IMPACT: Investigation Machine for Pavement ACoustic durability; Testing the durability of low noise road surfaces

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ABSTRACT

Acoustic durability of asphalt pavements depends mainly on the total number of loading cycles rather than the age of the road surface. Until now, testing acoustic and mechanical durability of asphalt pavements is only possible by constructing test-sections and monitoring the road surface loaded by real traffic. This approach is time-consuming (several years) and expensive. The aim of the present project is to develop a reliable, fast, and economical method that allows testing of "low noise road surfaces" regarding durability aspects. The developed testing equipment is denoted IMPACT and allows simulating traffic, temperature, load, tread pattern, tyre pressure and wheel spin in the laboratory. In the present project, noise emission is calculated by means of the computational model SPERoN, based on measurement of different parameters of the surface. Within only a few weeks of testing, the acquired data allows assessing the durability of the investigated pavement. Some tests are performed on different asphalt mixtures.
The results of this study will be presented and discussed.

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

1. INTRODUCTION

The sound emission of modern passenger cars is dominated by the noise of the tyres rolling over the pavement. Only under conditions of strong acceleration or speeds below 30 km/h can the propulsion noise dominate. For heavy goods vehicles at speeds above 60 km/h, again the rolling noise starts to become the major source. Within this context, it was recognised at a very early stage that the quality of the road pavement has a considerable effect on the level of noise emissions caused by road traffic.

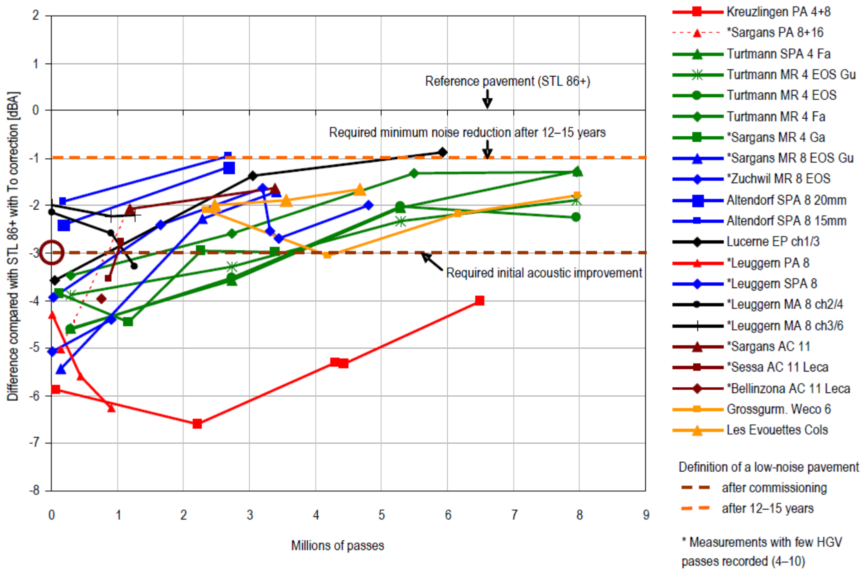
Low-noise pavements are of particular interest for urban areas with a high population density, which continue to have the greatest shortcomings in terms of the abatement of noise. Moreover, they show a high cost-effectiveness in comparison to the costs of conventional noise-reduction measures such as noise barriers or façade insulation. Finally, these pavements are often the only measures which can be applied on roads in urban areas.

The main problem of low-noise road pavements is the durability of its acoustic features. Measurements indicate that it is absolutely possible to achieve an initial acoustic improvement of 6 dB(A) or more compared to the reference bituminous pavement. This corresponds to at least a halving of the sound energy of the traffic volume. However, these pavement textures loose their good acoustic properties after a few years. The main reason for the transformation of the surface structure is the mechanical and thermal load as well as contamination.

Consequently the challenge for the future research on low-noise pavements is to develop products that have a minimal long-term acoustic degradation while its mechanical life-cycle is similar to a conventional pavement.

