Noise reducing effect of new dense asphalt layers

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ABSTRACT

In recent years new asphalt surface layers have been developed to reduce traffic noise. The noise-optimized asphalt surface layer (AC D LOA) has an adapted surface texture that causes a decreased mature stimulus and permits lateral air displacement. This surface layer is described in the new german technical regulation (E LA D).
The porous mastic asphalt (PMA) is a dense surface layer with a high void surface texture. It combines the advantages of porous asphalts, due to their noise excitation, with the good durability of dense layers. A working paper for its application is in process.
To evaluate the stimulus of tire of different asphalts a three-dimensional measurement of the surface texture is taken. Texture profiles with many peaks cause strong mature stimulus, flat profiles with venting options have a noise reducing effect.
Another noise reducing mechanism is the compliance, which is quantified by the mechanical impedance measured with an impact hammer. The compliance is mostly influenced by the composition of the asphalt (void content), type and amount of bitumen and the test temperature. Low mechanical impedance values indicate a reduction of the tire-road noise.
By these findings the mentioned noise reducing asphalts have been improved.

Keywords: Noise reduction, Surface Texture, Tyre/road noise

This paper respectively this examination is based on parts of the accomplished research project with number FE 02.0360/2012 IRB [1] and title "Development of a material tool for the extension of the noise forecasting method SPERoN 2020" on behalf of the Federal Ministry of Transport and digital Infrastructure represented by the Federal Highway Research Institute (BASt). The sole responsibility for the content lies with the author.

1. INTRODUCTION

The investigation of the impact of noise on humans has shown that exposure to noise can cause diseases [2]. The biggest part of noise pollution in Germany is caused by road traffic. That is why different national research projects in the past dealt with the physical background of noise generation and suitable test methods to define the potential of noise pollution of different surface layers [3] [4] [5].
Against the background of the research results, the first requirements on the texture of the surface could be defined. Based on these requirements new road surfaces that minimize the tire-road-noise were developed. In 2001 the project "LeiStra" (Leiser Straßenverkehr = quiet road traffic) started. Industrial and scientific staff members worked together on solutions for a permanent traffic noise reduction directly at the point of origin of noise generation. Besides new tires, tire casings and different surfaces layers (asphalt and concrete) have been developed and tested. Three joint projects are successfully completed by now, called *LeiStra 1*, *LeiStra 2* and *LeiStra 3*. Within the project *Leistra 3* an existing simulation model, called SPERoN 2020 (**S**tatistical **P**hysical **E**xplanation of **Ro**lling **N**oise), for the determination of tire road noise was extended substantially. Project FE 02.0360/2012 IRB [1] "Development of a material tool for the extension of the noise forecasting method SPERoN 2020" was part of the joint project *LeiStra 3* and was used to extend the database of SPERoN 2020.

2. PROBLEM AND PURPOSE

For the development of new road surfaces, elaborate laboratory test and the construction of demonstrators are necessary, before the actual noise development of the new surfaces can be evaluated. To reduce this effort, new road surfaces should already be evaluated during their conception with regard to its acoustic characteristics.
For the assessment of the acoustic characteristics of an asphalt surface, the texture analysis and the determination of the mechanical impedance are available as laboratory examinations. The texture analysis gives information about the material distribution in the surface area and with it the potential for the reduction of the tire-road-noise, which is achieved by reduced tire vibrations and a diminished air-pumping-effect. The mechanical impedance, which is determined by using an impulse hammer, is a measurement for the compliance respectively the damping of the asphalt surface. Due to the damping a reduction of the tire-road-noise can also be achieved.
Within the project, the dependencies of mechanical impedance and texture values of asphalt surfaces on asphalt technological composition and material characteristics are examined to develop material models for the noise prediction of new low-noise road surfaces for the simulation model SPERoN 2020.

3. EXAMINATION

3.1 Surface texture

The texture of asphalt surfaces affects the noise pollution directly. There are different ways of noise reducing by varying the surface texture. The most noise reducing effect is reached with an open texture full of cavities, which is realized in porous asphalt concepts. Because of the low resistance to shearing forces, these concepts cannot be used inner-city. A useful concept to reduce noise-pollution inner-city is paving asphalt with a concave surface texture. This means that the surface in detail shows plateaus with small gorges. The texture can be described by the shape factor g, which is the value of the material ratio at half the profile depth in the Abbott curve. If g is more than 50 %, the texture is concave and if it is less than 50 %, the texture is convex (Figure 1). By different measurements it has been found, that a shape factor g of asphalt surfaces between 75 % and 85 % results in reduced tire excitation and a lower tire-road-noise.

