INNOVATIVE ASPHALT SURFACE LAYERS TO REDUCE TRAFFIC NOISE

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ABSTRACT

From 2005 to 2010 the joint research project 'Quiet Road Traffic 2' was carried out with partners from industry, universities and other research institutes. A main topic was the further improvement of surface layers made of Porous Asphalt (PA). A conventional composition of PA reaches a limit in noise reduction which makes new approaches necessary. For this purpose Helmholtz-Resonators were used to control the absorption of PA. A second important research topic was the improvement of the acoustic durability by reducing the clogging process of the voids. Hopefully the use of additives in the binder generated a stain-resistant effect in the void system. Many of the research results were put into practice on 19 test sections in total on the Federal Motorway A24 located 40 km northwest of Berlin. Besides the sections based on the findings of the project 'Quiet Road Traffic 2', other new developments of non porous noise reducing surface layers were constructed. Conventional Stone-Mastic-Asphalt and one and two layered PA were included in the test-concept to assess the acoustic effectiveness. The acoustic measurement showed a high level of noise reduction, but the expected additional effect due to the use of the Helmholtz-Resonators was not achieved. Additional research in the laboratory identified the composition of the PA as a cause. An exceptional high void content shifted the frequency position of the absorption maxima which made the resonator elements less effective than expected.

Keywords: Noise reduction, Porous asphalt, Tyre/road noise

1. INTRODUCTION

The Federal Republic of Germany has approx. 230 inhabitants per square kilometre. It includes large areas with a high population density and is dominated by numerous population centres where the need to protect the population against traffic noise is particularly high. It is often not sufficient to use only noise protection walls or earth walls and the heights required can be problematic. It therefore seems obvious that the road surface should also make a contribution to noise reduction.

Noise-reducing road surfaces lower tyre/road noises very effectively, as prevention takes place where the noise is generated. Porous asphalt layers were found to be very effective because they facilitate the absorption of the noise as well as the ventilation of the tyre profile in a downward direction. In addition, there are several newly designed wearing courses, which produce less tyre vibration due to their fine texture (smallest grain size of the material used) and allow a ventilation of the tyre profile, although to a lesser extent.

In recent years, a wide range of research activities concerning the reduction of tyre/road noises have been performed in Germany and other countries. From 2005 to 2010, a consortium involving industry, universities and other research organisations worked on the joint project "Silent Traffic 2" [1]. The project partners were subsidised by the Federal Ministry of the Economy and Technology and supported by the Federal Ministry of Transport, Building and Urban Development. One focus of the project was the acoustic development of porous asphalt layers (PA) by optimising their absorption properties. A second research focus was the improvement of the acoustic durability of PA by reducing pollution. The results of this research project, in particular their practical implementation on a test track, are described below.

2. DEVELOPMENT OF A REACTIVE ABSORBER TO IMPROVE THE ABSORBING PROPERTIES OF POROUS ASPHALT

Porous asphalt wearing courses have been systematically tested and developed in Germany since 1986. The stepwise increase of the void content and stronger focus on the layer thickness available for absorption led to an increase in effectiveness and durability. However, the durability did not yet reach the levels of dense wearing courses, e.g. stone mastic asphalt.

In a first step, the interactions known from a parameter study based on absorption theory were extrapolated to porous asphalt wearing courses to allow further optimisation of the PA by the project partner Müller-BBM. Construction-related parameters, i.e. partially controllable parameters such as void content and layer thickness were investigated. It was shown that particularly an increase in the void content leads to improvement of the absorption over a broad frequency range. However, this is difficult to achieve in practical construction work. The porous asphalt wearing courses, which are made of common building materials, i.e. aggregate and binder, are approaching their natural upper limit regarding void content. The absorption levels achievable in this way initially appeared quite promising. However, closer investigation of the absorption spectrum shows that it only covers a small frequency range. Additional improvement of the absorption effects might be achieved by using reactive absorbers. Adjustment of these elements to a specific frequency could be used to make the absorption spectrum broader, i.e. to cover a wider range of frequencies (see Figure 1).

