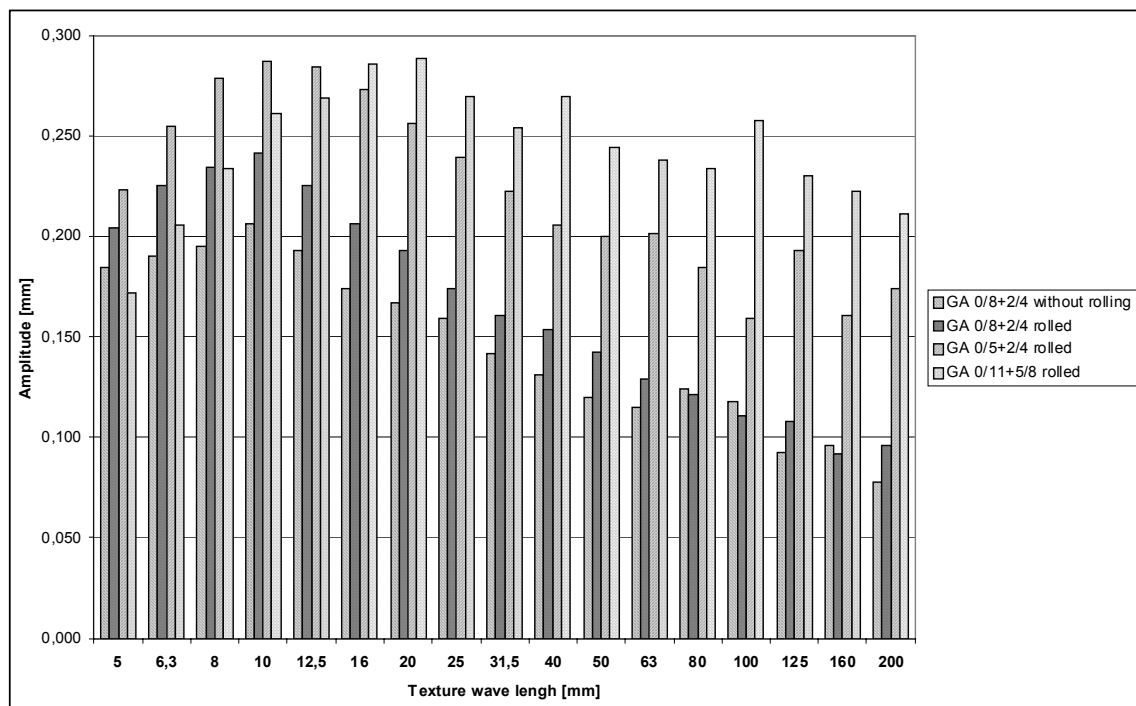
Table 3: SPB-Noise levels (ISO 11819-1) test sections Gussasphalt B56 Düren, Cars 100 km/h.

Section	Max aggregate size of chippings [mm]	Noise level cars Year 2002 100 km/h [dB(A)]	Noise level cars Year 2003 100 km/h [dB(A)]
Gussasphalt 0/5	3	80,2	79,5
Gussasphalt 0/8	3	80,5	80,3
Stone Mastix Asphalt (reference)	---	80,1	79,6

There is only slight difference between the two sections, as Table 3 shows. The main influence on the acoustical behaviour of the Gussasphalt surfaces is the aggregate size of the chippings, not the aggregate size of the mixture. The small size on the B56 resulted in noise levels comparable to the Stone Mastic Asphalt used as reference. A second measurement in the year 2003 showed a little lower levels.

Besides the use as a road surface, Gussasphalt is widely used as a bridge covering. The mixture has a closed structure almost without any voids and is therefore watertight. This characteristic makes it ideal for use as an surface layer on bridges. All efforts in improving the construction method is for the benefit of these special surfaces.

Figure 2: Texture amplitude spectra, Gussasphalt sections Motorway A3 (Ripke, O., 2004).



2.2.3 Thin layers

Different types of thin surface layers are tested in Denmark these years (Bendtsen, H.; Andersen, B., 2004), (Andersen, Bendtsen, Schmidt, Nielsen, 2004) on urban roads with a speed of 50 to 60 km/h and on a highway with a speed of 110 km/h. These thin layers come from three different pavement families:

- Open graded asphalt concrete (AC-open) (gap graded).
- Stone mastic asphalt (SMA).
- A thin layer constructed as a combination pavement (TSF c). On the existing road surface a thick layer of polymer modified bitumen emulsion (including water) is laid out. On the top of this a very open pavement (like porous asphalt) with a (built-in) Marshall air void of approx. 14 % or even more is applied. The bitumen layer “boils up” in the air voids of the pavement leaving only the upper part of the structure open. This reduces the real built-in air void of the pavement because the lower parts of the pores of the pavement are filled with bitumen.

A maximum aggregate size of 6 mm has been used on urban roads and 8 mm on highways.