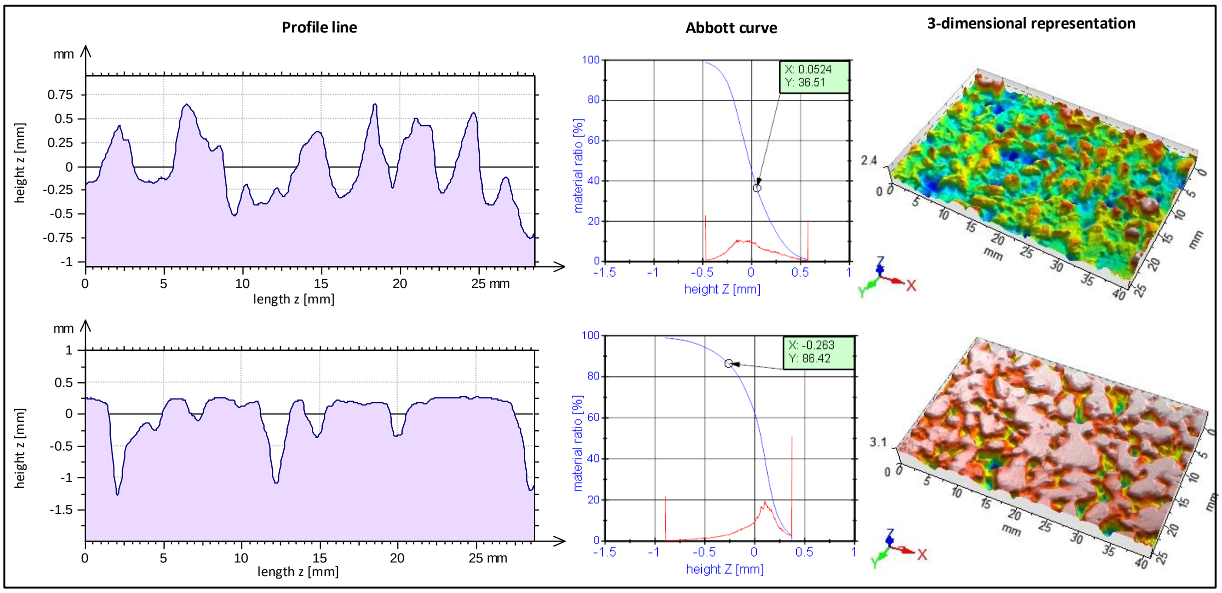

Figure 1: Mastic asphalt with a low value of g about 37 % has a convex surface (above figure), noise reducing asphalt with a g about 86 % has a concave surface (below figure)

3.1.1 Measurement process of surface texture and tire-road-noise

The asphalt surface texture can be measured by using the strip light projection, which is a triangulation method. For this method becoming thin lines are projected onto the surface and are recorded with a camera. This gray code is used to identify the projected points, which show a displacement in the recorded camera pictures depending on the height of the surface. With the help of the known angle between projector and camera the height of the surface can be calculated. The result of the measurement is a 3D surface. This surface can be described with different texture parameters (Mean Profile Depth MPD, shape factor g, maximum amplitude of the wavelength spectrum A_{max}, wavelength W_{max} at the maximum amplitude, arithmetic roughness S_a). [6]

The tire-road-noise in situ can be measured by using the close proximity method (CPX method). For this a trailer with a tire inside is towed by a car. Microphones near to the tire measure the tire-road-noise without being influenced by surrounding noises outside of the trailer. There are two different tires, which can be used for this measurement. The tire P is a standard passenger car tire and the tire H is a standard truck tire. [6]

3.1.2 Examination of routes

Within the project LeiStra3, existing urban roads as well as laboratory slabs were examined in terms of its surface texture and the acoustic characteristics.

On urban routes, whose surface layers consist of porous mastic asphalt PMA or noise optimized asphalt AC 5 D LOA, CPX-measurements were carried out at a speed of 50 km/h (31.25 mph), which is standard inner-city speed in Germany. To determine a potential correlation between the asphalt technological parameters and the CPX-measurement results, multiple linear regressions were performed with variations of the independent variables. The texture parameters of the existing routes, that were determined with the help of a texture measurement device in situ or on cores, were also considered.

Basis of this analysis were 13 routes in total, whereof seven were implemented as AC 5 D LOA-surface layers and six as PMA-surface layers. Three of the AC 5 D LOA-routes and two of the PMA-routes were implemented as part of the trial of the project *LeiStra 3* on the grounds of the NATO-Airbase in Geilenkirchen. The remaining routes are four routes in Cologne with AC 5 D LOA-surface layers and four variants of PMA-surface layers on the freeway A553.

The CPX_p- and the CPX_h-values were selected as dependent variables ($f(x_i)$) of the multiple linear regression. The proportion/amount of the coarse and fine aggregate, the filler content and the bitumen content as well as the degree of compaction were available as independent values (k_i). Furthermore, the texture parameters MPD, g and A_{max} were examined as dependent variables. The function of the multiple linear regression is as follows:

$$f(x_1, x_2, \dots, x_n) = k_1 \cdot x_1 + k_2 \cdot x_2 + \dots + k_n \qquad \text{(equation 1)}$$

It became clear that there were strong dependencies of the CPX-values on the composition of the respective asphalt surface (Figure 2 and Figure 3). The coefficients of determination of the measured and by regression factor calculated CPX-values were higher than 0.9 (Table 1 and Table 2).

Furthermore, other dependencies of the texture parameters on the mixing material composition could be determined. Due to additional consideration of the degree of compaction as an independent variable, higher coefficients of determination could be achieved.

Table 1: Factors k_i and coefficient of determination for CPX_p

Indepentend values	Faktor k_i
Coarse aggregate (2/5) [M.-%]	-0,21269215
Fine aggregate (0/2) [M.-%]	-0,25842657
Filler content [M.-%]	0,76189588
Bitumen content [M.-%]	0,26493712
Constant k_n	97,3483975
Coefficient of determination R^2	0,92945988

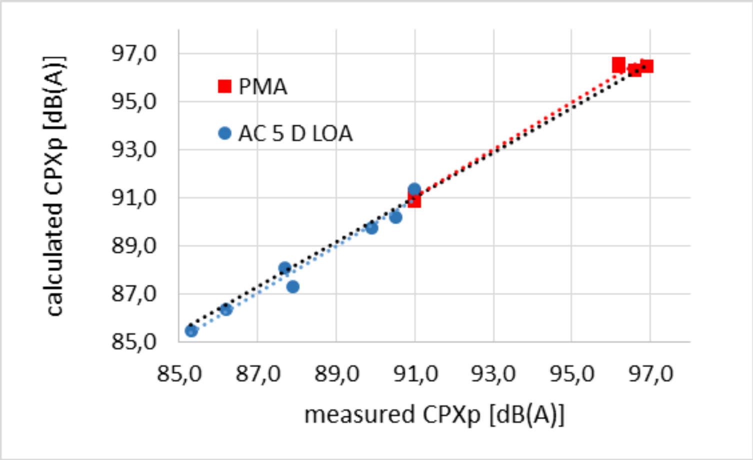

Figure 2: Correlation of the measured and calculated CPXp-values

Table 2: Factors k_i and coefficient of determination for CPX_h

Indepentend values	Faktor k_i
Coarse aggregate (2/5) [M.-%]	0,10127506
Fine aggregate (0/2) [M.-%]	-0,24475638
Filler content [M.-%]	0,44148265
Bitumen content [M.-%]	-1,10669381
Constant k_n	91,5460831
Coefficient of determination R^2	0,95990969

