Asphalt mixture performance and testing

Testing of a porous asphalt with a modified composition

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Abstract

Within the framework of the project, a modified mixture of Porous Asphalt (PA) was to be tested on the new Demonstration, Investigation and Reference Area (duraBASt) of the German Federal Highway Research Institute. The modified asphalt mix concept with a deliberate dosage of 5 % fine aggregates (≤ 2mm, hereinafter referred to as "sand") could probably reduce problems such as insufficient structural service life and process safety. The aim of the project was to test the targeted production (dosage of sand) and the behaviour of the optimised asphalt mix during paving and to record and analyse the resulting properties of the finished layer. Two different asphalt mix compositions, reference mix according to technical regulations and mix with modification, with a maximum aggregate size of 8 mm were applied under industrial conditions in two layer thicknesses (4.5 cm and 5.5 cm) each. After installation in October 2017, a relatively extensive test programme was carried out, the results of which can be summarised as follows: - The PA variant optimised by sand addition can be produced on an industrial scale. - The properties of the finished layer show that the void content of the sand variant is about 2 % lower by volume. - The resistance to scuffing on laboratory samples, as well as the particle loss show a more favourable behaviour of the variant with sand addition. - An assessment of the acoustic properties leads to the conclusion that a good level of noise reduction would be achieved in the new condition of the porous layer. In conclusion a higher structural service life can be predicted for porous asphalt wearing courses with a defined dosage of sand. These findings are supplemented by good acoustic properties when new. The acoustic service life could not be predicted within the period under investigation.

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1. INTRODUCTION

Porous asphalt (PA) is produced in Germany according to the actual specifications largely without the addition of fine aggregates (≤ 2 mm, hereinafter referred to as “sand” for linguistic simplification). This method enables the required high void content of at least 22 Vol.-% to be achieved in the finished layer.

Within the framework of this project, a modified composition of a PA was to be tested on the new Demonstration, Investigation and Reference Area (duraBASt) of the Federal Highway Research Institute in cooperation with the Road and Transportation Research Association (FGSV) and the construction industry. As part of a laboratory study, a committee of experts from the German Asphalt Association developed proposals for a modified composition of the asphalt mix which should reduce the problems arising from a constructional point of view, such as inadequate structural service life and process safety. This modified asphalt mix concept with a deliberate dosage of 5 % sand was to be tested in practice on the duraBASt. Two different asphalt mix compositions (reference according to specifications and the modified mix) with a maximum aggregate size of 8 mm were used under industrial conditions, each in two layer thicknesses.

The aim of the project was to test the accuracy of the production process (addition of sand) and the behaviour of the optimised asphalt mix during paving. The resulting properties of the finished layer had to be recorded and analysed.

2. VOID CONTENT AND VOID STRUCTURE

The high noise-reducing effect of PA surface layers is mainly made possible by the absorption of sound waves in a void structure. It must be ensured that as large a part as possible is accessible. Although the parameter void content allows an indirect assessment of the acoustic behaviour, it says nothing about the accessibility of the void structure. The first systematic investigations of PA surface layers from 1986 to 1993 showed that at a void content of 20 Vol.-% the accessible void content is approx. 2 Vol.-% lower. At a void content of 25 Vol.-%, the accessible void content is at a similar level [1].

Subsequent investigations again focused on the void structure and carried out flow-mechanical simulations after recording them by means of Computed Tomography (CT) scanning. It turned out that the highly complex structure of voids leads to a relatively low flow velocity when water flows through them [2]. Again, a connected void system is important here. In the event of pollution, they enable the transport of dirt particles through the suction of rolling tyres and thus delay the decrease of the noise reducing properties by clogging of the voids.

The precise observation of the void structure, for example with the aid of CT scans, is not an alternative for routine examinations due to high costs and a small number of laboratories equipped with such devices. In this case, the decisive value is the void content. If the void content of a PA surface layer is sufficiently high, it can be assumed that both good noise reduction and acoustic durability of the layer are guaranteed. For this reason, the minimum value for the layer was set at 22.0 Vol.-% according to the German guidelines.

3. LARGE SCALE TEST ON THE DURABAST AREA

For testing the two asphalt mix concepts, two lanes were used on the duraBASt, each 100 m long and 3.9 m wide. By varying the thickness, a total of 4 test sections, each 50 m long, were available (Table 1 and Figure 1).