Porous pavements are open in the entire thickness of the layer and the cavities are connected. As a contrast to this, dense open pavements are open only at the upper part of the pavement with cavities having a depth less than the maximum size of the aggregate used for the pavement. The basic concept of using open pavements for noise reduction is to create a pavement structure, with as big cavities at the top surface of the pavement as possible in order to reduce the noise generated from the air pumping effect, and at the same time ensuring a smooth surface so that noise generated by vibrations of the tires will also be reduced. Such a noise reducing open pavement can be thin, as the mechanisms determining the noise generation are only dependent on the surface structure of the pavement. The total thickness of a thin layer has no influence on the noise.

Initial noise reduction of up to 3 dB in relation to a dense asphalt concrete with 11 mm maximum aggregate has been measured.

2.3 Porous surfaces

2.3.1 Single layer porous pavements

Single layer porous pavements have been tested in Denmark over their entire lifetime on a highway with a speed of 80 km/h (Bendtsen, H., 1998). The pavements with the best noise reduction had a maximum aggregate size of 8 mm, a built-in air void of around 20-23 %, and a thickness of 40 mm. The measurements carried out indicated that they were not clogged, and they had an average noise reduction of around 3 - 4 dB in relation to a dense asphalt concrete of exactly the same age with 11 mm aggregate. The porous pavements were not cleaned. A similar porous pavement with 12 mm aggregate gave around 1 dB less noise reduction. In order to accelerate the lifetime test an unmodified binder was used. The pavements lasted for 7 years before intensive ravelling occurred. The porous pavement with 8 mm aggregate was also tested on an urban road with 50 km/h speed limit. An initial noise reduction of 3 dB disappeared after around 2 years because the pavement was clogged.

Porous surface with resonators

At the moment a surface which incorporates resonators under the porous surface layer is under investigation and will be further observed in WP F2.

2.3.2 Two-layer porous pavement

Two-layer porous pavements have been long-term tested on Øster Søgade in Copenhagen (Bendtsen, H.; Larsen, L. E.; Greibe, P., 2002) which is an urban road with a speed limit of 50 km/h. The project is ongoing on the 6th year. Three different twin-layer porous pavements were developed. All of the pavements have a high porosity with air voids about 22 to 27 %. A maximum aggregate size of 5 or 8 mm in the top layer is used, whereas the aggregate size in the bottom layer is 16 or 22 mm. The total thickness of the pavements varies between 55 and 90 mm. The pavements are cleaned twice a year using high pressure water. A comprehensive research program was developed to monitor the pavements every year. Factors such as noise, pavement texture, porosity, skid resistance, speed, traffic safety, winter maintenance, and the annoyance of the residents are measured. After two years the noise reduction of all 3 pavements was around 4 dB in relation to a dense asphalt concrete with 8 mm maximum aggregate size. After 4 and 5 years there is a tendency that the pavements with 5 mm aggregate in the top layer get clogged while the pavement with 8 mm aggregate tends to keep open and still reduce noise generation.

3 Investigation of new road surfaces

3.1 Combination Gussasphalt

As mentioned in chapter 2.2.2, Gussasphalt is a pourable mixture which is laid with surplus binder and at high temperature. After the mixture is put on the road surface a screed carries out the distribution. The resulting smooth surface made of mortar is normally covered with chippings to ensure skid resistance.

The hot and therefore sticky surface of asphalt mortar can be used to glue a prefabricated layer to the surface. This layer could be made of asphalt with natural or artificial building materials. Layers made of sandpaper or foils are conceivable. The principle of the construction method is shown in Figure 3. It's in the stage of a theoretical consideration and the feasibility has to be checked with the help of

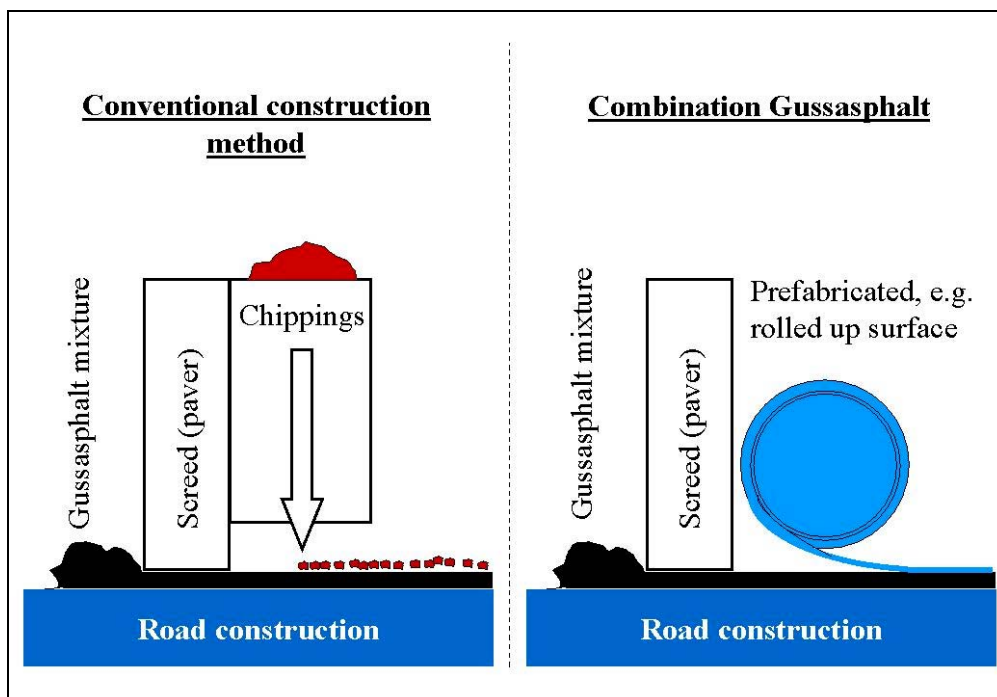
- laboratory experiments,

- tests in the interior drum facility of BAST (WP F5).