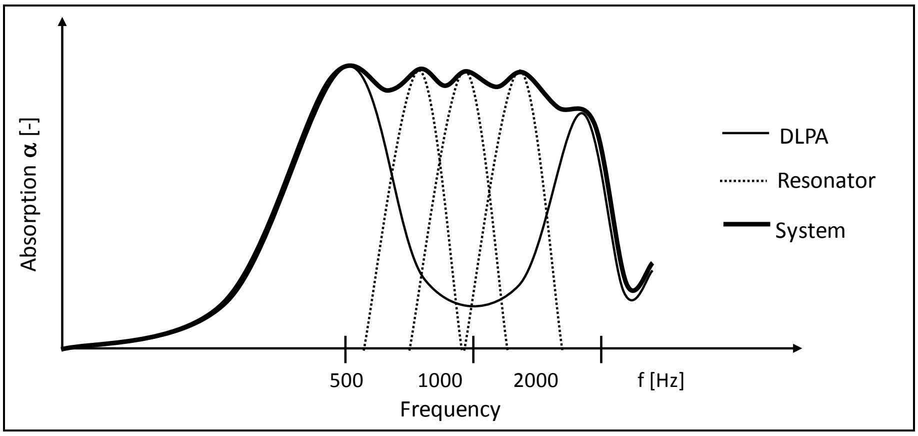

Figure 1: Spectra of absorption of a Double Layer Porous Asphalt (DLPA), the resonator elements and the system (schematic)

Different concepts for the integration of the resonators into porous asphalts were investigated in order to implement these theoretical considerations. The initial concepts envisaged the installation of a layer of resonators. This was abandoned due to the problematic system compatibility of asphalt and concrete. After additional investigations, a version with individual bodies made of polymer concrete was selected. It had approx. 20 such elements per square metre. The elements each contained 6 resonator elements of different sizes, which were therefore tuned to different frequencies. After strength tests at a university, the first test under road construction conditions was performed on a test site south of Berlin.

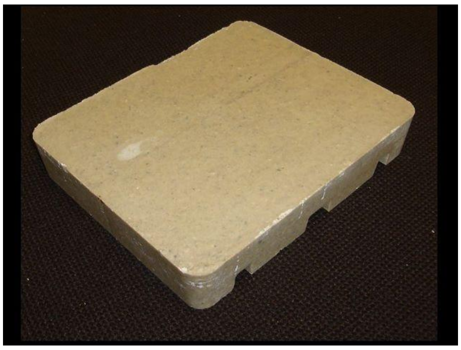

Figure 2: Resonator element (left: top surface; right: bottom)

After this preliminary test of the suitability for installation, the concept was implemented on an approx. 50 m long test section of the A24 motorway. On a base layer of mastic asphalt, a 2 mm layer of polymer-modified, hot bitumen was applied with a bitumen spray machine and the elements were placed onto that layer by using a template. No elements were placed onto the hard shoulder to facilitate driving of mixture transporters and other construction vehicles. After placing the elements, the test section was covered with DLPA 11 and 8 (see Table 1: Test Section 5).

3. STAIN-RESISTANT COATING OF THE VOID SYSTEM OF POROUS ASPHALT

A basic problem of PA is the susceptibility of such wearing courses to pollution. Their considerable exposure to dust, pollen, etc. leads to slow filling of the void structure. This reduces the noise-reducing effect of the wearing course.

Stuttgart University, a partner in the project, has managed to use a polymer based on nanotechnology to modify the void walls in PA in a way that significantly reduces their tendency to accumulate dirt. The adjustment of the individual binder parameters is a particular challenge in this process. Addition of the polymer may not negatively affect the binder parameters, e.g. its affinity to the aggregate. A reduction in dirt adhesion in the void structure could be shown in laboratory investigations on modified porous asphalts. In July 2009, a test section with this porous asphalt was installed on the Motorway A24 (see Table 2; Test Section 14,). Long-term observation will show whether the laboratory results can be confirmed and longer acoustic service life can be achieved under realistic conditions.

4. NEW CONCEPTS FOR NON-POROUS ASPHALT SURFACE LAYERS

New wearing courses are currently being developed in parallel to the very effective PA and DLPA. They generate less tyre vibration due to a finely structured texture (small grain size of the aggregates used) and also facilitate ventilation of the tyre profile, although to a lesser extent.