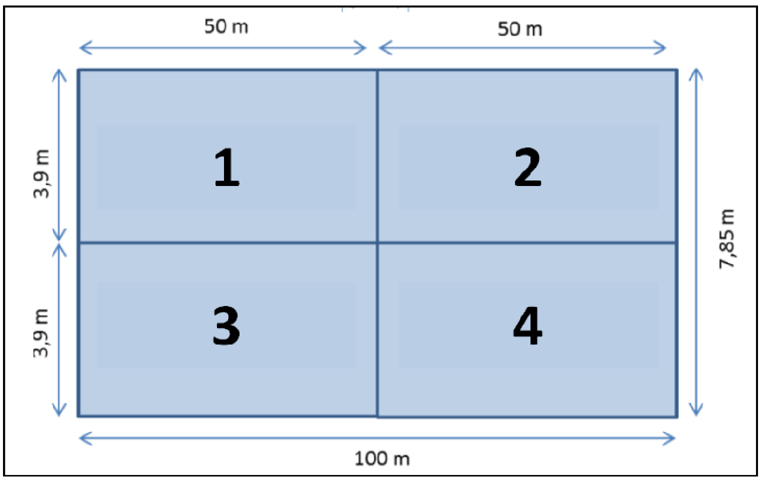


Figure 1: Layout and designation of the test sections on the duraBASt area

Table 1: Designation of the test sections

Mixture	Designation [Section Nr.]	Layer Thickness [cm]
PA8 **without** addition of sand	1	4.5
	2	5.5
PA8 **with** addition of sand	3	4.5
	4	5.5

The construction of the test sections took place on October 6th 2017. After relatively good initial weather conditions, precipitation started around noon, so that the sections with addition of sand were installed under less favourable conditions. However, the asphalt mix temperatures of this variant were significantly higher. The disadvantage could be compensated at least up to a certain point. Overall, the temperatures of the asphalt mix were within the permissible range of the German guidelines from 140 °C to 170 °C. Samples of the asphalt mix were taken in the middle of the respective test sections. Core samples were later drilled at these locations.

4. INVESTIGATION PROGRAMME

During the conception of the test program, an attempt was made not only to determine the asphalt-technological parameters but also to assess the performance of the finished layer with regard to durability and noise reduction. The following investigations were carried out:

- parameters asphalt mix (binder content, softening point ring and ball, grading, void content)
- parameters finished layer (void content, degree of compaction)
- resistance to scuffing according to CEN/TS 12697-50
- particle loss according to EN 12697-17
- surface texture 3-dimensional (structured light scanning)
- sound absorption coefficient according to EN ISO 10534-2,
- noise level with the close-proximity method according to EN ISO 11819-2

5. RESULTS

5.1. Asphalt Mixture

The parameters of the asphalt mixtures are compared in Table 2 with the values from the initial type testing. It is evident that the asphalt mix formulations were adhered to very well. Both the aggregate composition and the binder content deviate only slightly from the specifications of the initial tests and are clearly within the tolerances of the German guidelines.

Table 2: Test results asphalt mix

Parameters asphalt mixture	Section 1	Section 2	type testing	Section 3	Section 4	type testing
	without addition of sand			with addition of sand		
Binder content [%]	6.5	6.4	6.2	6.3	6.4	6.4
Softening point RB [°C]	73.4	73.9	70.3	73.4	76.8	70.3
Coarse aggregates [%]	93,9	93.9	93.8	89.4	90.1	90.2
Fine aggregates [%]	0.7	0.8	1.4	5.1	4.7	5.2
Filler [%]	5.4	5.2	4.8	5.5	5.2	4.6
Maximum density [g/cm^3]	2.538	2.576	2.557	2.554	2.567	2.533
Bulk density [1] [g/cm^3]	1.963	1.966	1.905	2.042	2.046	1.968
Void content [1] [Vol.-%]	22.7	23.7	25.5	20.0	20.3	22.3

1) Marshall specimen

Deviations from the values of the respective type testing can be seen in the void content. Differences between the laboratory mixes and the asphalt mix samples can be seen here. In the case of the latter, significantly higher bulk densities of the Marshall specimen were found, which has a direct effect on the void content in the form of lower values. Taking into account the tolerances according to the German guidelines, values of at least 21.0 Vol.-% would be tolerable here, which is fulfilled by the variant without sand addition. As expected, the variant with sand addition is considerably denser with approx. 20 Vol.-%.

5.2. Finished PA surface layer

From the finished layer, two cores were taken from each test section. The PA layer was separated and the bulk densities were determined in accordance with EN 12697-6, Procedure D (bulk density by dimensions).

