# INNOVATIVE DENSE-GRADED ASPHALT FOR SUSTAINABLE MITIGATION OF NOISE POLLUTION ON URBAN ROADS

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## ABSTRACT

*The available experiences in Germany with noise optimized asphalt mix (coarse grain size of < 5 mm) show that this material is suitable for noise mitigation up to -4 dB(A) of urban roads with traffic speed between 40 to 60 km/h. But, this asphalt does not provide long lifetime and cause high maintenance costs. Hence, in this study 8 different noise optimized asphalt mixes have been produced and investigated in accordance of lifetime and noise mitigation. Therefore resistance against rutting and noise reduction by means of acoustic absorption and surface texture measurement with static T3D-Measurement have been carried out. The gained test results show, that the lifetime of low noise asphalt by means of design optimization can be significantly improved. To verify the laboratory tests two different projects have been realized. Thereby the most economic and the technical best variants have been selected. The optimized variant shows a sufficient rutting resistance and a noise mitigation up to -4 dB(A). The technical best variants with rubber modified asphalt confirms the laboratory test results of rutting resistance and noise mitigation (up to -6 dB(A)) on a highly trafficked urban road of City of Cologne.*

**Keywords:** noise mitigation, urban road, dense graded asphalt, rubber modified bitumen, noise absorption

## 1. INTRODUCTION

In a statistical survey, carried out in Germany in Year 2010, 55 % of respondents felt affected by road traffic. According to a numerical modulation of German Government, it is to suspect that around 12 million inhabitants are suffering by health disease caused by noise pollution [1]. It is not a local problem of Germany, even it is an important environmental problem thoroughly European Union. As consequence, to impact mitigation of noise pollution, the European Union adopted the Directive 2002/49/EC.

The noise pollution affects significantly the quality of urban life and wellness by means of direct and indirect effect of the health. The noise pollution in urban is mostly caused by several transportation systems: motor vehicle, aircraft and railway. In this study the roadway noise pollution will be discussed.The amounts of roadway noise are depending on automobile type: aerodynamic of vehicle, engine size, tyre and design of roads. For roadway noise mitigation, a lot of methods are available. The noise barriers are the most effective method, but it is not always possible to apply. The environmental friendly solution is the speed control, but it is not vehicle users' friendly solution. Thus, effective methods for mitigation of noise pollution should be developed for reducing the noise at sources.

In this study, the mitigation of noise pollution by means of road material design will be discussed. In Germany, a lot of different types of noise optimised asphalt mix designs are available, but in common this asphalt pavement show low life time and high maintenance. Accordingly, the target of this study is development of adequate asphalt pavement for sustainable mitigation of noise pollution with long lifetime and low maintenance costs. Therefore, different noise optimised asphalt mixes have been produced in the laboratory and the resistance against permanent deformation, sound absorption and texture characteristics of asphalt surface have been determined.

## 2. ASPHALT MIX DESIGN

In common, the open graded, porous asphalt pavement with air voids around 25 % by volume can be considered as quieter pavement. The high amount of air voids in compacted asphalt absorbs the sound waves. But, the use of open graded porous asphalt in urban area shows still significant low effectiveness and cause high maintenance. For example, the road salt used during the winter, reduce the air voids compared to highways because of the missing wake of water by high speed traffic. As consequence the affect of noise mitigation decrease within short lifetime. In addition, the permanent excavation does not promote the drainage. It is also well known, that the porous asphalt does not show high resistance against shear forces, trends rapidly to fretting and ageing. Thus, the porous asphalt is not to recommend for urban roads with inhomogeneous traffic flow, with crossing, light system and curves. Thus, dense graded asphalt with small size of aggregates in combination with thin layer shall be developed.

The most important criterion for rehabilitation of flexible pavements in urban roads is permanent deformation. In common, the existing dense graded asphalt with small size of aggregates (≤ 5 mm) does not show sufficient resistance against permanent deformation. As consequence, dense graded asphalt with small size of aggregates is not proper to use in heavy loaded urban roads. Thus, the asphalt mix design shall be optimised with respect to improvement of rutting resistance in combination of noise mitigation. Therefore 8 different asphalt wearing course materials with systematically verification of grading and binder have been produced with respect to improve the lifetime, see Table 1 and Figure 1. In the Table 1 the binder used and the gained volumetric properties of asphalt mixes used can be taken.