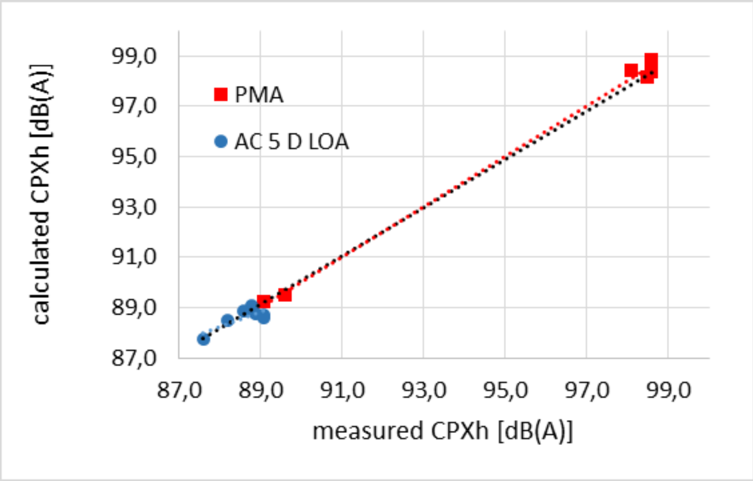

Figure 3: Correlation of the measured and calculated CPXh-values

The analysis did not include installation specific parameters, such as the influence of the roller on the surface. Moreover, the mixing material amount could only gravimetrically be included in the calculation because the information on the particular bulk density of the rocks, which are needed for the volumetric calculation, were not available. Through a volumetric consideration of the material amount, the connections between the CPX-measurements and the asphalt technological connections could be improved. It should be taken into account, that different bitumen types were used on the existing routes. The influence of the bitumen types could not be determined because there were not enough examinations of the bitumen available.
Furthermore, it should be considered that there is a low examination scope with only 13 routes in total. In the future additional routes should be analyzed in this way, in order to check whether the found dependencies could be confirmed on a bigger standard.

3.1.3 Examination of laboratory slabs

To examine the influence of the particular components of the asphalt on the texture and the mechanical impedance, 53 asphalt sample slabs were produced with the roller compactor. The noise optimized asphalt surface AC 5 D LOA and the stone mastic asphalt SMA 5 were produced.
Diabase as well as greywacke were used as rock types for the fine and coarse aggregate and the oversize amount.

For the two asphalt concepts, several variants that differ in bitumen content, the mixture of the aggregate and/or the degree of compaction, were tested. With the objective to determine the influence of the asphalt composition, the bitumen type with the ready-made modified bitumen 25/55-55 A was kept constant for all asphalt concepts.
Every variant was examined in a double determination (sample slab a and b). To determine a potential correlation between the compositional parameters (material composition) and the texture respectively the mechanical impedance, multiple linear regressions were performed with variation of the independent variables.
The slabs a and b show different asphalt technological parameters, despite identical composition (Figure 4). The parameters are too different to make a statistical representative average of each slab a and b.

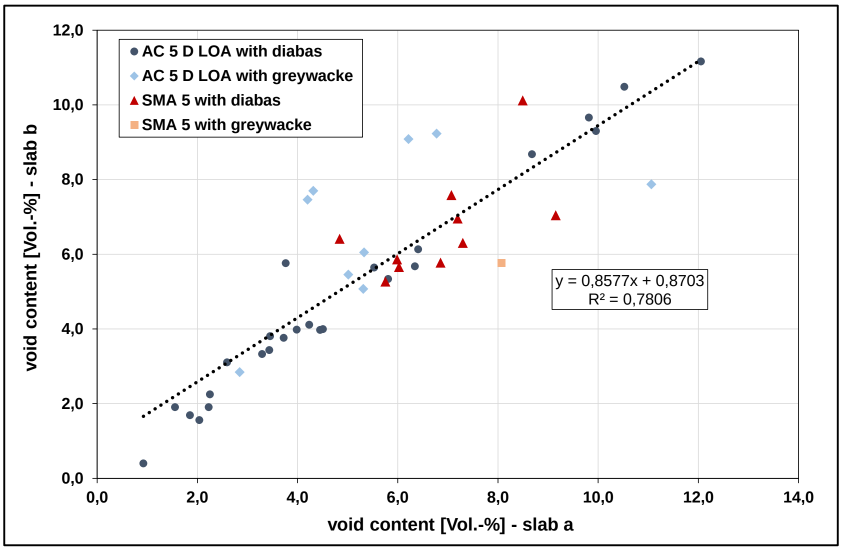

Figure 4: Correlation of the void content - slab a and b

These differences are also shown in the texture parameters. The parameters of slab a and b deviate from each other, so that averaging is not useful here. The reason for the significant deviations of the texture parameters of the slabs a and b is probably the production process of the roller compactor slabs. Although the slabs were all compressed by the same program, the influence of the compaction on the surface of the slab is not sufficiently clarified. It is possible that already smallest material accumulations in the form of the roller compactor, as it can occur during the filling of the mixing material, have an immediate influence on the resulting surface. Such influences can affect the texture data. Therefore, the results of the slabs a and b were considered individually for the additional statistical evaluation.
To include the surface shape in the texture analysis, a height analysis was performed. In this process two contour lines are defined and the material respectively air content that is located below this line is determined. As a result of the analysis the material volume and the air volume are given in percent and the average air thickness respectively the average material thickness is given in mm (Figure 5).