During the first Swiss research programme on low-noise road surfaces in urban areas [1,2], the acoustic and mechanical properties of 21 full-scale test tracks were monitored under real traffic conditions over a period of six years. The study involved a wide range of noise-reducing asphalt mixtures. The characteristics of the decreases in acoustic performance were more or less the same for all new experimental pavements and most of the existing pavements. The acoustic performance of pavements subjected to low traffic volumes decreased less rapidly than those subjected to higher traffic volumes. Thus, traffic volumes do play an important part in relation to acoustic working life of pavements. This conclusion corresponds to the results of a Danish study [3].

From studying the amount of passing vehicles, it became clear that the acoustic performance of all test tracks decreased asymptotically as a function of traffic load (Figure 1). From this figure, it follows that the loss of the acoustic performance for all road surfaces, in a similar way, depends on the number of roll-over cycles.



porous pavements. : ***grain size 4 pavements***. : ***grain size 8 pavements***. : ***grain size 11 pavements***
gravel. : ***special pavements***.

Figure 1: Acoustic performance of pavements as a function of the cumulative traffic load [2]

2. THE IDEA BEHIND IMPACT (Investigation Machine for Pavement ACousTic durability)

Up until now, the development of low-noise asphalt has been time consuming, and it has not been economical. The fact that a suitable place for building the test track has to be found, the test track has to be built, and several years of measuring are necessary make the evaluation expensive. Additionally, it is important to meet the following requirements for test sections:

- minimum length of 200 m
- stable sub layers with an even surface - no crossroads, no traffic lights or pedestrian crossings
- high traffic load
- no more than 5 % of longitudinal slope
- for measuring the noise level, the right place has to be found for the statistical pass-by SBP method at which no sound reflections on walls or buildings occur.

Considering the fact that on-site track testing is very expensive and time-consuming, and taking into account that acoustic durability is well correlated to traffic load, the idea was born to develop a device that would allow the simulation of pavement ageing in the laboratory. This device, called IMPACT (**I**nvestigation **M**achine for **P**avement **AC**ous**T**ic durability) will be a mechanism that enables fast, reproducible and cost-effective testing and development of new low-noise pavements.

Because it is technically impossible to measure noise emissions in the laboratory, the noise emission in the present project will be calculated by the mathematical model SPERoN [4], based on the measurement of different parameters of the surface, like the macro-texture, the air flow resistance, the acoustic absorption and the mechanical impedance.

3. THE CONCEPT IMPACT

The investigation machine IMPACT simulates the traffic stress by over rolling test samples under evaluated test conditions with a test tyre. The machine has the following characteristics:

- Temperature:
  The temperature can be regulated between room temperature and 50°C with an IR-thermometer measuring the surface of the sample. The conditioning is done by heating/cooling the surface. To create changes in the texture by rolling the surface, it is important to control the temperature of the surface and not the temperature in the sample.
- Load:
  A load of 4 kN has been chosen, which is considered to be a typical load for both passenger cars and lorries
- Wheel spin:
  The spin can be changed to any value between + 5% (acceleration) and -5 % (braking). To make sure that the shear force acting on the surface of the sample does not change its direction with each wheel-pass, the spin changes its direction at each wheel-pass (see Figure 2)