### 2.1 Asphalt Wearing Course Mix

In this study three different types of asphalt wearing course mixes have been used, see figure 1. Thereby the binder used have been systematically varied to improve the rutting resistance, see Table 1. The variant 1 (SMA) is the mostly applied variant as asphalt wearing course for heavy loaded asphalt in urban area. It can be designated as conventional variant. The variant 2 has the similar grading like the variant 1, but an additive Polyolefine has been added. This additive improves the noise mitigation. The variants 3 (LOA 5 D) is a noise optimised innovative dense asphalt variant. The variants 4 – 7 have similar grading like the variant 3, but the binders used have been systematically varied. The variant 3 with a binder 50/70+ additive (Plastomere based on polyethylene-copolymere) has been placed in several projects in last three years. A long term experience for this asphalt mix is not available. But the first experience with respect to noise mitigation show certain noise mitigation. Due to, in this study the effectivity of the noise mitigation of the variant 3 shall be investigated compared to other asphalt wearing course. The variant 8 is standardised conventional asphalt for thin layer (< 20 mm) in Germany. In common, this variant will be used during the maintenance works to improve the surface characteristics. For this asphalt sufficient experiences are availabe. It is well known that this variant cause a significant reduction of noise pollution, but the lifetime is short and causes a lot of maintenance compared to conventional asphalt wearing course like SMA. The volumetric properties of asphalt wearing course used are summarised in Table 1.

- Stone mastics asphalt with aggregate size of maximum 8 mm: SMA 8 S
- Noise optimised asphalt concrete with aggregate size of maximum 5 mm. LOA 5D

Asphalt concrete for thin layer (≤ 2.0 cm) on sealing of bitumen emulsion: DSH-V

**Table 1: Composition of Asphalt Mix accordingly Marshall Method**

| **Variant** | **Mix Type** | **Binder / Bitumen** | **Volumetric Properties of Asphalt Mix accordingly Marshall Method** |
|---|---|---|---|
| **Asphalt Wearing Course Mix** | | | |
| **1** | SMA 8S | 25/55-55 | Binder content (B): 7.0 % by weight<br>Air voids (Vm): 2.8 % by Vol<br>Voids in Mineral Aggregates (VMA): 20.2 %<br>Voids filled with binder (VFA): 86 % |
| **2** | | 25/55-55 + Polyolefine | |
| **3** | LOA 5D | 50/70 + Plastomere based on polyethylen-copolymere | B: 5.5 % by weight<br>Vm: 6.8 % by Vol<br>VMA: 20.0 %<br>VFA: 66.3 % |
| **4** | | Grumb rubber modified bitumen (CRB) | |
| **5** | | 50/70+ Fischer-Tropsch synthetic wax | |
| **6** | | High polymer modified special bitumen (PmB 25H) | |
| **7** | | 50/70 | |
| **8** | DSH-V | PmB 45/80-50 | B: 6.4 % by weight; Vm: 5.2 % by Vol<br>VMA: 21.1 %; VFA: 75.3 % |
| **Asphalt Binder Course Mix** | | | |
| **A** | Deustab 0/22 | Nypave 30W | B: 4.5 % by weight; Vm: 6.8 % by Vol<br>VMA: 18.1 %; VFA: 62.5 % |
| **B** | AC 22 BS | 30/45 | B: 4.4 % by weight; Vm: 4.4 % by Vol<br>VMA: 15.5 %; VFA: 71.5 % |
| **B2** | AC 16 B-HSF | 30/45 | B: 5.0 % by weight; Vm: 6.1 % by Vol<br>VMA: 18.3 %; VFA: 66.5 % |

## 2.2 Asphalt Binder Course Mix

It is also well known among the experts that permanent deformation on wearing course will be mostly caused by the binder course. Thus, to minimize the rut depth on surface of pavement, it is important to design an asphalt binder course mix with high resistance against permanent deformation. In this study, three different asphalt binder course mixes with high resistance against permanent deformation have been tested in the preliminary stage and finally the asphalt binder variant with high resistance against rutting shall be considered for further investigation; see Table 1 and Figure 2.

Thereby the binder used has been selected with respect to experience gathered till now for respective binder mix. The volumetric properties are summarised in Table 1.