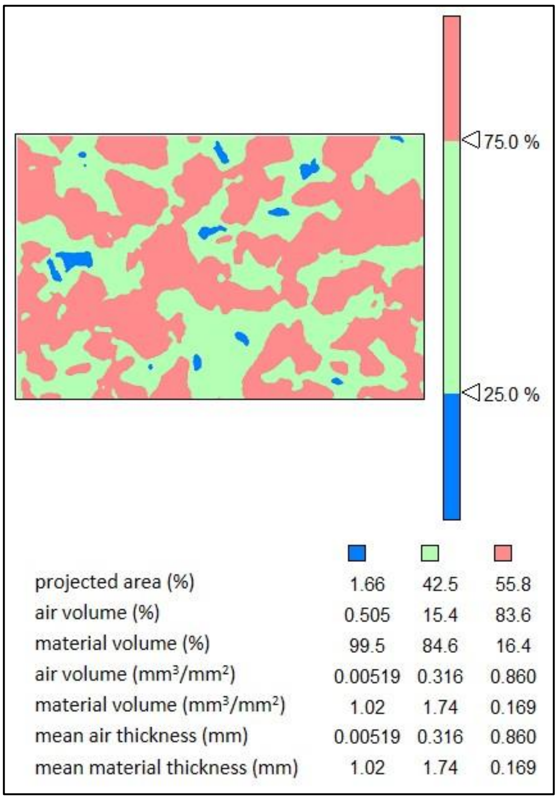

Figure 5: Height analysis

The connections between the asphalt technological parameters and the texture parameters that turned out very well on the existing routes could not be confirmed by the examination of the roller compactor slabs that were produced in the laboratory. The results of the multiple linear regression show relatively low coefficients of determination. Basically, the coefficients of determination were higher, the more asphalt technological parameters were included in the multiple linear regression. Therefore, besides the ratio of the aggregate and the bitumen, the degree of compaction and the bulk density were also considered as independent variables.

The best correlation showed the profile height related texture parameters MPD with a coefficient of determination of 0.648 and S_a with a coefficient of determination of 0.770 (Figure 6, Table 3 and Figure 7, Table 4). The shape factor g shows the lowest correlation of determination of 0.461, which shows, that this cannot be determined solely from the composition of the mixing material (Figure 8, Table 5).

Table 3: Factors and coefficient of determination for MPD

Independent variables	Faktor k_i
Bulk density [g/cm³]	0,891827541
Degree of compaction [%]	-0,050307456
Oversize grain ratio (5/8) [M.-%]	-0,049046632
Coarse aggregate (2/5) [M.-%]	-0,050807154
Fine aggregate (0/2) [M.-%]	-0,070671761
Filler content [M.-%]	-0,039582812
Bitumen content [M.-%]	-0,029438633
Constant b	8,296426008
Coefficient of determination R^2	0,648036152

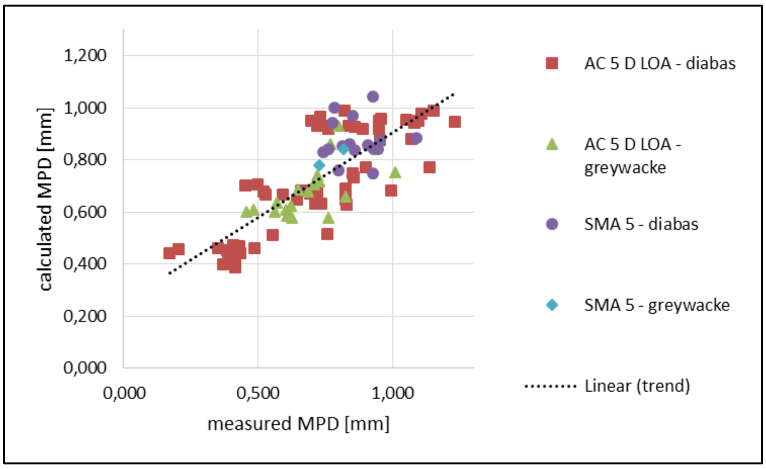

Figure 6: Correlation of the measured and calculated MPD-values

Table 4: Factors and coefficient of determination for S_a

Independent variables	Faktor k_i
Bulk density [g/cm³]	-0,7815452
Degree of compaction [%]	-0,02249208
Oversize grain ratio (5/8) [M.-%]	0,020657898
Coarse aggregate (2/5) [M.-%]	0,014800999
Fine aggregate (0/2) [M.-%]	0,000754575
Filler content [M.-%]	0,008663087
Bitumen content [M.-%]	-0,00131588
Constant b	3,578075913
Coefficient of determination R^2	0,769744669

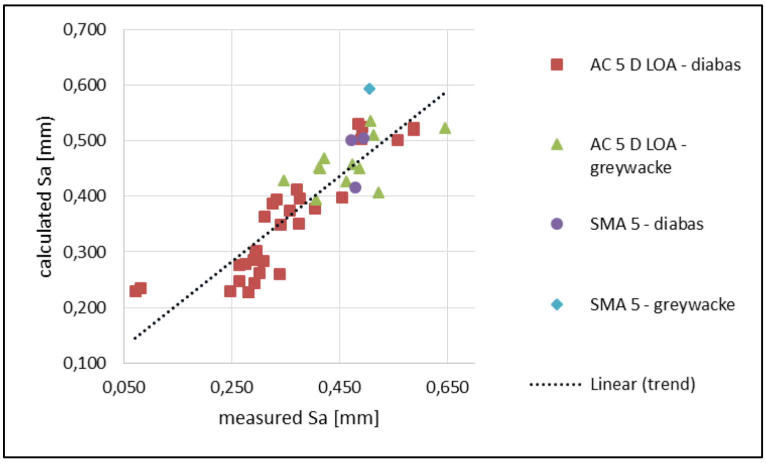

Figure 7: Correlation of the measured and calculated S_a-values

Table 5: Factors and coefficient of determination for g

Independent variables	Faktor k_i
Bulk density [g/cm³]	57,54119686
Degree of compaction [%]	-0,08912954
Oversize grain ratio (5/8) [M.-%]	-0,54811167
Coarse aggregate (2/5) [M.-%]	-0,31574455
Fine aggregate (0/2) [M.-%]	-0,49053953
Filler content [M.-%]	-2,84997225
Bitumen content [M.-%]	-1,21451498
Constant b	23,70028271
Coefficient of determination R^2	0,461652392