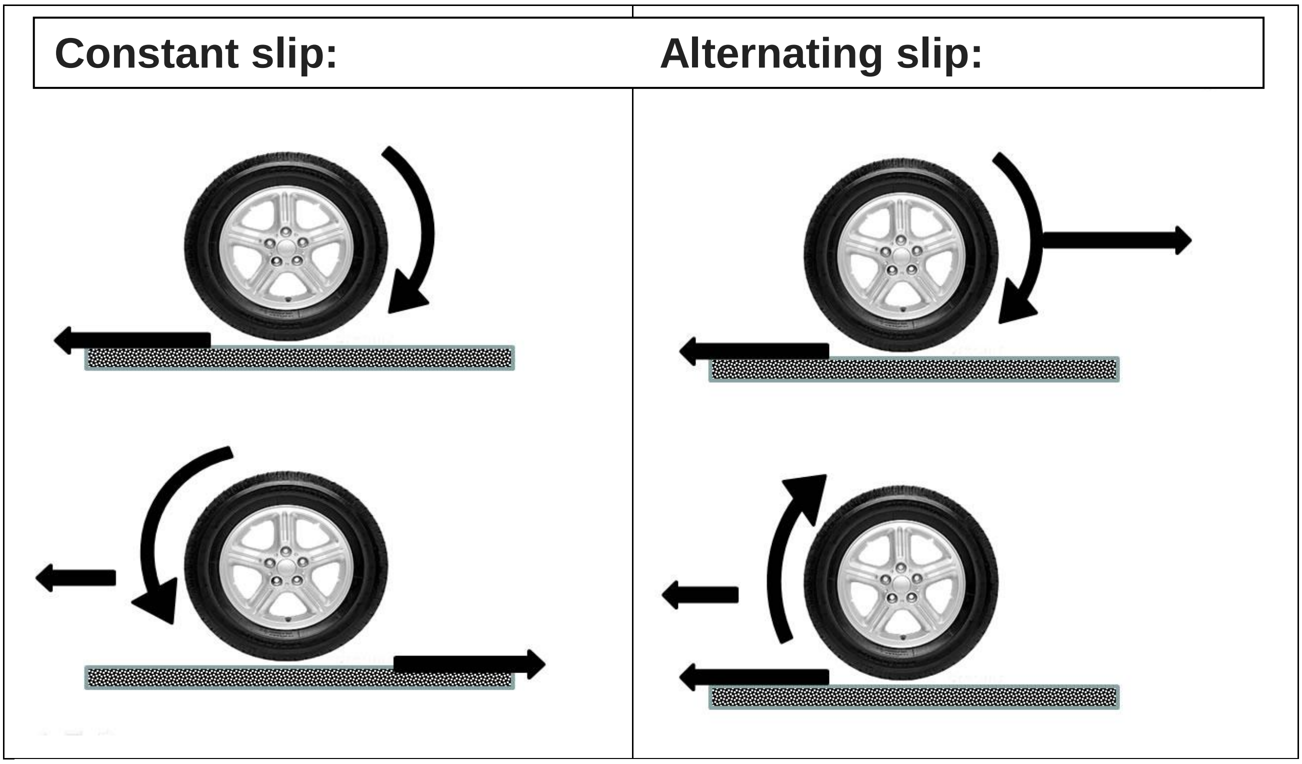


Figure 2: By changing the direction of the wheel spin, the shear force acting on the sample maintains the same direction during all cycles of over rolling. Left changing direction of the shear stress on the surface with constant spin; right constant direction of the shear stress on the surface by changing the direction of the spin.

- Driving speed:
  The driving speed was determined as being 0.94 m/s to conform with the rutting test (EN-12697-22).

- Tyre:
  Dust and dirt have a big influence on the wear of the road surface in practise. In the testing machine, this type of stress is lacking. To compensate for this ommission, the required tyre consists of a hard and abrasive rubber compound including silica- filler. Because there was no testing tyre with the required properties on the market, a testing tyre was defined and produced in a small amount with the following properties
  - tread pattern: V-tread tries (see figure 3):

Figure 3: Pattern of the test tyre

- dimension of the tyre : 205/60 R15

- compound: so called “DK-Mischung” (used in the German car industry) including silica-filler

- length to be tested:
  The distance to be rolled (2 000 mm) is longer than the circumference of the tyre. Therefore, a homogenous abrasion of the tyre is assured. The beginning and the end of the length tested, consists of a section of 500 mm length on which the wheel is accelerated and decelerated. As such, the sample tested is rolled at a constant speed.

- Length of the sample:
  By using a laboratory roller compactor (smooth steel roller according to EN 12697-35), test specimen with a length of 500 mm and width of 180 mm can be compacted. Two plates where fixed on a mat, one behind the other, in such a way that possible differences in height can be balanced. In this way, a pavement with a length of 1000 mm and with a good longitudinal evenness is produced. The testing apparatus makes it also possible to take test specimen from existing roads in order to test them.

In order to measure the surface characteristics for the prediction model, the test specimen can be taken out of the testing device.

4. Test method

The test conditions have to be chosen in a way that changes in the texture of the surface of the sample can occur, but without creating deformations in the form of rutting.

4.1 Test parameters

In a previous Paper [6], the results of the parameter studies for the load, inflation pressure, wheel spin and the temperature were presented.