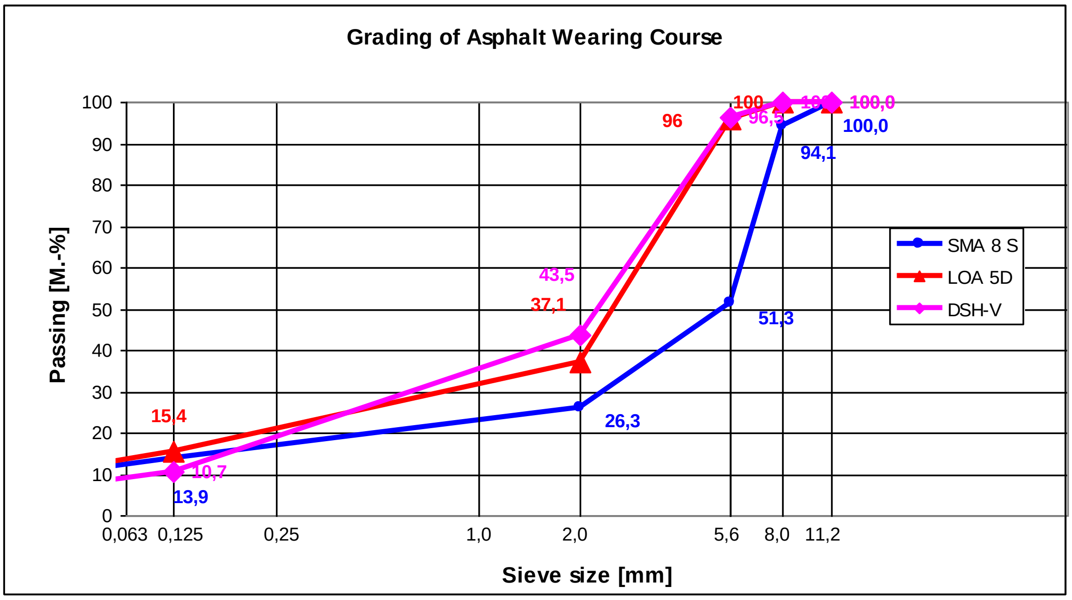

Figure 1: Grading of Asphalt Wearing Course

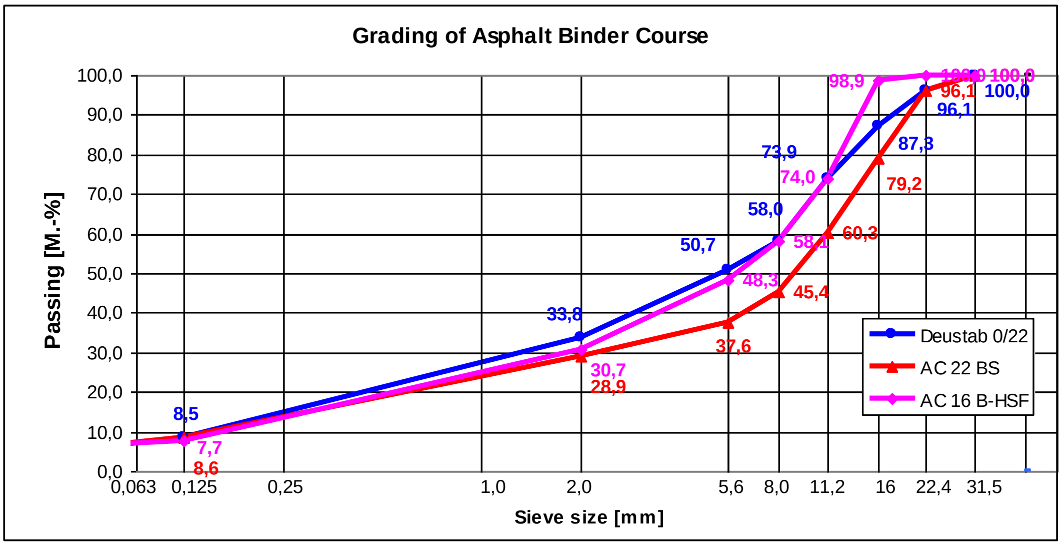

Figure 2: Grading of Asphalt Binder Course

## 3. LABORATORY TESTS

### 3.1 Binder Properties

Totally, nine different binders have been used. Thereby the application of binder for respective asphalt mixes take place on the one hand with respect to the German Standard and on the other hand with respect to the required performance properties. The determined test results of bitumen properties by means of softening point ring and ball (SP R&B, EN 1427, 2007), needle penetration (penetration, EN 1426, 2007) and elastic recovery (EN 13398) with respect to European Standard are listed in the figure 3. In common the gained test results of conventional binders are in the permissible range of EN 12591 and the polymer modified binders in the permissible range of EN 14023. The polymer modified binder PmB 25H shows the highest SP R&B and the lowest penetration values as well as a high elastic recovery. The

CRB show also a high SP R&B and elastic recovery in combination with a high penetration values. As expected the addition of additive Plastomere and Wax increase also the SP R&B and decrease the penetration.

High softening point R&B indicates a high viscosity. Low penetration value cause in common a high stiffness. Due to stiff asphalt variants with high viscosity and stiffness will show high resistance against permanent deformation. Asphalt mixtures with a soft binder (low softening point R&B and a high needle penetration value) will cause a relatively high rutting compared to asphalt mixtures with a stiff binder, if identical aggregate structures were used. Furthermore asphalt with a high elastic recovery will affect the rutting resistance positively. The elastic properties of binders can reform the displacements after load removal.