One of these developments is low-noise stone mastic asphalt (SMA LA). Such wearing courses, which have more void content than conventional SMA, are currently being tested on federal motorways. The results are promising and the products might provide an alternative for applications in cities. Based on these experiences, it was decided to integrate the concept in the form of a test section in the A24.

A second new development used on the A24 is a construction type with the working title "Porous Mastic Asphalt (PMA)". It has been developed by the road-building administration of the State of North-Rhine Westphalia. It is based on a grain structure made up of course aggregate that is filled with mastic asphalt up to a remainder of approx. 1 cm. The fine parts of the aggregate in the mastic asphalt are limited to 1 mm. The resulting surface is similar to that of SMA/PA. Below this surface is mastic asphalt, which has perfect sealing properties. The installation is achieved with conventional asphalt-laying devices, i.e. dump trucks, road pavers and light rollers. Three test sections were implemented on the A24 road section. They differ with regard to the aggregates and binders used (see Table 2).

5. TEST SECTIONS ON FEDERAL MOTORWAY A24 NEAR THE TOWN OF NEURUPPIN

The concepts developed in the project parts mentioned above, i.e. the modified binders to repel dirt and increased effectiveness due to resonators, were to be implemented on a test section in a practical application.

The search for a suitable test road started early during the project. It had to allow unrestricted acoustic measurements and had to fulfil all other requirements for a test road. This includes a challenging but not extreme traffic load.

In March 2006, a suitable road section was selected in cooperation with the Ministry of Infrastructure and Agriculture of the State of Brandenburg and its road construction administration. Thereafter, the necessary planning and tender processes were initiated. The road section is approx. 6 km long, scheduled for renewal and located on the A24 Federal Motorway Berlin-Hamburg in the area between the Neuruppin and Neuruppin South interchanges. The road section includes approx. 11 km of one-way causeway and allows for a large number of test variations and a generous length of the individual test sections. The basic concept included tests of PA and DLPA in two approx. 2.5 km long middle test sections. The ends of these test sections were to be delimited by test sections of stone mastic asphalt (SMA). The resonators were to be tested in the DLPA test section of the causeway leading towards Berlin (see Figure 2).

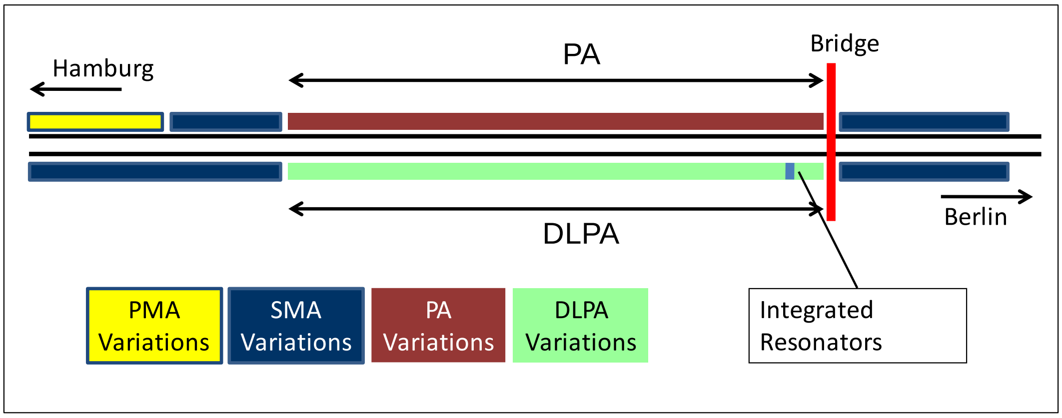

Figure 2: Concept of test sections on Motorway A24

The detailed test concept for the test sections included tests of the "Leistra 2" products as well as the utilisation and testing of additional theoretical concepts concerning the effects of OPA. These include the influence of the acoustically effective thickness, sealing below the porous layer and the binder. Table 1 and 2 list all the test sections implemented.