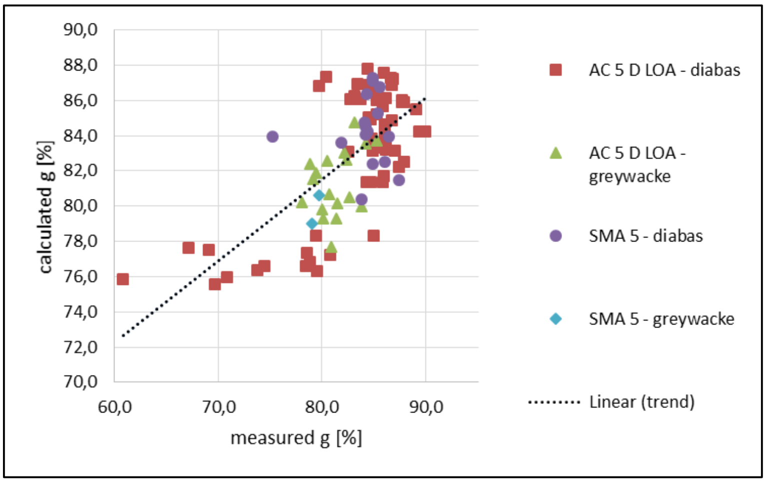

Figure 8: Correlation of the measured and calculated g-values

The height analysis also showed no dependencies on the mix composition. However, it appeared that the air thickness in the upper part of the profile has a good correlation with the MDP-value, which shows that the pores at the surface are wider the deeper they are (Figure 9).

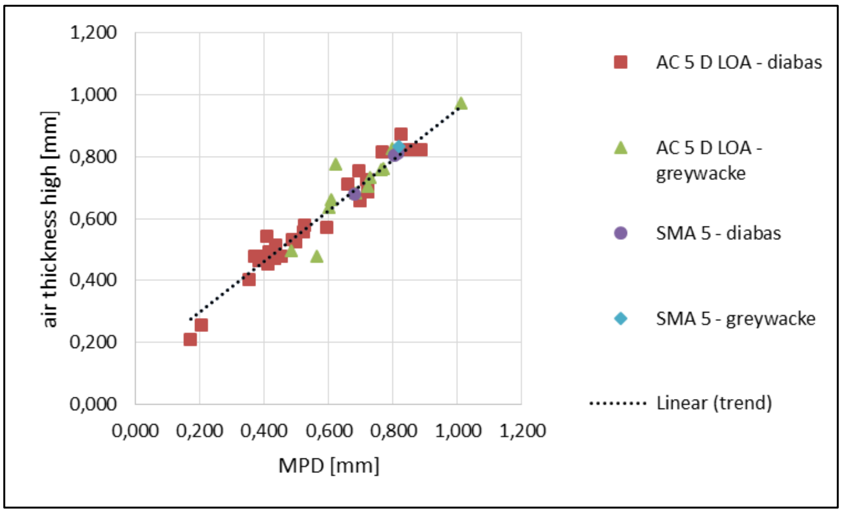

Figure 9: Correlation of MDP and air thickness high

In the performed analyses no additional parameters could be considered, besides the composition and the degree of compaction, as well as the space density. Thus, the compaction process in the roller compressor is disregarded. Further investigations should contain important parameters during the production of the slabs, such as the force and the number of passes of the roller segment because it can be assumed that the surface of the asphalt slab is significantly affected by them.

3.2 The impedance of asphalt surfaces

3.2.1 Mechanical impedance

In asphalt technology the mechanical impedance describes the resistance of an asphalt structure against forces, which cause the asphalt to oscillate [7]. Forces of this type occur in dynamic processes. These processes include the tire road contact in the rolling process of a vehicle tire in traffic [8]. Due to the fast change between pressure and release, mechanical vibrations occur in the road surface. The emission of vibrations into the surrounding air layer causes an airborne sound, which results in noise emission.
A concrete definition and description to determine the mechanical impedance are summarized in the research reports FE 09.0145/2012/HRB [9] and FE 09.0166/2012/HRB [10].

3.2.2 Measurement methods

For the determination of the mechanical impedance the impulse hammer is needed. The impulse hammer is equipped with an integrated piezoelectric force sensor and records the applied force immediately. The force sensor is located right after the so-called “Kalotte” (front part), which brings the impact pulse on the system by the short contact during the hammer stroke. The answer of the impact pulse is determined by an accelerometer in the form of a frequency-dependent resonance. During the measurement the load-time function of all signals (input and output signal) are submitted to the computer using a data recorder. The measurement of the mechanical impedance in the laboratory is performed according to the schematic experimental setup shown in Figure 10. The application of the hammer impulses have to take place in the middle of the slabs from a defined drop height. An elastic 3-point-bearing of the asphalt system has been proved useful. To achieve a high reproducibility of the measurements, the impulse hammer is flexibly attached to the mount and a spacer ensures the same distance between the impulse hammer in the deflected position and the asphalt slabs.