The advantages of the new method could be as following:

- The Gussasphalt base and the surface layer are produced in one step. No additional glue is necessary.
- The surface is prefabricated under the best possible conditions, e.g. no influence of the weather.
- The Gussasphalt base is watertight and can be laid in thin layers down to 2 cm.
- Designing the texture of the surface with the help of a tyre-road model for low noise generation is possible.

Figure 3: Principle of Combination Gussasphalt



It is to be expected that the construction method enables the use of “artificial” surfaces with the best possible surface texture. A considerable reduction of the noise generation of dense surfaces could be reached.

3.2 Dense asphalt with high content of polymer-modified binder

In USA, mainly in Arizona, a type of dense asphalt with a high content of polymer-modified binder, “Asphalt Rubber Friction Course” (ARFC), with excellent acoustic properties has been developed and used. ARFC surfaces differ from conventional surfaces in two major ways:

- -The binder is mixed with crumb rubber (granules 0.5-2.0 mm) with a proportion of approx 15 % (by weight) of the binder being rubber.
- -The amount of binder (including the rubber) is typically about 10 % of the total weight of the surface.

Thus, in total, the amount of rubber in the surface is around 1.5 % by weight. This is more than twice the amount normally used when rubber is used as a polymer modifier to a porous asphalt surface. Figure 4 shows the rubber material whereas Figure 5 shows a typical bore

core and Figure 6 shows a typical surface view. The surface texture has two rather distinct features: (1) aggregate of a “medium” size dominates, this should give a texture which is well optimized for low noise tyre/road emission, (2) there is a substantial amount of binder covering the aggregate.

It shall be noted that the surface is not porous. The picture of Figure 6 was taken during rainfall and it appears that the water does not penetrate the surface but stays on it. Measurements of modulus have shown that the surface is softer than a conventional dense asphalt concrete or an SMA.

Figure 4: The raw rubber material used in Asphalt Rubber surfaces produced by Arizona DoT. The rubber granules are 0.5-2.0 mm in diameter, the square mesh is 6 mm (1/4 inch).

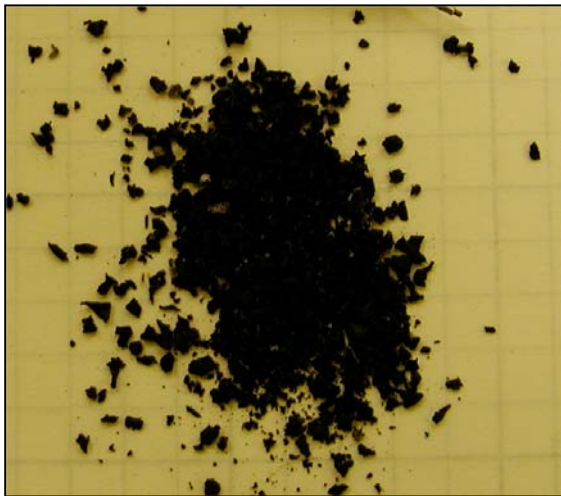


Figure 5: A typical bore core of an Asphalt Rubber Friction Course (ARFC) produced by Arizona DoT.



Figure 6: View of the surface texture of an Asphalt Rubber Friction Course (ARFC). Location: Freeway in Phoenix, Arizona. The coin is a quarter dollar (about 25 mm diameter).