On the basis of this parameter-study, the testing conditions have been determined as follows:

- load: 4000 N
- inflation pressure of the tyre: 2.3 bar
- wheel spin: 3% (synchronous to the movement direction)
- temperature: 35°C

4.2 Sample preparation

The compaction of the sample is done by using a smooth steel roller compactor according to EN 12697-35. The sample is compacted to the same density of the previous run Marshall-Compaction test.

In the context of the research project, it is important to get the “same” characteristics for the surface in the laboratory as occurs in practise. To compare the surface characteristics, asphalt samples were taken from two test sections and compacted in the laboratory. The same measurements were made to characterise the surface on the laboratory-compacted samples and on the test sections in situ. The characteristic of the asphalt mixtures laid on the test sections are presented in Table 1.

Table 1: Characteristics of the two mixtures on which the validation was performed

Mixture	Mixture		As-built layer		
	Binder content [M.-%]	Void content of marshall specimen [Vol.-%]	Thickness [mm]	Void content of cores [Vol.-%]	Compaction degree [Vol.-%]
SDA 8 B	6.17	10.0	32	13.5	98.9
SDA 4 C	6.02	19.4	35	18.2	101.0

4.3. Methods to assess the surface characteristics

For the validation of the sample preparation, the characteristics of the surfaces were examined using the following test methods:

- airflow resistance (Rs) according to [12]
- mean profile depth (MPD)
- Laser texture measurement and spectral analysis of surface profile according to [9,10]. Determination of the wavelength λmax at which the max amplitude is measured. The maximum amplitude is called the effective roughness depth, Reff,max.

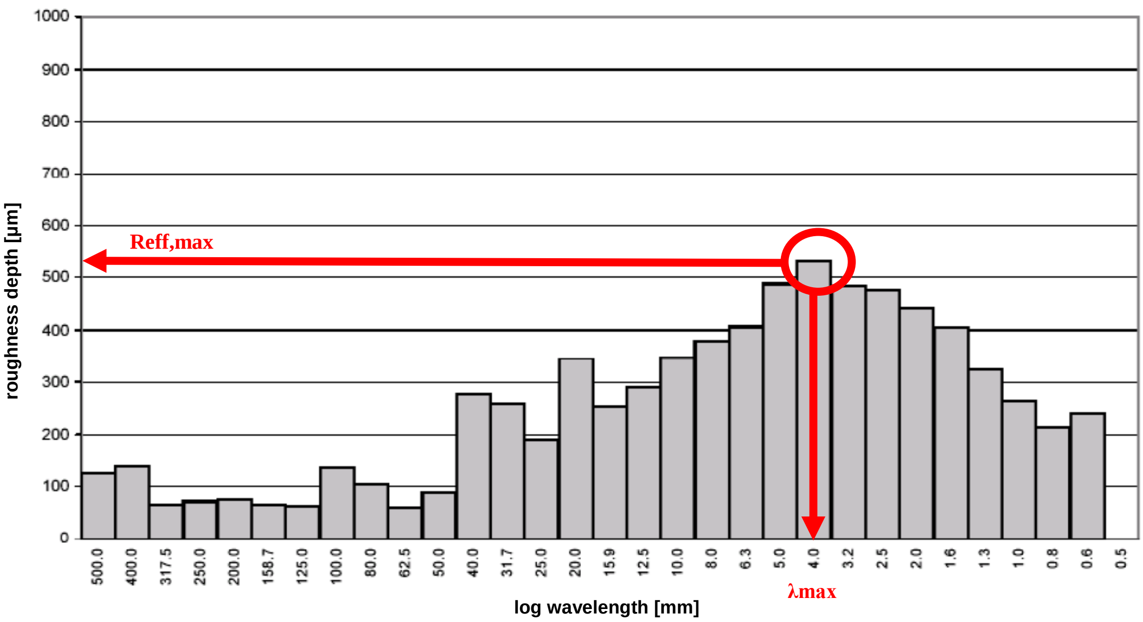


Figure 4: Spectral analysis of the surface profile and determination of the wavelength λmax at which the maximum amplitude occurs, Reff,max (= roughness depth)

The surface texture of a pavement has a crucial influence on the origin of noise. Therefore, Sandberg [10] suggested the analysis of the measured profile by using the Fourier-transformation and to classify the waves in then into 1/3 octave bands.