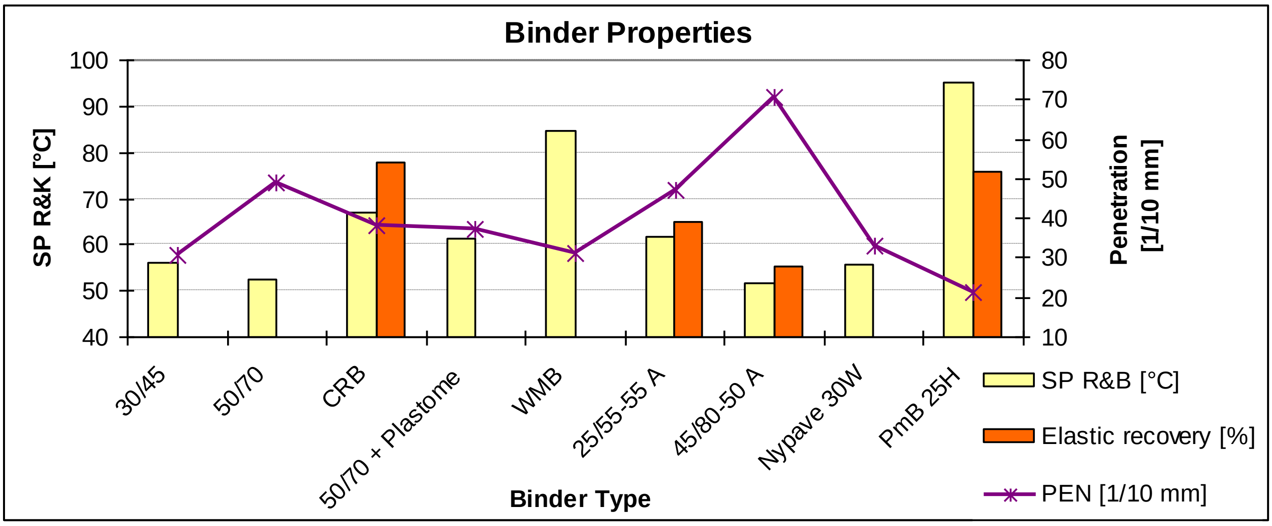

**Figure 3: Properties of binder used**

### 3.2 Wheel Tracking Test (WTT)

One of the most important deterioration of flexible pavements is rutting and this is the main criteria for a lot of maintenance works in urban area. Worldwide, there exist numerous test methods and mixture response parameters to characterize rutting. In this work the resistance against rutting was determined by means of the wheel-tracking test after the European Standard Standards [EN 12697-22].

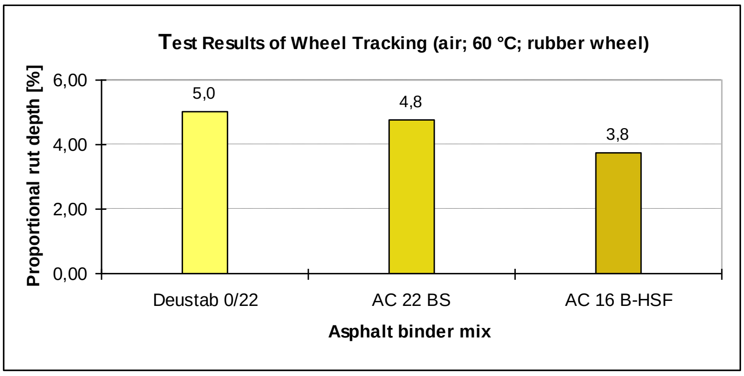

**Figure 4: Composite slabs made of asphalt wearing course and asphalt binder course material**

**Figure 5: Test Result of Wheel Tracking Test (Asphalt binder mix)**

Rutting is mostly formed within surface and binder courses. Thus, the rutting resistance for the both layer shall be determined. Therefore, in this study the rutttng tests were done on composite samples made of asphalt wearing course material and asphalt binder course material. Adequate in situ the asphalt slabs with asphalt binder course material (6 cm thickness) has been produced by means of roller compactor (EN 12697-33, 2007) as first. On the binder course slab

after applying the bitumen emulsion, the wearing course material (4 cm thickness for material with aggregates size ≤ 8 mm; 2.5 cm thickness for material with aggregates size ≤ 5 mm) has been placed and compacted [Figure 4].
Test results of wheel tracking tests for asphalt binder mixes are displayed in figure 5. The variant AC 16 B-HSF show the lowest rut depth compared to other variants of asphalt binder mixes and can be designed as rutting resistance asphalts. Due to, this asphalt will be used for production of the composite slabs.

The gained test results of composite slabs are displayed in Figure 6. In common, the gained rut depths of modified asphalts can be considered similar and indicates on high resistance against rutting. As expected, the variant LOA PmB 25H highlights the lowest rut depth and the variants SMA Polyolefine and LOA CRB show the next lowest rut depth.