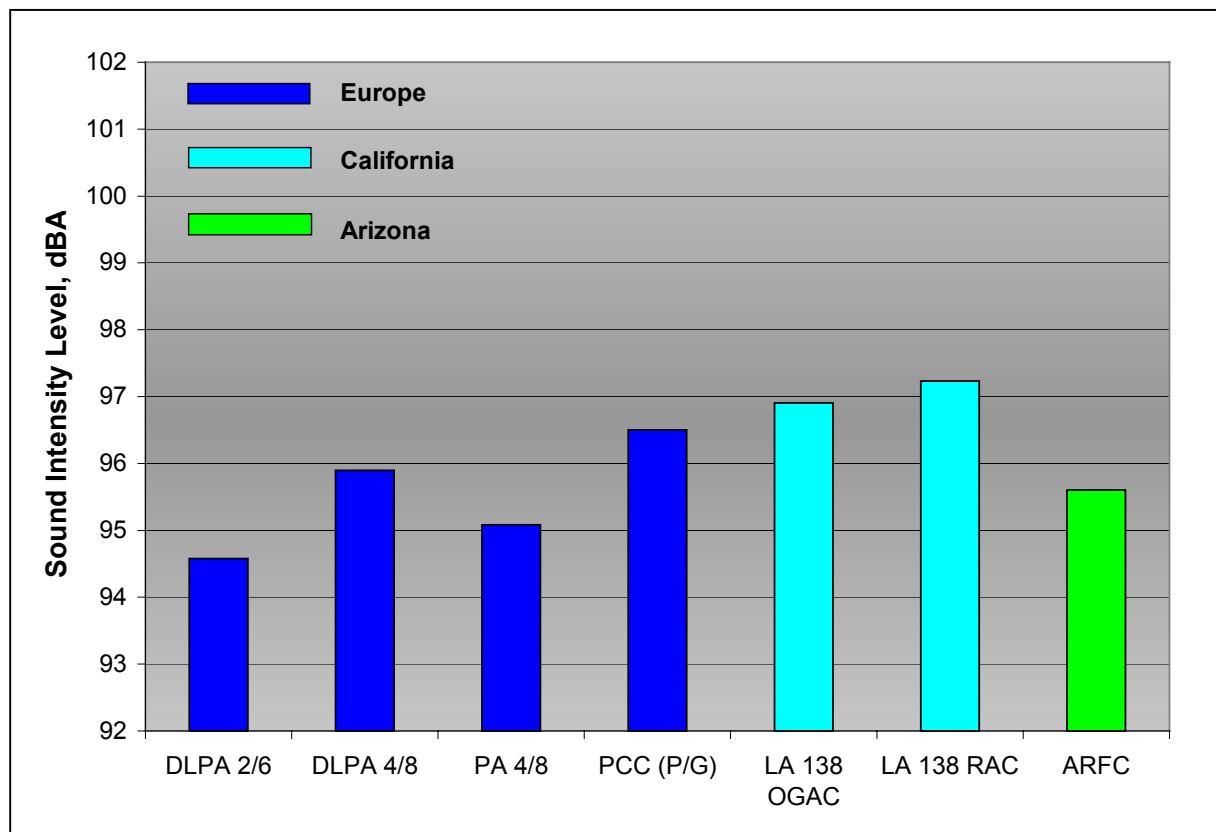
Noise measurements of a standard type which can be compared to European conditions have been made only very sparsely. Earlier, noise measurements on non-standard types have been made comparing the ARFC to transversely tined cement concrete, which is an extremely noisy surface. The noise reductions obtained have then been extremely high. However, in an experiment last autumn, a researcher from California took his equipment from Arizona and California and made measurements on west European roads, using a method which resembles the CPX method which is subject to standardization within ISO. A major difference is the tyre used (Goodyear Aquatred), which may eventually bias results a little. The most interesting results are summarized in Figure 7 which compares the best European with the best US surfaces. It appears that the ARFC are almost as effective in reducing noise as the best European porous asphalt surfaces, which is an amazing result. Systematically higher temperatures in the US than in Europe during the measurements may have favoured the US surfaces a little, but not more than 1 dB.

The ARFC surfaces in Arizona have demonstrated an amazing durability. The oldest ones, on high-volume roads and motorways, are now 18 years and still in use. They also seem to have a kind of self-curing property acting against cracks such as joints in cement concrete. However, the noise characteristics are usually impaired with time. Current data suggest that the initial noise reduction is reduced at a rate of approximately 0.3 dB per year. This is a slower decay in acoustic efficiency than typical of porous asphalt.

ARFC or similar surfaces have lately been laid also in Texas and Colorado, and one of the authors (Sandberg) is somewhat involved in cooperation with US colleagues on this subject.

In Europe, similar surfaces have been laid and still exist in Portugal (contacts established). Some rumours have suggested that such surfaces may also exist in Greece and Germany (contacts being explored). It is the aim to explore in SILENCE possibilities to study any such surfaces that can be found in Europe. It may be desirable to consider whether different climates in southern versus middle and northern Europe may influence the potential benefits of ARFC, since this is a matter of concern in the US.

Figure 7: Results of noise measurements made with a method resembling the CPX method. From [Donavan, 2005]. Legend: DLPA = double-layer porous asphalt, PA = single-layer porous asphalt, PCC = porous cement concrete, LA138 OGAC = porous asphalt, LA138 RAC = unknown type of asphalt rubber, ARFC = Asphalt Rubber Friction course.



The authors speculate that the noise-reducing properties come from the following properties:

1. A surface texture with an appropriate mix of aggregate sizes creating an open (but not porous) texture with tyre/road contact points close to each other. A good drainage between the peaks in the texture gives a rather good drainage of water and air, minimizing the so-called air pumping noise generation mechanism.
2. A relatively soft surface, making the impact between tyre tread elements and the road texture peaks somewhat damped. The extremely high amount of binder creates a membrane around the stones which may be blocking the sound structural transmission between stones, to make each stone a softly embedded particle acoustically more separate from the adjacent stones than in a normal surface, such as an SMA with extremely stiff stone-stone contact.

3. A third mechanism could be that the extremely high amount of binder, remaining on the surface a rather long time after construction, may give different adhesion between tread rubber and the road binder than if there is only a direct rubber-stone contact.

The conclusion is that it appears to be very important to test this road surface concept also in Europe.