Table 1: Test sections on Motorway A24, direction Berlin

Section	Position [km]	Thickness [cm]	Bituminous mixture	Binder	Type of Sealant below PA
1	206+169 to 207+400	4	SMA 11 S	25/55-55 A	n.a.
2	207+400 to 208+200	3	SMA 8 LA (low noise)	40/100-65 A	C60BP1-S
3	208+200 to 209+300	3 + 5	DLPA 8+16	40/100-65 A	MA 5 S 2 cm
4	209+300 to 209+950	3 + 5	DLPA 8+11	40/100-65 A	MA 5 S 2 cm
5 Resonator	209+950 to 209+995	3 + 5	DLPA 8+11	40/100-65 A	MA 5 S 2 cm
6	209+995 to 210+250	3 + 5	DLPA 8+11	40/100-65 A	MA 5 S 2 cm
Bridge: km 210+250 to 210+297					
7	210+297 to 211+200	4	SMA 11 S	10/40-65 A + Sasobit	n.a.
8	211+200 to 212+250	4	SMA 11 S	25/55-55 A	n.a.

Table 2: Test sections on Motorway A24, direction Hamburg

Section	Position [km]	Thickness [cm]	Bituminous mixture	Binder	Type of Sealant below PA
9	210+297 to 211+130	4	SMA 11 S	Mexphalte 45 RM	n.a.
Bridge: km 210+250 to 210+297					
10	209+650 to 210+250	5	PA 8	Mexphalte 45 RM+	Mexphalte 45 RM+
11	209+050 to 209+650	5	PA 8	tecRoad premium	40/100-65 A
12	208+200 to 209+050	5	PA 8	40/100-65 A	40/100-65 A
14	208+100 to 208+200	5	PA 8	40/100-65 A +TEGOPREN®	40/100-65 A
15	207+500 to 208+100	5	PA 8	40/100-65 A	MA 5 S 2 cm
16	207+186 to 207+500	4	SMA 11 S	tecRoad premium	n.a.
17	206+760 to 207+186	4	PMA 5 Granodiorite	Sübit VR 35	n.a.
18	206+340 to 206+760	4	PMA 5 Granodiorite	10/40-65 A +Sasobit	n.a.
19	206+169 to 206+340	4	PMA 5 Eolite	10/40-65 A +Sasobit	n.a.

Abbreviations for the binders and sealants used in Table 1 and Table 2:
- 40/100-65 A; 10/40-65 A: Polymer modified bitumens according to EN 14023 with a penetration of 40 to 100 0.1 mm and 10 to 40 0.1 mm respectively. Softening Point ≥ 65 °C. Elastomer modified (A).
- Mexphalte 45 RM and RM+; tecRoad premium: Rubber modified bitumens.
- Sübit VR 35: Modified bitumen for warm mix asphalt.
- C60BP1-S: Cationic bituminous emulsion according to EN 13808. Bitumen content 60 %. Polymer modified. Used for tack coat application (S).

6. PROPERTIES OF THE BITUMINOUS MIXTURES ON MOTORWAY A24

Proof of suitability for the use of the planned asphalt mixtures was submitted by the construction company tasked with the implementation. Tables 3 and 4 provide an overview of the most important key variables and the type of binders and coarse aggregates used.

A comparison of the values indicates very high void contents for the PA types, which are approx. 30 % per volume. This can be explained by the extremely favourable grain shape of the electrical furnace slug used (eolite), which originated from the Henningsdorf plant. The grading curve was not unusual, as it is prescribed in detail by the German asphalt regulations. The proportion of badly formed grains was 0% for the grain group 5/8 and 1% for the grain group 8/11. This resulted in a structure very similar to a sphere packing. Version PA 8 with the Tegopren® additive in Test Section 14 was an exception. The laboratory evaluation showed that the mixture was clearly easier to compact, which resulted in a rather low void content of 21.7 % per volume. The binder content relative to the total mass was unusually low due to the high bulk density of eolite. The minimum values in the German regulations for asphalt were therefore reached. The bulk density of the aggregate mixture for PA 8 (40/100-65 A) was 3.639 g/cm^3, which reduced the minimum value from 6.5 % by volume to 4.7 % by volume.