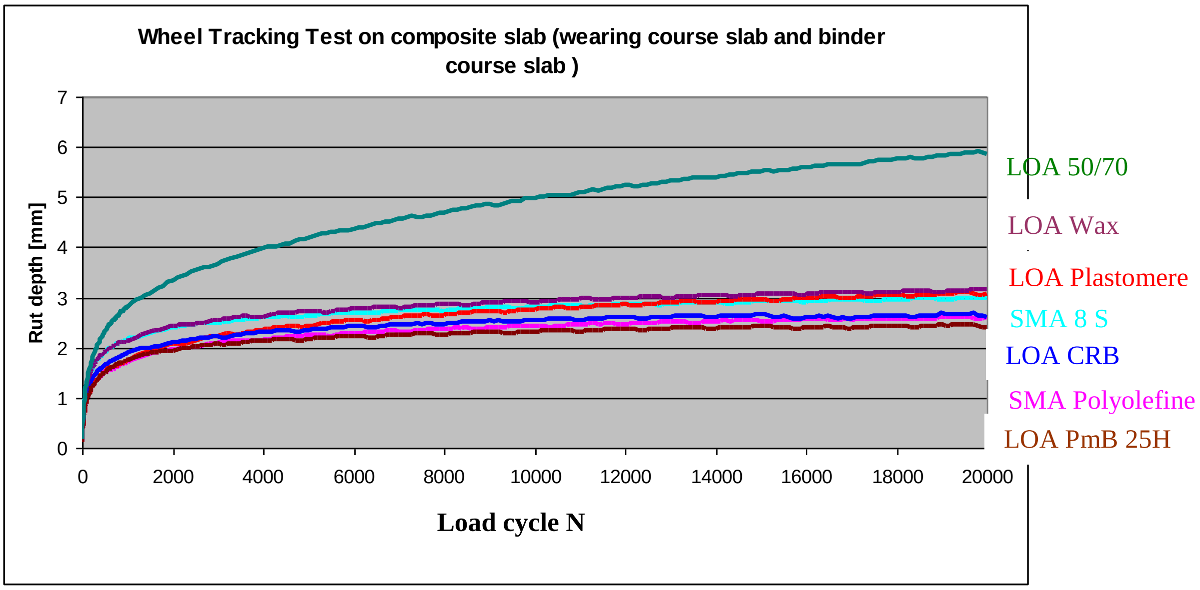

**Figure 6: Test Results of Wheel Tracking Test on Composite Slabs**

### 3.2 Determination of Sound Absorption

Sound absorption is that property of asphalt layer that changes the acoustic energy of sound waves into another form. The sound absorption quality is highly dependent of the structure of the surface layer and surface texture. It can be described by means of sound absorption coefficient. The sound absorption coefficient can be determined by means impedance sound tube in the laboratory with respect to ISO Standard ISO 10534. As asphalt samples drill cores from composite slabs for each variant have been used, see Figure 7. In addition, the drill cores have been also sandblasted to simulate the condition during the service time. Samples were tested both before and after sandblasting.

**Figure 7: test methods impedance in impedance tubes (ISO 10534-2:1998)**

The gained test results of impedance tubes setup depending on frequency are listed in the figure 8. The measured sound absorption α vary between 7 %and 22 % of applied sound load. But the trends of gained test results show that the sound absorption might be significantly increase for frequency > 1600. By means of gained test results it can be summarised that the variants with stone mastic asphalt SMA show the lowest sound absorption (< 7 % sound absorption). The variant LOA with crump rubber modified bitumen CRB exhibit the higher sound absorption (sound absorption of 22 %) compared to other variants tested in this study. The variants LOA except the variant with CRB does not show significant effect on sound absorption. The additive Polyolefine does not contribute to mitigate the sound.