Table 3: Test results core samples finished layer

Parameters core sample	Section 1 Core 1	Section 1 Core 2	Section 2 Core 1	Section 2 Core 2	Section 3 Core 1	Section 3 Core 2	Section 4 Core 1	Section 4 Core 2
	without addition of sand				with addition of sand			
Height specimen [cm]	4.3	4.3	5.2	4.9	4.2	4.1	4.9	4.6
Bulk density [g/cm^3]	1.913	1.942	1.922	1.925	1.991	1.971	1.965	1.965
Void content [Vol.-%]	24.6	23.5	25.4	25.3	22.0	22.8	23.5	23.4
Mean void content [Vol.-%]	24.1		25.3		22.4		23.5	
Degree of compaction [%]	98.2		97.9		97.0		96.1	

As Table 3 shows, the variant with sand addition is also denser in the finished layer and achieves about 2 Vol.-% lower void contents. In the case of the degree of compaction, a lower level was achieved in the variant with sand addition, possibly due to the incipient rain. Here the thicker section with 5.5 cm fell below the minimum compaction level of 97.0 %. There are indications that somewhat more compaction would have been necessary in the sections with the greater layer thickness in order to complete the rearrangement of the aggregates. This may also be due to the short sections of 50 m each, which makes the use of the rollers difficult.

5.3. Resistance to scuffing

The resistance to scuffing with the Darmstadt Scuffing Device (DSD) according to EN/TS 12697-50 simulates the steering process of a slowly rolling passenger car on a warm day, comparable to parking with slow manoeuvring. The method was chosen in this study in order to identify a possible better resistance to scuffing of the variant with sand addition.

During the test, a test tyre (go-kart tyre) with a force of 1 kN is pressed onto the surface to be tested (26 cm x 26 cm). This is moved back and forth with a table and oscillated by 180°. The material loss is determined after two of these double shear load cycles. The test is usually completed after 10 cycles.

The tests were carried out on the one hand on laboratory test specimen obtained from slabs using a steel roller sector compaction device and on the other hand on cores Ø 225 mm which had been plastered into the basic form with the necessary dimensions of 26 cm x 26 cm. The two asphalt mix variants were only tested for a thickness of 5.5 cm. The Technical University of Darmstadt was commissioned to carry out the tests.

Table 4: Resistance to scuffing (DSD), material loss, mean value of 2 specimen

Section	Material loss Laboratory specimen [g]	Material loss Core samples [g]
2 (without sand)	96	152
4 (with sand)	84	170

When comparing the results (Table 4), the different measurement levels between the laboratory specimens and the cores are noticeable. In general, the test method shows a relatively high dependence on the degree of compaction of the specimens [3]. This seems to be reflected in the results of the higher compacted laboratory plates. In each case, a degree of compaction of 100 % is aimed for, whereas in the finished layer only 97.9 % (without sand addition) and 96.1 % (with sand addition) were achieved.

The answer to the question of the resistance to scuffing cannot be conclusively answered. The level of the two variants is too similar and the number of samples too low. The variant with sand addition tends to show a slightly more favourable behaviour with less material loss, at least in the laboratory samples.

5.4. Particle loss according to EN 12697-17

In this test method, Marshall specimen are subjected to mechanical stress in the drum of the Los Angeles test device and the particle loss PL is determined. The values are shown in Table 5. The variant with sand addition shows good behaviour with an average PL of 10 %. The value for the variant without sand is twice as high with an average PL of 21 %. The addition of sand seems to lead to an increase in the strength of the microstructure.

Table 5: Particle loss, mean value of 5 specimen

PA mixture	Particle loss PL [g]
without sand	21
with sand	10

5.5. Surface texture

The measurement of the surface texture is an important parameter for the assessment of the effectiveness of noise reducing asphalt surface layers, especially of dense or semi dense road surfaces. For PA, the texture influence is superimposed by the sound absorption, i.e. it is the dominant parameter for reducing tyre/road noise.

In order to compare the variants used here in this project, the surface texture was nevertheless included in the investigation programme in order to be able to detect possible changes in the structure of the surface due to the addition of sand.

A linear measuring system is usually used to measure the surface texture, which scans the surface by means of triangulation laser technology and determines the roughness wavelengths and roughness depths. In this investigation, a measuring system was chosen which scans the surface three-dimensionally and thus represents changes in the structure, in addition to the texture characteristics, also visually.

The basic principle of structured light scanning is that geometric light strip patterns are projected onto the surface to be examined and the resulting optical distortion of the light strips is precisely determined. From this distortion the height image of the object to be measured is calculated as a result.