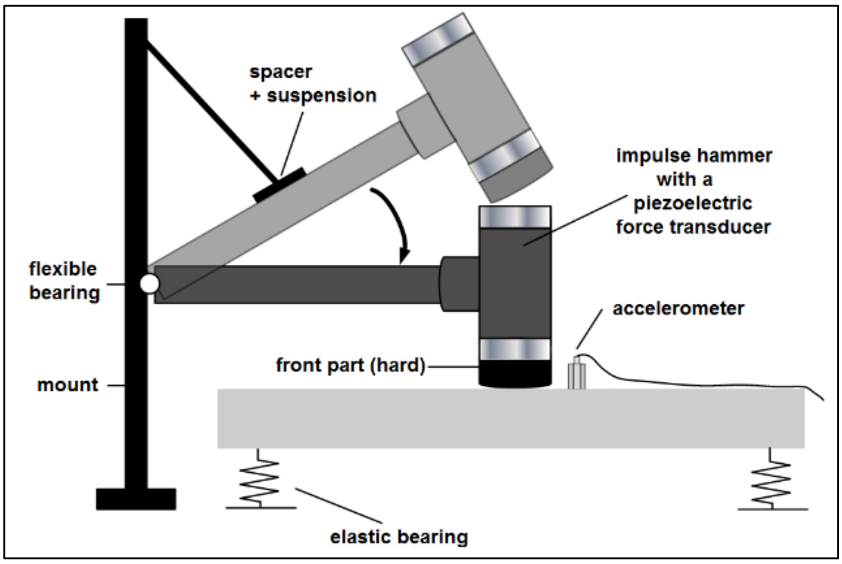

Figure 10: Schematic depiction of the experimental setup for the measurement of the mechanical impedance with the impulse hammer

The compliance, measured with the mechanical impedance, is a temperature-dependent value in terms of asphalt and leads to an increasing emission value with decreasing temperature. For this reason the measurement with the impulse hammer is performed on differently tempered asphalt slabs in the range of -10 °C to 30 °C. The mechanical impedance is a complex variable, which is composed of a real and an imaginary part and depends on the frequency. The measurement of the impedance is shown in a diagram, where the frequency (X-axis) is plotted against the mechanical impedance (Y-axis). A typical curve shows Figure 11.

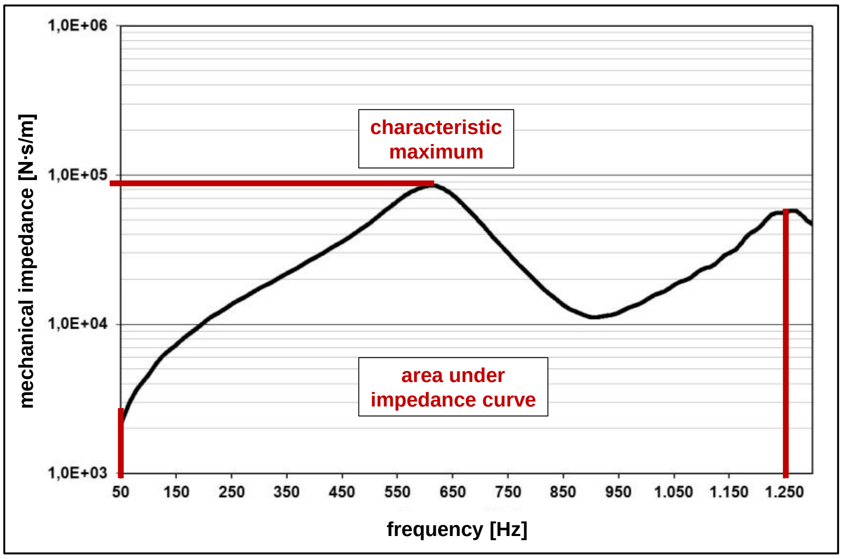

Figure 11: Evaluation of the mechanical impedance curve

3.2.3 Examinations

The examination of the influence between the asphalt technological parameters (bitumen characteristics and material composition) and the mechanical impedance, which is determined with the impulse hammer, was based on the analysis of various asphalt concepts manufactured in the laboratory. Some of these were the 53 analyzed slabs described in chapter 3.1.3. In another research series, the asphalt concepts asphalt concrete AC 8 D N, stone mastic asphalt SMA 5 N and SMA 8 N, mastic asphalt MA 5 N and MA 8 N, which were regulated by [11], were analyzed. The same ready-made modified bitumen 25/55-55 A was used in both research series.

To include the influence of the bitumen characteristics, the noise optimized asphalt surface concepts AC 5 D LOA, SMA 8 LA and porous asphalt PA 8, which were also produced with varying bitumen types, were included in the evaluation. Furthermore, the stiffnesses of the asphalt concepts were determined. To characterize the bituminous binder, the rheological behavior of the used bitumen variants were determined according to [12] using the dynamic shear rheometer (DSR).

The assessment of the mechanical impedance was based on the characteristic maximum of the mechanical impedance and the area under the mechanical impedance curve in the range of 50 Hz to 1250 Hz (Figure 11).

The comparison between the area under the mechanical impedance curve and its maximum shows that both measurements correlate with each other. This coherence can be represented very well by a potential function ($R^2 > 0.9$).