Table 3: Properties of bituminous mixtures A24 in the direction of Berlin

Test section	1, 8	2	3	4, 5, 6	3, 4, 5, 6	7
Mixture	SMA 11 S	SMA 8 LA	PA 16	PA 11	PA 8	SMA 11 S
Binder	25/55-55 A	40/100-65 A	40/100-65 A	40/100-65 A	40/100-65 A	10/40-65 +Sasobit
Binder content [%]	6.5	6.3	4.4	4.6	5.0	6.5
Void content [Vol.-%]	2.6	11.9	30.3	28.9	29.6	2.6
Type of aggregate	Granodiorite	Granodiorite	Eolite	Eolite	Eolite	Granodiorite

Table 4: Properties of bituminous mixtures A24 in the direction of Hamburg

Test section	9	10	11	12, 15	14	16
Mixture	SMA 11 S	PA 8	PA 8	PA 8	PA 8	SMA 11 S
Binder	Mexphalte 45 RM	Mexphalte 45 RM	tecRoad premium	40/100-65 A	40/100-65 A +Tegopren®	tecRoad premium
Binder content [%]	6.5	4.8	4.8	5.0	4.8	6.5
Void content [Vol.-%]	2.7	27.0	25.8	29.6	21.7	2.8
Type of aggregate	Granodiorite	Eolite	Eolite	Eolite	Eolite	Granodiorite
Test section	**17**	**18**	**19**			
Mixture	PMA 5	PMA 5	PMA 5			
Binder	Sübit VR 35	10/40-65 A +Sasobit	10/40-65 A +Sasobit			
Binder content [%]	7.2	7.2	6.0			
Void content [Vol.-%]	n.a.*	n.a.*	n.a.*			
Type of aggregate	Granodiorite	Granodiorite	Eolite			

* As for Mastic Asphalt practically zero.

7. NOISE MEASUREMENTS

7.1 Close Proximity Method (CPX)

In April 2010, the BASt performed noise measurements in the near-field with a measuring trailer (CPX method) (Table 5). No measurements could be performed after completion of construction work in the autumn of 2009 due to the winter weather.

Table 5: CPX measurement on test sections of Motorway A24

Direction	Section	Type of surface layer	CPX 80 km/h [dB(A)]	
			Tyre P1	Tyre H1
Berlin	1	SMA 11 S (Reference)	97.3	97.7
	2	SMA 8 LA	93.0	93.9
	3	DLPA 8 + 16	91.0	90.6
	4	DLPA 8 + 11	91.5	91.0
	5	DLPA 8 + 11 Resonators	90.3	91.0
	6	DLPA 8 + 11	90.6	90.3
	7	SMA 11 S Sasobit	97.9	97.9
	8	SMA 11 S	97.6	98.3
Hamburg	9	SMA 11 S Mexphalte RM	97.3	97.7
	11	PA 8 tecRoad	93.2	93.3
	12	PA 8 (PA reference)	93.0	93.4
	15	PA 8 on MA sealant	92.7	93.0
	17	PMA Granodiorite Sübit	94.0	95.0
	18	PMA Granodiorite Sasobit	93.8	94.7

7.2 Statistical pass-by method (SPB)

In April 2010, the BASt performed noise level measurements with the statistical pass-by method (SPB). No measurements could be performed after completion of the construction measures in the autumn of 2009 due to inappropriate weather. Measurements were only performed at five "key points" of the section (Table 6). The total performance of the route can nevertheless be derived from comparative consideration regarding the CPX measurement.

Table 6: SPB measurements on test sections of Motorway A24

Direction	Section	Type of surface layer	SPB [dB(A)]	
			Cars 120 km/h	Heavy trucks 80 km/h
Berlin	5	DLPA 8+11 (with resonators)	76.4	80.6
Hamburg	15	PA 8 (MA-sealant)	75.8	80.7
Hamburg	12	PA 8 (reference PA)	75.9	81.6
Hamburg	17	PMA 5 (Sübit VR 35, Granodiorite)	81.2	85.4
Berlin	2	SMA 8 LA	79.7	85.0

7.3 Additional laboratory analysis

The proof of suitability and the control test for the resonator and the reference section showed very large void contents of up to 30 % by volume. Such large void contents generate a structure of voids that is likely to deviate from that of PA with normal void contents of >22 % by volume. The structure of the absorbing medium can be described by the structure factor. This value increases when the curvature and the interconnection of the air channels increase. According to [2], the maximum of the noise absorption spectrum is shifted towards lower frequencies when the structure factor increases. This indicates that test specimen of equal height made of different PA mixtures will have different absorption characteristics. Asphalt plates with a height of 5 cm were produced with a roller compactor to test this hypothesis. They consisted of PA 8 and PA 11 mixtures from the A24 and a PA 8 reference mixture from the A61 federal motorway. Two cylindrical specimen with a diameter of 100 mm were produced from each sample and investigated in the Kundt's Tube of the BASt. The results are shown in Table 7.