Table 6 shows the following selected parameters of the surface texture:

- **MPD** (Mean Profile Depth)
- **ETD** (Estimated Texture Depth): Can be compared to a texture depth volumetrically determined with the sand patch method. PA shows high values outside the acoustically favourable value range of 0.4 mm to 0.8 mm [4].
- **A_{max}** (maximum amplitude of the wavelength spectrum): At the measuring points listed here, this occurs predominantly at a wavelength of 16 mm and 25 mm.
- **g** (Shape Factor): Bearing area curve value according to Abbott at half profile depth. Rolled asphalts, and thus also PA, have concave textures with several adjacent plateaus of coarse aggregates interrupted by depressions. The values are mostly around 80 %.

Table 6: Selected parameters of the surface texture (mean value of 3 measurements per section)

PA mixture	Section	MPD [mm]	ETD [mm]	A_{max} [mm]	g [%]
without sand	1	1.350	1.280	0.302	81.4
	2	1.176	1.141	0.290	82.9
with sand	3	1.506	1.405	0.394	83.2
	4	1.322	1.257	0.331	82.9

All values are at a level that can be expected for an asphalt mix PA 8. There are smaller differences between the variants in the texture depths MPD and ETD, but also in the maximum amplitude A_{max}. The variants with sand addition show slightly larger values, which indicates differences in the rearrangement of the aggregates and may be due to the somewhat poorer compaction of the two sections. There are also slight differences in the layer thicknesses. The thicker variants with 5.5 cm (section 2 and 4) have slightly lower texture depths. The greater layer thickness may lead to slight differences in the rearrangement of the aggregates.

Figure 2 shows an example of the surface image of two measuring points with and without sand addition. They have similar texture characteristics. The sand addition is not visually recognizable.

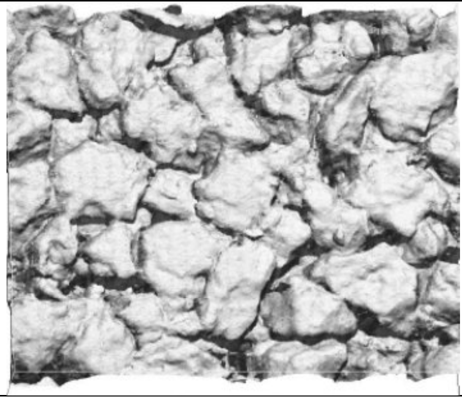
Without addition of sand (section 2)	With addition of sand (section 4)
	
Texture parameters	
MPD: 1.277 mm ETD: 1.221 mm A_{max}: 0.309 mm g: 82.2 %	MPD: 1.344 mm ETD: 1.275 mm A_{max}: 0.302 mm g: 82.6 %

Figure 2: Surface texture at selected measuring points with comparable texture parameters

5.6. Sound absorption coefficient in the laboratory

The measurement of the sound absorption coefficient in the laboratory is one way of estimating the noise-reducing effect of the finished PA layer. A sample Ø 100 mm in Kundt's pipe according to EN ISO 10534-2 is measured for this purpose. The height of the sound absorption coefficient determined depends on the dimension of the voids accessible from the outside. The position of the maximum in the frequency spectrum, on the other hand, is determined by the thickness of the layer. Usual layer thicknesses of 4.5 cm lead to a position of the maximum at about 1,000 Hz. As a result, the higher-frequency noises of passenger cars can be absorbed well. Larger layer thicknesses lead to a shift in the position of the maximum to lower frequencies, which is advantageous for the absorption of truck noise.

The investigation program carried out in this study distinguishes between two different samples. On the one hand, they were obtained from a steel roller sector compaction device in the laboratory, and on the other hand from cores (Ø 100 mm) out of the finished layer. The latter were drilled out from cores Ø 150 mm.

Table 7: Sound absorption coefficient, laboratory specimen

Section/ specimen	Thickness specimen [cm]	Void content [Vol.-%]	Bulk density [g/cm^3]	Frequency [Hz]	Sound absorption [%]	mean value [%]
1/1	4.5	22.4	1.970	1010	97	93
1/2	4.5	22.8	1.960	1010	88	
2/1	5.5	23.3	1.976	630	72	77
2/2	5.5	23.3	1.977	620	81	
3/1	4.5	20.0	2.044	900	86	77
3/2	4.6	20.0	2.042	890	67	
4/1	5.6	22.3	1.994	750	74	71
4/2	5.7	21.2	2.024	640	67	