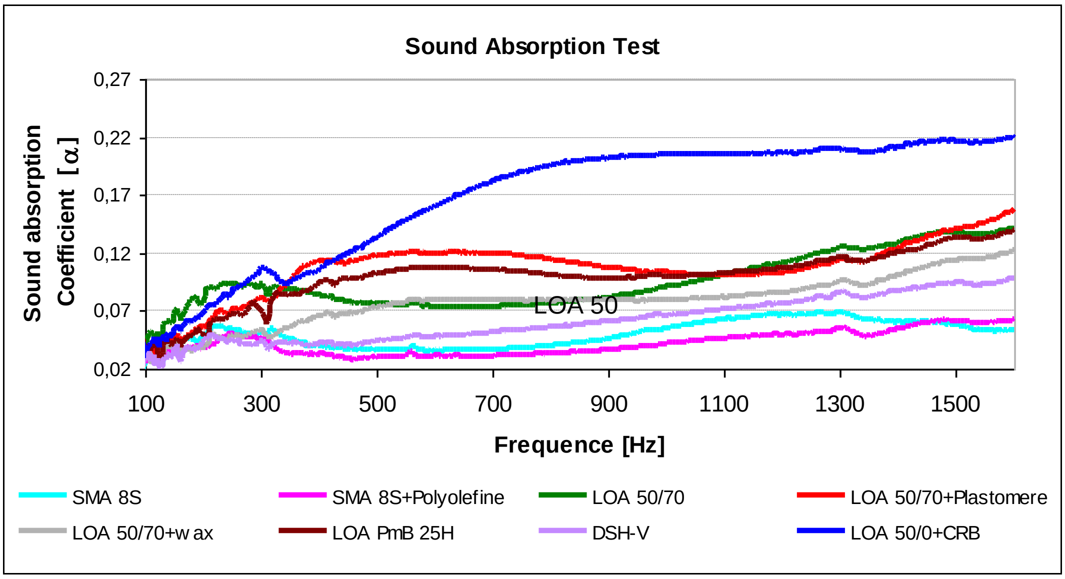

**Figure 8: Test results of impedance tubes depending on Frequenz**

### 3.4 Texture Measurement

The texture of asphalt pavement surface has significant influence on sound initiation, emission and expansion. The surface texture can be divided into micro-,(wavelength λ < 0.5 mm) macro- (wavelength 0.5 < λ < 50 mm) and mega (wavelength 50 < λ < 500 mm) texture range. The range of wave length 0.5 mm < λ < 10 mm is decisive responsible for the development of noise caused by air pumping at high frequency (> 1000 Hz). The noise developed in low frequency (< 100 Hz) in a range of wavelength 10 < λ < 500 mm can be considered as innoxiously.

The texture characteristics of asphalt surface will be influence by surface design (aggregate type used), binder content and volumetric properties. The surface design (g) contributes extremely the noise development. It can be divided into concave surface (plateau with canyon) and convex surface (mountain with valley). By means of texture measurement test results the surface design can be calculated [3]. Surface design between 20 % and 60 % has a convex surface and surface design between 60 % and 90 % has a concave surface design. A dense asphalt pavement with a surface design of > 75 % shows high sound mitigation [4].

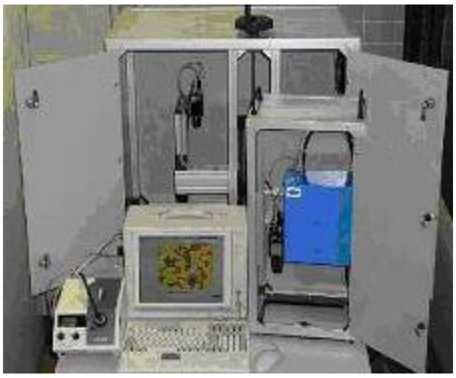

**Figure 9: Static T3D- Measuring System**

In this study, the texture of asphalt surface has been determined by means of static T3D- Measuring system [Figure 9]. It is an automated surface inspection with 3D measurement system based on laser inspection technology and can be used to determine micro- and macro texture of surface. As samples drill cores with 100 mm-diameter has been applied.

### 3.5 Estimated Texture Depth

By means of measured **m**ean **t**exture **d**epth (MTD) the **e**stimated **t**exture **d**epth (ETD = 0.2 mm + 0.8 Mean profile Depth) has been determined. Sufficient skid resistance will be available at ETD of > 0.4 mm. But for an effectively noise reduction an ETD between 0.4 mm and 0.8 mm is necessary [4]. The calculated ETDs for the asphalt used in this study are displayed in Figure 10. The determined test results range between 0.66 mm and 1.437 mm and meet the requirements accordingly to skid resistance. ETD for SMA range significantly out of the requirements for noise optimised asphalt. The ETD of noise optimised asphalt is within requirement, although the variants LOA Wax and Plastomere lightly exceed the border value of 0.8 mm, see Figure 10.