3.3 Poroelastic road surfaces

A poroelastic road surface (PERS) is a wearing course made essentially of rubber granules bound together with a binder and with a selection of particle sizes, resulting in a porous structure. Originally, this is a Swedish invention approximately 25 years old, found to be acoustically very efficient but with unacceptable durability. Its design from a durability point of view was never tried in a professional way. Japanese researchers pick-up the idea and developed more professional variants of the surface in the 1990's (work is still underway in Japan), a work which was finally developed to include a Swedish-Japanese cooperation, including VTI in Sweden and PWRI in Japan. Regular workshops and exchange of ideas and some materials have occurred; the latest Japanese-Swedish workshop was organized in May 2005.

The latest years, partly in the EU project SILVIA, VTI has worked with the objective to construct and test in laboratory and in field experiments three poroelastic surfaces intended for road traffic noise reduction in urban areas. The surfaces have been made up of rubber particles bound with polyurethane to create a 30 mm thick porous structure with 30-35 % interconnecting air voids. Figure 8 shows the appearance of the three surfaces.

Figure 8: The surfaces of the three tested PERS materials. The white coin has a diameter of 25 mm.



Laboratory experiments have indicated very low wear of the test specimens due to exposure to studded tyres as well as very low emissions of particles in the air. They have also indicated rolling resistance to be comparable to that of a conventional asphalt surface. Adhesion to the base course and skid resistance received particular attention and the laboratory experiments indicated satisfactory performance.

Three types of poroelastic road surfaces were laid in 2004 on one lane of a street in Stockholm City, carrying a mix of light and heavy traffic (5400 AADT, 50 km/h posted speed). See Figure 9. Wet skid resistance measurements and dry braking tests indicated satisfactory performance.

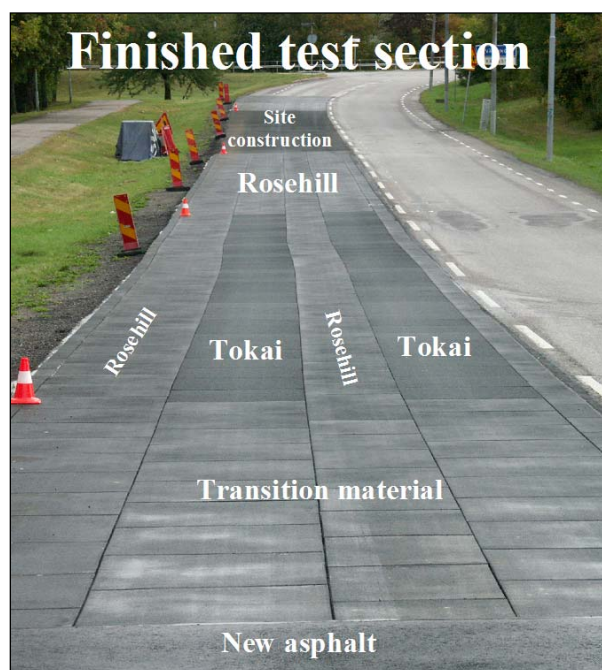


Figure 9: The test site when production was completed in early September 2004 (edge markings added later). The asphalt used as a reference is in the right lane.

Noise measurements with the CPX method gave L_{eq} values measured in the near-field typical of the CPX method and averaged over approximately 32 m test length. As a supplement a few controlled pass-by (CPB) measurements were made too. In this case, a Ford Focus car equipped with "summer" tyres cruising-by the roadside microphones placed at 7.5 m from the centre of the test lane with the engine running, and the A-weighted maximum levels were measured. Figure 10 presents the results. The noise reductions are 8-12 dB, depending on the type of surface. The lower noise reduction for the "Rosehill" surface is due to a chamfer which (unintentionally) occurred on the edges of the rubber plates from Rosehill; see Figure 8. It appears, for this limited case, that the CPB values are just a little less positive than the CPX ones; probably a result of the engine noise contribution in the case of CPB. Typical frequency spectra from the CPX measurements are shown in Figure 11.

After a few months, the experiment was interrupted due to the underlying asphalt surface separating from the asphalt layer beneath. This was very unfortunate since the rubber surfaces and the adhesion of them onto the first asphalt layer still seemed to perform well.

PERS can also be used to improve the acoustic characteristics of block pavements. Such tests were made already in 2002 in Japan; see Figure 12. The result was a surface which was 7-8 dB quieter than the conventional dense asphalt surface. This concept may be of special interest in several urban locations, where one may want to combine a visually very

pleasing and different surface with a quiet surface. The Japanese experiment was interrupted after the first winter due to problems with rutting of the surface. There were also some problems with snow chains making minor damage to the surface, since the surface was located in a winter climate on a country road carrying heavy traffic. The sand in which the paving blocks sat was dispersed from the underside of the blocks and pressed up between the joints of the blocks, creating a thinner sand bed under the most heavily loaded blocks, i.e. in the wheel tracks. The problems that the Japanese experienced with rutting must then be overcome, but such knowledge exists in Sweden where block pavements are frequently used in urban areas carrying a lot of heavy (bus) traffic.

More information is available in [Sandberg & Kalman, 2005].

Figure 10: Results of CPX (left) and CPB measurements (right) on the test sections, at a test speed of 50 km/h.