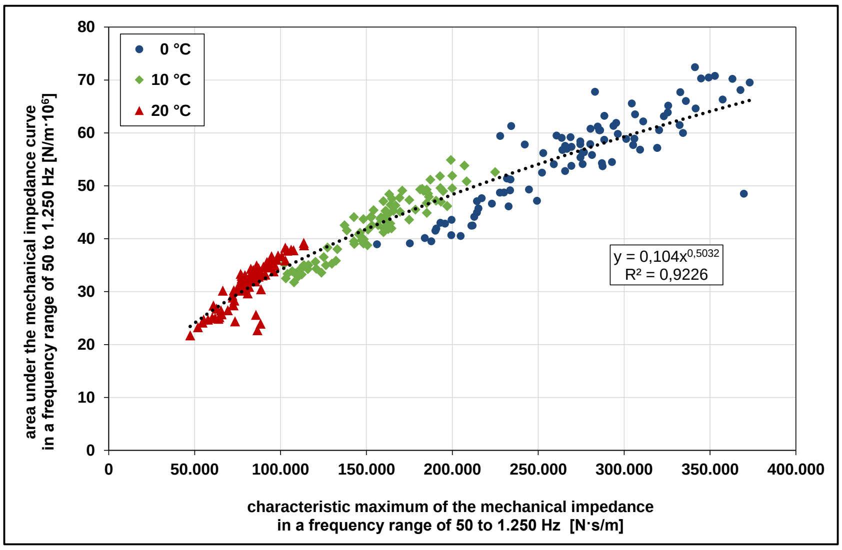

Figure 12: Correlation between the characteristic maximum of the mechanical impedance and the area under the mechanical impedance curve – each temperature

There is a strong correlation between the characteristic maximum of the mechanical impedance respectively the area under the impedance curve and the text temperature. This dependency is precisely formulated by an exponential function:

$$\mathbf{y = d \cdot e^{k \cdot x}} \qquad \text{(equation 2)}$$

The parameter y describes the temperature-dependent maximum of the mechanical impedance in [N*s/m] respectively the area under the impedance curve [N/m] and x the test temperature in [°C]. The parameters d and k are dependent on the particular asphalt technological conception.

The rheological characteristics of bitumen have an essential influence on the mechanical impedance in form of varied characteristic maxima of the impedance and varied areas under the mechanical impedance curve. The mechanical impedance increases with a higher stiffness of the bitumen. The characteristic value of the bitumen G*/sinδ, which is a measure for the assessment of the deformation characteristics, shows good dependencies on the mechanical impedance with a coefficient of determination > 0.83 (Figure 13). Also the type of the asphalt concepts plays an important role. High void asphalts have lower mechanical impedances than low void asphalts.

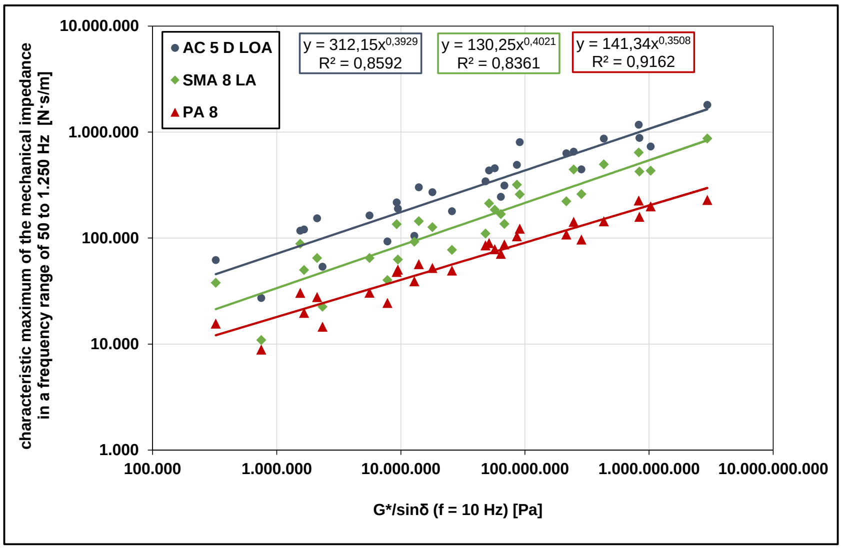

Figure 13: Correlation between the value G*/sinδ and the characteristic maximum of the mechanical impedance – each concept

Furthermore, the existence of a linear dependency between the stiffness modulus of asphalt and the characteristic value of the mechanical impedance curve (area and maximum) was proved by a simple regression (Figure 14). The mechanical impedance of an asphalt concept also seems to be affected by the void content respectively the bulk density of the aggregate, so that the individual consideration of greatly varying values of the void contents show better correlations.

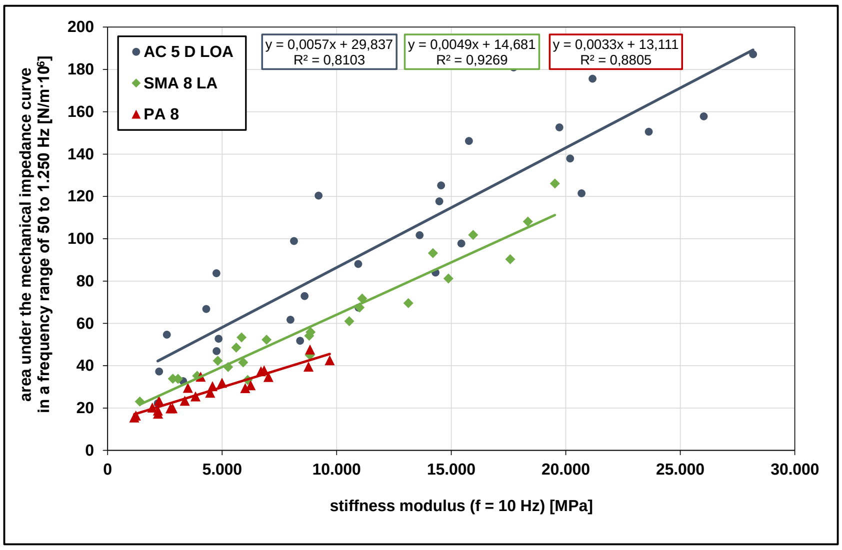

Figure 14: Correlation of the stiffness modulus and the area under the mechanical impedance curve – each concept

The parameter d is included in the described temperature-dependent exponential function (equation 2). The value of the parameter d varies depending on the asphalt conception. Thus, it can be concluded that the mixing material composition of the asphalt as well as the asphalt technological parameters (bitumen characteristics and the stiffness modulus) affect this parameter. The parameter k is assumed to have a value of -0.06. Accordingly the area under the mechanical impedance curve is assumed to have a value of -0.03. Multiple linear regressions resulted in functions to describe the parameter d, which depends on the grain size distribution, the bitumen content and the void content as well as the bitumen characteristics and the stiffness modulus. Thus, the characteristic maximum of the mechanical impedance and the area under the impedance curve can be calculated in a frequency range between 50 Hz and 1250 Hz.
To quantify the impedance characteristics first of all the maximum impedance is calculated by only considering bitumen volume and void content. The coefficient of determination for this is 0.9290 (Figure 15).