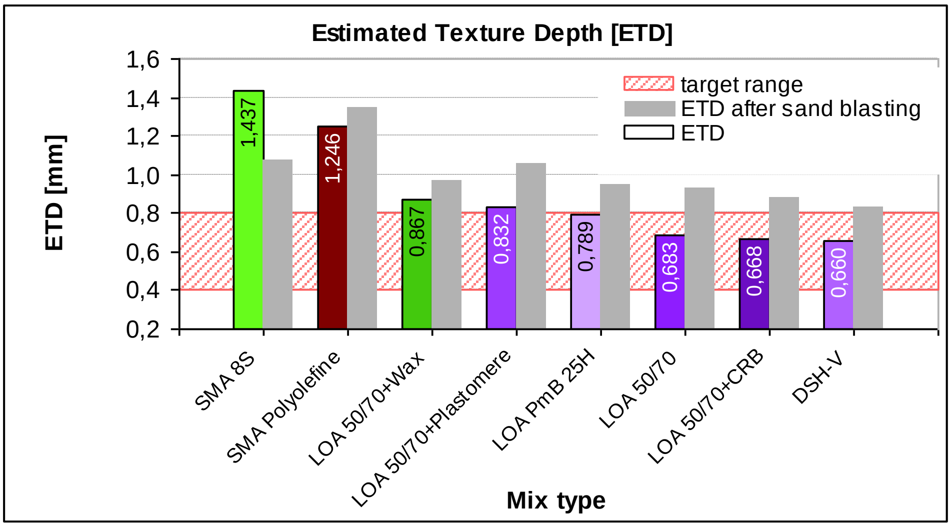

**Figure 10: Estimated Texture Depth**

### 3.6 Surface Design Factor (g )

The calculated surface design factor [g] by means of measured texture depth will be displayed in Figure 11. The determined surface design factor range between 65.7 % and 85.1 %. Asphalt design used can be designated as concave surface texture. Except the SMA the other variants show a surface design factor of > 75 % and meet the requirements for noise optimised asphalt.

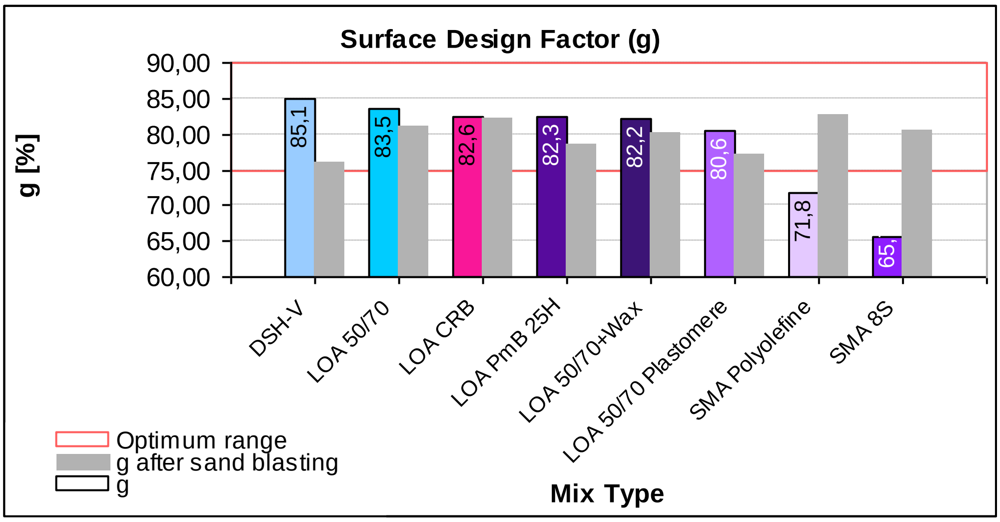

**Figure 11: Surface Design Factor [g]**

## 5 SUMMARY

By means of gained test results, an asphalt variant with high noise mitigation and long lifetime shall be determined for urban area. Therefore a ranging of asphalt variants by means of following marking system has been carried out. Thereby different factor has been considered for respective characteristics accordingly to their impact on lifetime and noise mitigation. So, the highest mark for test results of rutting test and lowest mark for the estimated texture depth has been considered. In addition rutting test result ≤ 3.5 % [Proportional Rut Depth] will be designated as high rutting resistance asphalt and test result > 4.0 % as low rutting resistant asphalt. According to this the high rutting resistance asphalt get the best mark of 1 and the low rutting resistance asphalt variant the poor mark of 3. The similar system has been continuously kept for other characteristics.
The final mark will be calculated for example for SMA 8S as following $\frac{3\times1+2\times2+1\times3+2\times3}{3+2+1+2}=2$

**Table 2:Graduation of Asphalt Characteristics in Marking- Method**

| **Mark** | **Rutting test [%]** | **Absorption [%]** | **ETD [mm]** | **g [%]** |
|---|---|---|---|---|
| 1 | ≤ 3.5 | ≥ 6.0 | 0.4 – 0.8 | ≥ 80 |
| 2 | 3.6 – 4.0 | 4.0 – 5.9 | 0.9 – 1.0 | 75 – 79 |
| 3 | > 4.0 | 0.0 – 3.9 | > 1.0 | < 75 |
| ***Factor:*** | ***3*** | ***2*** | ***1*** | ***2*** |