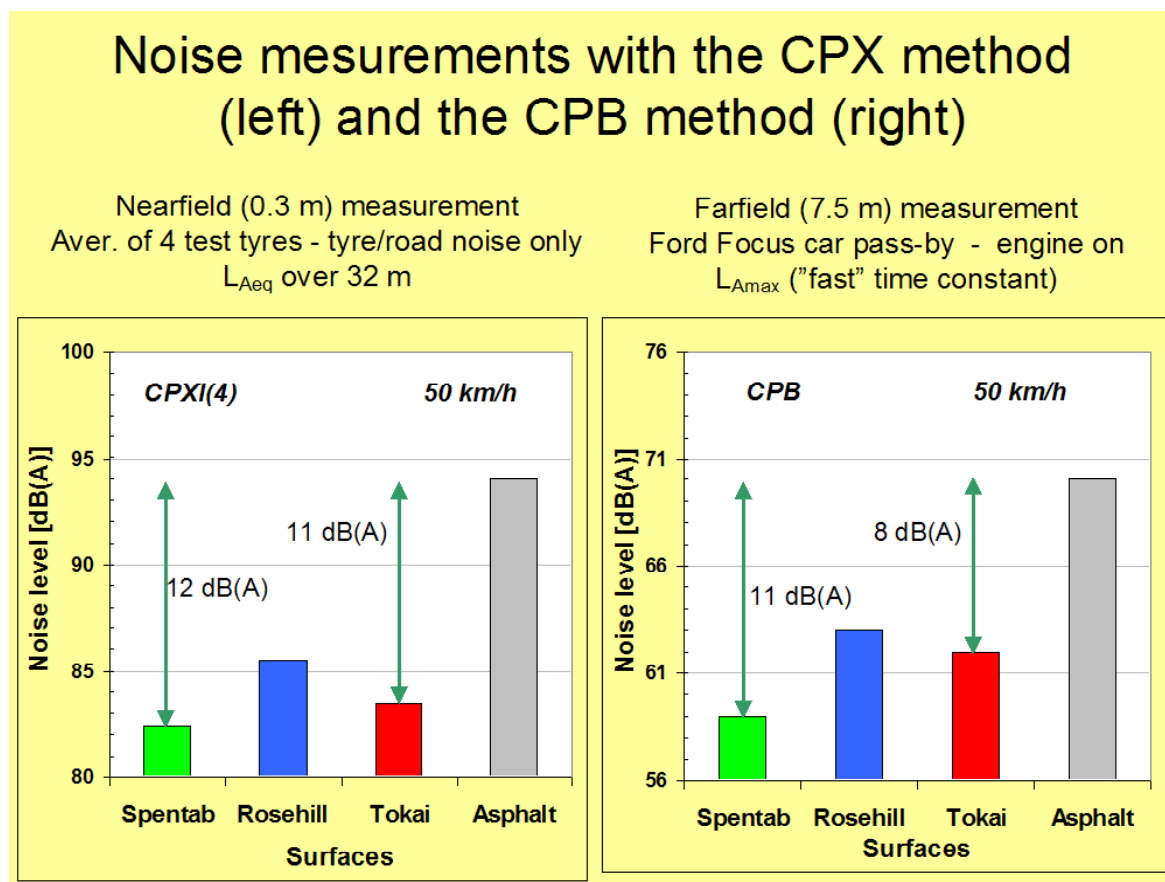


Figure 11: Frequency spectra of the CPX measurements on the test sections, using the four CPX tyres and calculating the mean spectrum of these, at 50 km/h.

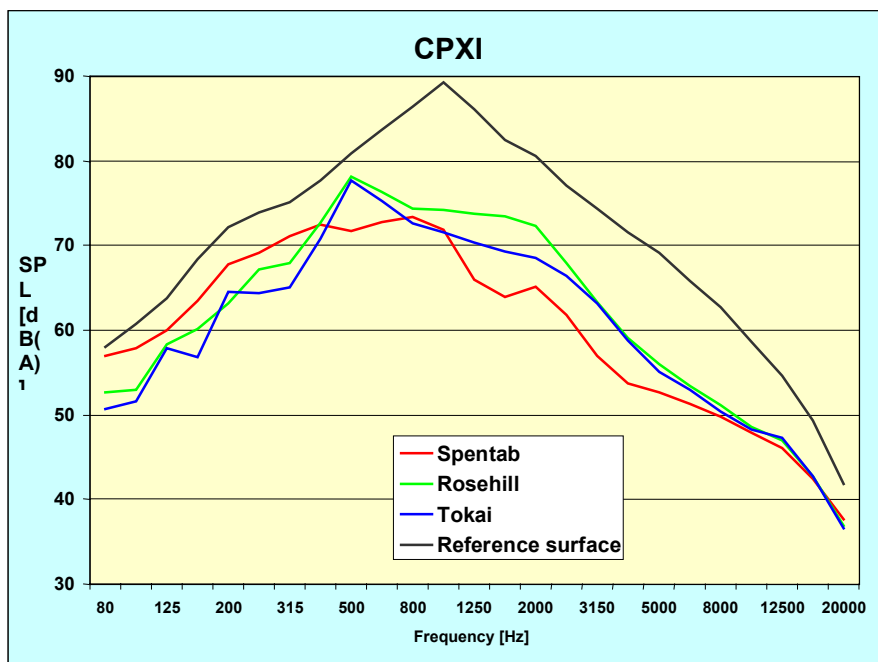


Figure 12: Two types of PERS mounted on interlocking blocks, as tested in Japan. The left one has some recycled plastic particles included, potentially to increase friction.