Table 7: Absorption of specimen (laboratory) on Motorways A24 and A61

Bituminous mixture	A24 PA 11	A24 PA 8	A61 PA 8
Max. Absorptivity [-]	0.99	1	0.93
at frequency [Hz]	1175	1185	940
Flow resistance R_S [Pa s/m]	4125	2688	19094

Comparison shows that the test specimen made of the A24 mixture have a clearly lower flow resistance than the reference samples and that the position of the absorption maximum is shifted by approx. 200 Hz towards higher frequencies.

8. CONCLUSIONS AND OUTLOOK

One of the goals pursued in the sub-project "Integrated improvements of porous wearing courses" of the joint project *Silent Road Traffic 2* was a further optimisation of the noise absorption capabilities of this construction type. The Müller-BBM company, which was a partner in the project, has developed resonator elements that are integrated into the porous wearing course and that are supposed to reduce the noise within a wide range of frequencies, due to their special frequency adjustment.

Extensive tests were performed in the acoustic laboratory of Müller-BBM. The results for the test bodies in a sound chamber demonstrated the effectiveness of the resonator elements with absorption maxima in the frequency range of 800 to 1000 Hz. These elements seem capable of compensating for the absorption minimum of DLPA from 630 Hz upwards. Integration of the resonator bodies is intended to optimise the acoustic performance of the whole system. Additional noise-reduction of up to 3 dB(A) was predicted on the basis of these laboratory tests.

The laboratory experiments were to be put into practice with the construction of a test section at the A24. Construction issues were clarified in advance by building a test section at a test range.

The installation of the resonators in the summer of 2009 proceeded without problems. In April 2010, once the entire road section has been released for traffic, the BASt performed extensive noise measurements.

A comparison of the individual test sections led to the following conclusions:

- The additional, noise-reducing effect of the resonators is approx. 1 dB(A) and therefore only half the expected value (compare Sections 4 and 5). The spatial arrangement of the measurements, which is not shown in the paper, indicates that the 45-m-long section is divided into two parts. The first half is approx. 1 dB(A) louder (also found in the SPB measurement). This may be due to slight unevenness that may have resulted from initial problems experienced when covering the resonators. These findings led to further investigations on the A24 and in the acoustic laboratory. Initial results indicate that the void-rich OPA mixture used on the A24 produced absorption maxima in unusual frequency ranges. It can therefore be assumed that there was an overlap of the frequency ranges in which the PA and the resonators were most effective: The practical application did not cover the desired, broad frequency range. There is obviously room for improvement.
- The PA and DLPA sections are clearly the quietest ones. Compared to the reference surface SMA 11 S up to 7 dB(A). The DLPA sections are up to 2 dB(A) more silent than PA.
- Rubber modification of the binder did not result in the expected, additional acoustic effect with SMA and PA.
- The noise-optimised SMA 8 LA and PMA are 3 to 4 dB(A) more silent than conventional SMA 11 S.
- Section 15 with PA 8 on an MA sealing layer is approx. 1 dB(A) more silent with trucks than the conventional PA 8 on a bitumen sealing layer. This may be due to the thicker acoustically effective layer (no rising of the bituminous sealant layer into the PA).

The design and the implementation of the A24 test road can be rated as an overall success. Noise reductions of 7 dB(A) were achieved in the various test sections. The results of the construction of the test field with resonator elements show that no major practical construction problems were encountered and that no major damage had occurred after one year of high traffic load and partially extreme weather conditions (prolonged cold and hot periods).

Further investigations should include laboratory tests concerning the effects of the void content on the acoustic efficiency of the resonators and possible adaptation of the elements. A second test section should be built, based on these findings. It should, in particular, be aimed at the adaptation of the resonators to optimise the noise absorption performance of porous asphalt wearing courses. Also the method of the resonator application should be reworked to reduce manual work and therefore cost.

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