A comparison of the characteristic values of the laboratory samples (Table 7) confirms the correlation between the frequency position of the maximum of sound absorption and the layer thickness, or in this case the specimen height. The values of the sound absorption coefficient show a dependency on the specimen height and the sand content. The increase of the specimen height by 1 cm causes a decrease of the absorption coefficient by about 15 %. The decrease is of a similar order of magnitude when sand is added. Starting with a very good mean value of 93 % (without sand; 4.5 cm), the degree of absorption decreases to up to 71 % (with sand; 5.5 cm). The difference in the asphalt mix variants can be explained by the lower void content of about 2 Vol.-%. The difference in the two layer thicknesses is more difficult to analyse. It is possible that the greater thickness in the production of the plates in the laboratory causes a change in the rearrangement of the coarse aggregates, which leads to an at least partially inaccessible structure of the voids.

The correlations are less pronounced when comparing the characteristic values of the in-situ specimen (cores) (Table 8). The separation of the PA layer from the core reduces the differences in thickness to some extent and the frequency position of the maximum is less clear.

Table 8: Sound absorption coefficient, in-situ specimen

Section/ specimen	Thickness specimen [cm]	Void content [Vol.-%]	Frequency [Hz]	Sound absorption [%]	mean value [%]
1/1	4.2	24.6	885	91	91
1/2	4.1	23.5	1040	91	
2/1	4.9	25.4	890	85	88
2/2	5.0	25.3	850	91	
3/1	4.5	22.0	870	89	90
3/2	4.5	22.8	870	91	
4/1	5.0	23.5	810	81	82
4/2	5.1	23.4	790	83	

If only the mix variants are considered, neglecting the specimen height (layer thickness), there is a difference in the mean sound absorption coefficient of 10 % for the laboratory specimen and only 4 % for the in-situ specimen (Table 9).

Table 9: Sound absorption coefficient, mean values depending on mixture

PA mixture	Laboratory specimen [%]	In-situ specimen [%]
without sand	84	90
with sand	74	86

5.7. Noise level with the close-proximity method

The Close Proximity Method (CPX) according to EN ISO 11819-2 is particularly suitable for measuring the homogeneity of a pavement with regard to its acoustic properties or for carrying out relative investigations of different sections or lanes.

The measurement is carried out with two different tyres, a car-like tyre P1 and a truck-like tyre H1 with regard to profile, not dimensions. The results are averaged on the considered section and displayed with standard deviation. The standard deviation is a measure of the acoustic and thus also structural homogeneity of a surface.

Only the tyre P1 was used for the measurement on the duraBASt. Basically, it should be noted that the section lengths of the PA sections of 50 m represent the lower limit for a meaningful evaluation of the measured values, since only one value is output per 20 m interval. Furthermore, the boundary conditions of the duraBASt only allowed a measuring speed of 50 km/h. Section 1 (without sand addition; 4.5 cm thickness) was not measurable due to necessary braking processes and was replaced by a measurement of a similar test section on the duraBASt, which was constructed at the same time and with the same mixture. This test section is used for calibrating processes and is called Field 39.

Table 10: Close Proximity noise measurement (CPX), mean value CPXP left and right tyre, standard deviation S_{CPXP}

PA mixture	Section	CPXP [dB(A)]	S_{CPXP} [dB(A)]
without sand	Field 39 (substitute for section 1)	89.3	0.3
	2	87.9	0.4
with sand	3	89.2	0.0
	4	87.7	0.3

The measured values show no differences in the levels of the two asphalt mix variants (Table 10). The respective very small differences are negligible. The standard deviations of less than 0.5 dB(A) indicate homogeneous sections. However, differences can be seen in the layer thicknesses. The thicker sections of both variants with a layer thickness of 5.5 cm are about 1.5 dB(A) quieter. The third-octave spectra indicate a more broadband absorption with individual levels with up to 5 dB(A) lower in the frequency range from 630 Hz to 1250 Hz (Figure 3).