4 Surfaces for further testing

4.1 Comprehensive approach

In the development of new pavement technologies it is important to keep in mind that not only low noise levels are important. Different requirements shall be fulfilled over the lifetime of the pavements such as:

- Maintain the noise reduction over the structural lifetime of the pavements.
- Long structural lifetime (good resistance towards ravelling and rutting).
- Sufficient or good traffic safety properties.
- Reasonably low rolling resistance.
- Reasonable construction and maintenance costs in relation to other means of noise abatement (barriers, façade insulation) when used in big scale. Prototypes can be expensive.

Speed and concepts

It must be discussed how different speed limits, total volumes of traffic as well as the percentage of heavy vehicles can affect the optimisation of types of pavements used for noise reduction.

4.2 Existing road surfaces

4.2.1 Dense surfaces

Stone Mastic Asphalt

A quiet road surface with a fixed and well-tried process of laying and compacting. Only small variations in optimising the texture are possible. The use of small aggregate sizes proves to be useful.

-> No further testing in WP F2.

Gussasphalt

A proven road surface with high skid resistance and unsatisfactory acoustic properties if constructed in the conventional way. The use of smaller chippings which are applied without the use of rollers improves demonstrably the acoustical behaviour.

-> No further testing in WP F2.

4.2.2 Thin layers

On the background of this report the following lines for optimisation can be drawn for thin pavements:

- Maximum aggregate size of 6 mm or even 4 mm might increase the noise reduction.
- The use of cubic aggregate might ensure a smoother top surface and therefore lower noise levels.
- A big openness at the top of the surfaces ensures the lowest noise generation. This can be archived by a relative high built-in air void, even though the pavements must not exceed around 15 % built-in air void because then they will become semiporous or porous.

- The combination pavements might have the best potential for ensuring the largest openness in the top of the surfaces.
- There is also a potential to achieve good noise reduction by using the open graded or the SMA concepts.

It shall be suggested to test some improved types of noise reducing thin layers in WP F2.

4.2.3 Porous surfaces

Single layer

On the background of this report the following lines for optimisation can be drawn for single layer porous pavements for roads with an average speed above 70 - 80 km/h:

- 8 mm maximum aggregate size seems to be good for noise reduction and avoiding clogging.
- 6 mm maximum aggregate size might reduce the noise a little further.
- The air pumping noise might be reduced further by increasing the built-in air void to as much as 25 - 30 %.

The air pumping noise might be reduced further by increasing the thickness of the porous pavements. This will also increase the noise absorption of the pavement. However, there might be some limitations to this, since a rule of thumb says that the thickness of a pavement layer should be around 3 times the maximum aggregate size in order to avoid problems during the compaction. A very thick porous layer can be applied in two or more laying processes.

It shall be suggested to test some improved types of single layer porous pavements in WP F2.

Two layer

On the background of this report the following guidelines can be drawn for optimisation of two-layer porous pavements:

- For urban roads with low speeds 8 mm maximum aggregate size seems to prevent clogging.
- For roads with speed above 70 - 80 km/h 6 mm maximum aggregate size might be used since the high speed traffic itself might prevent clogging. This might reduce the noise further.
- The air pumping noise might be reduced further by increasing the built-in air void of the top layer (and also the bottom layer) to as much as 25 - 30 %.
- Making the top layer as thin as possible might reduce the tendency towards clogging especially on low speed roads.
- Increasing the aggregate size and the thickness of the bottom porous layer might increase the reduction of air pumping noise and of noise absorption.

It shall be suggested to test some improved types of two layer porous pavements in WP F2.

Other fields of research

Porous surfaces are under further development in several countries. This includes fields of research like clogging and the use of resonators. The level of knowledge shall be integrated into WP F2.

4.3 New road surfaces

4.3.1 Combination Gussasphalt

As described in chapter 3.1, a proven construction method is combined with the use of “artificial” surfaces. The further testing in the laboratory (WP F2) will lay the foundations for further investigations in the interior drum facility of BAST (WP F5). The task includes

- selection of “artificial” surfaces in the terms of durability, costs, rolling resistance etc. (suitable new surfaces from WP F1 can be included),
- production of test specimens (slabs),
- evaluation of the durability (adhesiveness with the tensile test, wear resistance in the wheel tracking test),
- measurement of the texture of the specimens with and without the added “artificial” surface.

With the help of the test results one Combination Gussasphalt will be selected for testing in the interior drum facility.