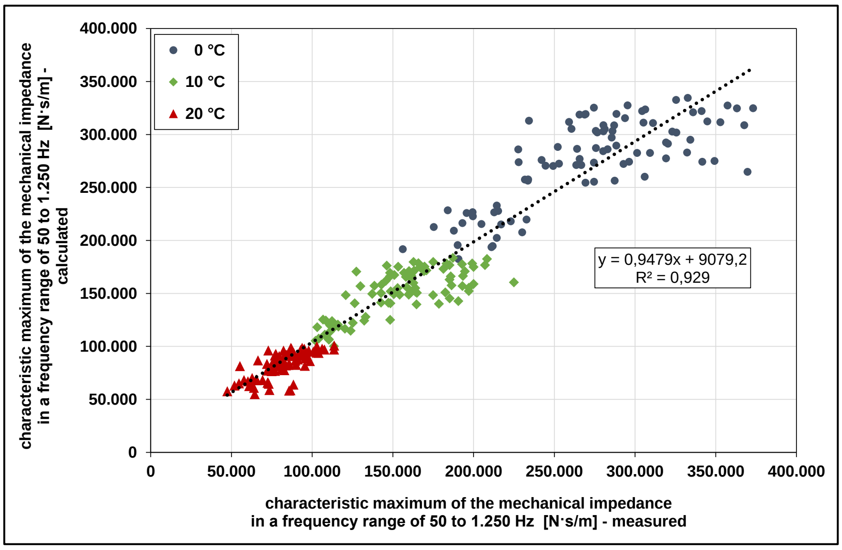

Figure 15: Correlation of the measured and calculated values for the characteristic maximum of the mechanical impedance – each temperature

Besides, the coefficient of determination can be increased by consideration of the stiffness modulus and/or the characteristic value of the binder G*/sinδ.

Additionally, the maximum impedance seems to be influenced by the void content respectively the bulk density of the aggregates, so the different asphalt concepts show different coefficients of determination. For example, the asphalt concept SMA 8 LA shows a coefficient of determination of 0.9751 (Figure 16).

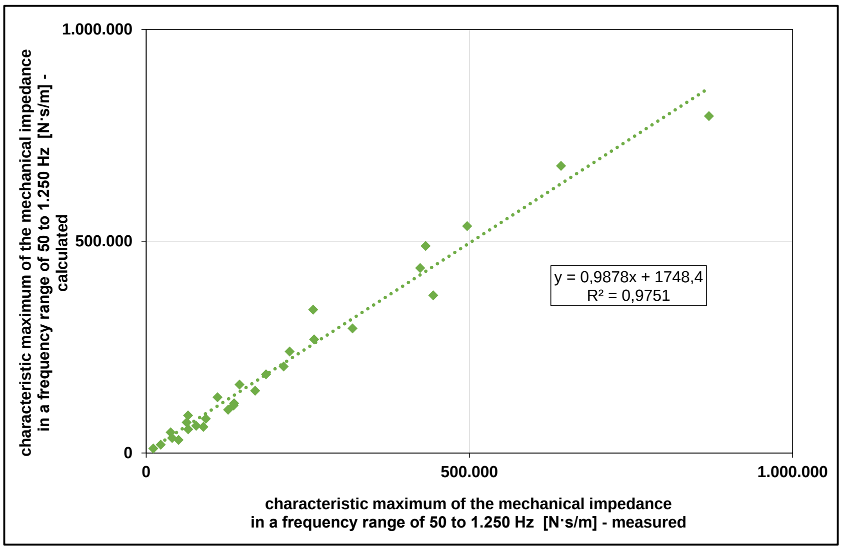

Figure 16: Correlation of the measured and calculated values for the characteristic maximum of the mechanical impedance – SMA 8 LA

4. SUMMARY

The in situ measured acoustical characteristics of different asphalt routes showed good correlations to the respective asphalt composition. Because of the low examination scope, a confirmation by measurements and analysis of additional routes is needed.

The detected correlations of the texture parameters could not be confirmed by model analyses of laboratory slabs. The implementation of additional height analyses did not lead to an improvement of the correlation results as well. Further research approaches should deal with the analysis of the influence of compaction processes on the surface texture.

The compliance is quantified by the mechanical impedance or rather the characteristic maximum and the area under the impedance curve. The multiple linear regression of the compositional parameters bitumen volume and void content showed high correlations with the compliance. These could be improved by consideration of rheological bitumen characteristics and stiffness behavior of the asphalt.

To confirm the results of the project FE 02.0360/2012 IRB [1] more measurements of the texture and mechanical impedance should be taken on laboratory slabs as well as on new built roads. Here many different surfaces should be examined to verify if different asphalt concepts can be identified by their values of the texture and mechanical impedance.

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[11] TL Asphalt-Stb, Technische Lieferbedingungen für Asphaltmischgut für den Bau von Verkehrsflächenbefestigungen, Köln: Forschungsgesellschaft für Straßenwesen, 2007.

[12] DIN EN 14770, Bitumen und bitumenhaltige Bindemittel - Bestimmung des komplexen Schermoduls und des Phasenwinkels - Dynamisches Scherrheometer (DSR).