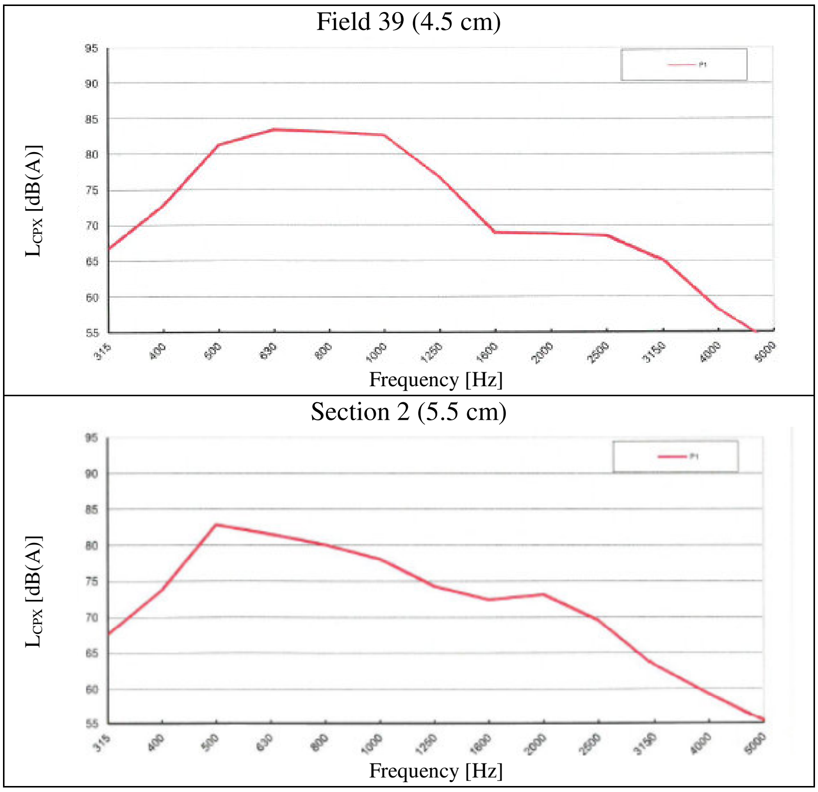


Figure 3: CPX noise measurement, third-octave spectra

6. CONCLUSIONS

Within the framework of this project, a modified composition of a PA was tested on the duraBASt, the new Demonstration, Investigation and Reference Area of the Federal Highway Research Institute. After construction in October 2017, a relatively extensive investigation programme was carried out. The results can be summarised as follows:

- The PA variant with sand addition can be produced on a large scale. The asphalt mix formulation could be maintained well.
- The asphalt-technological characteristics of the finished layer show that the void content of the variant with added sand is about 2 Vol.-% lower. This was to be expected from the previous laboratory examination.
- The resistance to scuffing according to CEN/TS 12697-50 and the particle loss according to EN 12697-17 show a more favourable behaviour of the variant with sand addition. On the basis of these laboratory tests, a longer structural service life can be predicted.
- An assessment of the acoustic effectiveness with the aid of the sound absorption coefficient and the close proximity noise level leads to the conclusion that a good noise reduction would be achieved in new condition due to the relatively high void content of both variants. In the laboratory samples, however, the different void contents are recognizable.

Overall, the results allow the conclusion to be drawn that PA asphalt surface layers with good acoustic behaviour when new can be built if the sand addition is precisely adhered to. Laboratory tests have predicted that this asphalt mix variant will have a higher service life than the variant without sand addition. The acoustic service life could not be predicted within the framework of the project.

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REFERENCES

[1] Projektgruppe „Lärmmindernde Straßendecken“, Offenporige Asphaltdeckschichten auf Außerortsstraßen, Berichte der Bundesanstalt für Straßenwesen, Heft S12, Bergisch Gladbach, 1996, ISBN 3-89429-684-4 (in German)

[2] Projektgruppe „Leiser Straßenverkehr 2“, Verbundprojekt „Leiser Straßenverkehr 2“, Reduzierte Reifen-Fahrbahn-Geräusche (Project “Quiet Road Traffic 2“), Berichte der Bundesanstalt für Straßenwesen, Heft S74, Bergisch Gladbach, Germany, 2012, https://bast.opus.hbz-nrw.de/files/547/S74.pdf, ISBN 078-3-86918-183-7 (in German)

[3] Blumenfeld, T. et al., Die Entwicklung eines Prüfverfahrens zur Beurteilung des Widerstandes von Asphalt-deckschichten gegen Schubbeanspruchungen an der Oberfläche mit der Oberflächen-Verschleiß-Prüfmaschine (OVPM), Straße und Autobahn, Heft 1, 2017, Seiten 13-25 (in German)

[4] Müller, I., Untersuchung der Messunsicherheit und der Klassifizierungsfähigkeit von Straßenbelägen, Berichte der Bundesanstalt für Straßenwesen, Heft S69, Bergisch Gladbach, 2011, https://bast.opus.hbz-nrw.de/files/546/S69.pdf (in German)