**Table 3: Determination of Ranging of Noise optimized Asphalt**

| **Variant** | **WTT** | | **Sound Absorption** | | **ETD** | | **g** | | **Final mark** | **Ranging** |
|---|---|---|---|---|---|---|---|---|---|---|
| | Test result | Mark | Test result | Mark | Test result | Mark | Test result | Mark | | |
| **SMA 8S** | 3.0 | 1 | 4.5 | 2 | 1.4 | 3 | 65.7 | 3 | 2.0 | **7** |
| **SMA Polyolefine** | 2.6 | 1 | 3.7 | 3 | 1.2 | 3 | 71.8 | 3 | 2.3 | **8** |
| **LOA CRB** | 2.6 | 2 | 7.9 | 1 | 0.7 | 1 | 82.6 | 1 | 1.4 | **2** |
| **LOA 50/70 Plastomere** | 3.6 | 2 | 8.3 | 1 | 0.8 | 2 | 80.6 | 1 | 1.5 | **4** |
| **LOA 50/70+Wax** | 3.2 | 1 | 5.9 | 2 | 0.9 | 2 | 82.2 | 1 | 1.4 | **2** |
| **LOA PmB 25H** | 2.3 | 1 | 7.8 | 1 | 0.8 | 1 | 82.3 | 1 | 1.0 | **1** |
| **LOA 50/70** | 6.2 | 3 | 7.9 | 1 | 0.7 | 1 | 83.5 | 1 | 1.8 | **6** |
| **DSH-V** | 4.0 | 2 | 4.6 | 2 | 0.7 | 1 | 85.1 | 1 | 1.6 | **5** |

The determined ranging by means of marking system result in, that the variants LOA PmB 25H has long lifetime and the high noise mitigation and range as first one. Followed by variants LOA with innovative crumb rubber modified bitumen CRB and 50/70+Wax can be designated as rang two. The variant LOA 50/70+Plastomere does dot differ much from the variant LOA 50/70+wax and LOA CRB. The variants with SMA have the last range and can not be recommended as noise optimized asphalt in urban area.

## CONSTRUCTION OF NOISE OPTIMIZED ASPHALT

By means of gained range the variants LOA PmB 25A, LOA CRB, LOA 50/70+Wax and LOA 50/70+Plastomere can be recommended as noise optimized asphalt with long lifetime and low maintenance costs. Thereby, the LOA PmB 25H as technical best and LOA CRB and LOA 50/70+Plastomere as the most economics variants can be designated. In 2008 a test track for LOA 50/70+Plastomere has been constructed in the city of Duesseldorf with traffic speed of 50 km/h. The noise measurement show significant noise mitigation. Up to now, this test section show a significance noise mitigation and rutting resistance.

The economical and technical best variant with rubber modified asphalt has been paved in 2010 on highly trafficked road of City of Cologne. The gained test results in site acknowledge the high rutting resistance and show significance improvement of noise mitigation (up to -6 dB(A) by means of CPX-Method), see figure 6 [5].

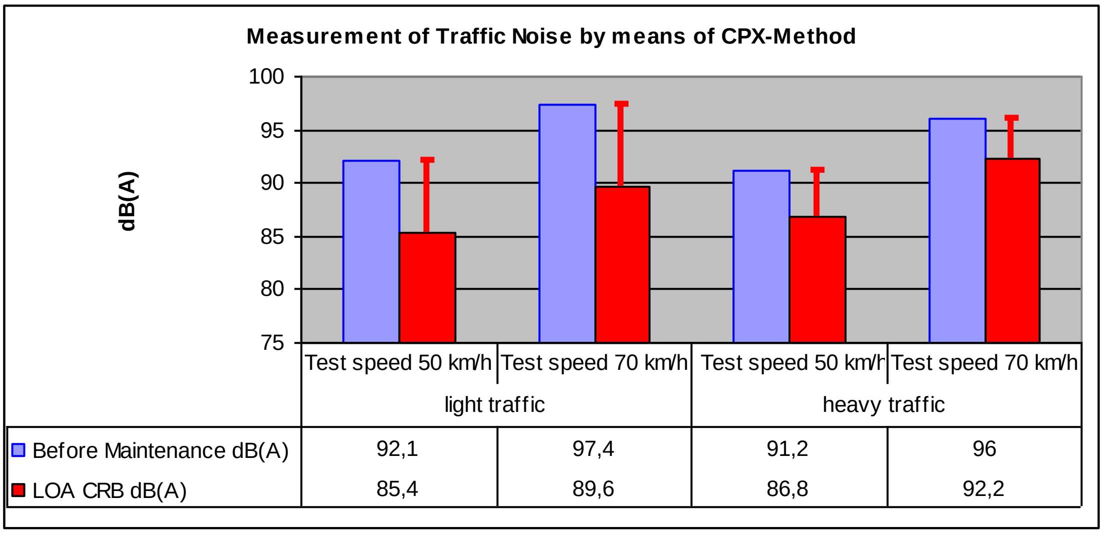

**Figure 11: Test result of Noise Measurement by CPX-Method**

In common the experience of one construction as test field for respective variant is not enough to make a general conclusion or to predict the long term behaviour in combination with laboratory test results. Thus, the long term behaviour with respect to performance and noise mitigation as well as the maintenance work shall be observed to find correlation between laboratory test results and site behaviour.

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