4.3.2 Dense asphalt with high content of polymer-modified binder

The ARFC surfaces described in chapter 3.2 are in regular use in the state of Arizona but not elsewhere. The surface type is not yet accepted by the Federal Highway Administration for a wider use in the USA; although Arizona DoT (only) has received a temporary acceptance to use it for noise reduction purposes, subject to further testing. In Europe, similar surfaces have not been tested sufficiently and must still be considered as rare and unique and not very coordinated efforts. Scientific reports including standard noise characteristics in Europe are not available. It is not known how climate might affect the performance of the surface type. For European conditions, therefore, the surface type requires further testing.

With the very high noise-reducing potential suggested by the US measurements in comparison to the best European low-noise surfaces, and with the slow decay in noise reduction demonstrated in Arizona so far (better than for porous asphalt), this surface type appears to be extremely promising for a wide use as a noise-reducing and durable surface. Currently, nothing says that this is limited only to a limited speed range; it is likely that the efficiency may follow the same trend of noise versus speed as the porous surfaces.

Studies of this surface type, therefore, shall be included in the activities of F2.

4.3.3 Block pavement improved by a cover of quiet poroelastic surface

As described in chapter 3.3, the use of interlocking paving blocks is widespread. Reasons include cultural aspects, aesthetic aspects, or a desire to create a visual and acoustic change (for example for traffic safety reasons). Most such surfaces increase the noise level in relation to conventional dense asphalt. However, the acoustic change may be equally desirable for safety reasons if it means that noise suddenly disappears since the important thing is the sudden *change* of sound level; for environmental reasons it would of course be very desirable that noise disappears. Almost always, paving blocks are used where there is a lot of people either living in their homes very close to the street or being in motion in a shopping area. A substantial noise reduction would be very welcome in both cases and would increase the quality of life.

Mounting a quiet and soft poroelastic layer on paving blocks appears to hold a high potential for noise reduction, while still maintaining a very pleasing and different visual appearance. Patterns may be made very different according to the objectives, just as with paving blocks, but also colour may be (durably) varied without problem. The cost of the extra cover is expected to be relatively low.

This type of surface is, therefore, one of those that should be tested in this Work Package. This will be made in close cooperation with Work Package F1.

4.4 Overview

The following surfaces were identified to have potential for further testing:

- Combination Gussasphalt
- Dense asphalt with high content of polymer-modified binder
- Block pavement improved by a cover of quiet poroelastic surface
- Porous asphalt
- Thin layers

5 Sources

Reference List

- Sandberg, U.; Ejsmont, J. A., 2002. Tire/Road Noise Reference Book. Informex, SE-59040 Kisa, Sweden (www.informex.info).
- Beckenbauer et al., 2002. Einfluss der Fahrbahntextur auf das Reifen-Fahrbahn-Geräusch, Forschung Straßenbau und Straßenverkehrstechnik, Heft 847, Hrsg. BMVBW (Federal Ministry of Transport, Building and Housing).
- Ripke, O., 2004. Reducing traffic noise by optimising hot-mix asphalt surface courses. *In: Proceedings 3rd Eurasphalt & Eurobitume Congress 2004*, S. 1061 – 1067.
- Philips, S., Nelson, P., 1997. Developments in Lower Noise Road Surfaces. Available from: http://europa.eu.int/comm/transport/road/research/2nd_errc/contents/07%20ROAD%20POLLUTION/road%20pollution.doc [Accessed 26 July 2005]
- Köllmann, A., Steven, H., Haberkorn, U., 1999. Ausprägung von Mega- und Makrotextur auf Fahrbahnoberflächen. Unpublished research report on behalf of the Federal Highway Research Institute. TÜV Automotive GmbH, Herzogenrath.
- Federal Highway Research Institute, 2004. Verbundprojekt "Leiser Straßenverkehr – Reduzierte Reifen-Fahrbahn-Geräusche". Berichte der Bundesanstalt für Straßenwesen, Heft S37 (Report S37).
- Bendtsen, H.; Andersen, B., 2004. Thin open layers as noise reducing pavements. Proceedings Inter.Noise 2004 in Prague. Danish Road Institute, DRI report 135, Danish Road Directorate (www.roadinstitute.dk).
- Andersen, Bendtsen, Schmidt, Nielsen, 2004. Måling af trafikstøj fra vejbelægninger på M10 ved Solrød (Measurement of road traffic noise from road surfaces on the M10 near Sol-rød". In Danish). Danish Road Institute, DRI note no. 21, Danish Road Directorate.
- Bendtsen, H., 1998. Drainage asphalt and noise reduction over a long period. *In: Proceedings from EuroNoise 1998*.
- Bendtsen, H.; Larsen, L. E.; Greibe, P., 2002. Udvikling af støjreducerende vejbelægninger til bygader. Statusrapport efter 3 års målinger. (Development of noise-reducing road surfaces for urban roads. Status report after 3 years of measurements. In Danish with extensive English summary). Danish Transport Research Institute, Report 4. (www.dtf.dk).
- Rymer, Bruce; Donavan, Paul (2005): "Comparative Measurements of Tire/Pavement Noise in Europe and California/Arizona". Presentation at the summer meeting of TRB ADC40, Seattle, WA, USA, July 2005.
- Sandberg, Ulf; Kalman, Björn (2005): "The Poroelastic Road Surface – Results of an Experiment in Stockholm". Proc. of the Forum Acusticum 2005 conference in Budapest, Hungary, August 2005.