- Shape factor g

The shape factor is calculated by statistical evaluation of the frequency of profile depth. For low-noise asphalt, the shape of the surface should be concave (plateau with valleys) because this shape generates less vibration by the interaction of the tyre with the surface than a convex shape (plateau with mountains) (see Figure 5). These vibrations of the tyres produce noises.

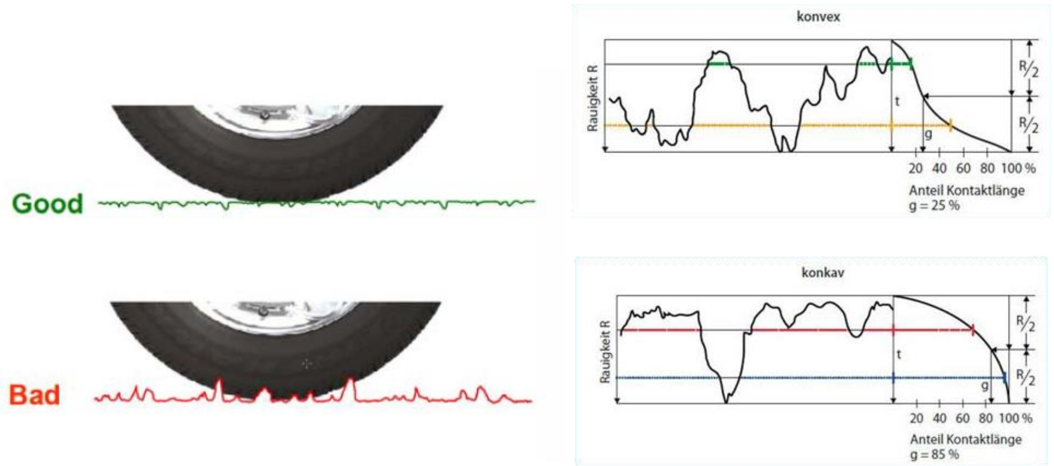


Figure 5: Shape factor

The results are presented in Table 2. The values for the shape factor g and the texture analysis (λmax and Reff,max) are very similar. The values for the mean profile depth differ, particularly at the SDA 4 mixture. The values for the airflow resistance are very low on the laboratory-compacted samples. This low value may be due to the fact that measurements on the test sections where done on the surface without cleaning it, while the surface of the laboratory sample where totally clean.

In general, the comparison of the samples taken out of the road with the samples compacted in the laboratory is satisfactory.

Table 2: Comparison of the texture characteristics of the IMPACT saples with in-situ measurements

Mixture	SDA 8 B		SDA 4 C	
Measurement	IMPACT	in-situ	IMPACT	in-situ
Rs [Pas/m]	747	29803	3157	n.b
MPD [mm]	0.9	0.76	0.6	1.05
g [%]	80.0	87.7	81	82.4
λ_{max} [mm]	12.5	12.5	8.0	6.3
$R_{eff,max}$ [µm]	214	202.2	107	130

5 Long-term test

The IMPACT gives the possibility to test two samples at the same time; the two mixtures shown in Table 3 where selected to run a long-term test. The mixture was a semi-dense-asphalt (SDA); a mixture type with a grading curve between asphalt concrete AC and porous asphalt PA.

Table 3:Characteristics of the mixtures for the long-term test

mixture	Binder content [mass-%]	Void content of Marshall specimen [vol.-%]	binder	Sample thickness [mm]	Degree of compaction [%]
SDA 8	6.17	10.0	PmB 45/80-65	30	98.8
SDA 4	6.02	19.4	PmB 45/80-65	36	101.8

The two samples where tested with the defined test parameters up to 5 million of rolling cycles. The following parameters to characterise the surface were periodically measured

- Airflow resistance
- Texture measurements
- Acoustic absorption

The first measurement took place after 2000 cycles of roll-over, the following measurements where done periodically. The measured parameters where used to calculate the tyre/road noise by using predicting model SPERoN [5]. The estimated tyre/road noise was the crucial factor for the evaluation of the investigation machine IMPACT.

6 Results

6.1 Development of the airflow resistance

Usually the airflow resistance is bigger on finer mixtures than on coarse mixtures; in accordance to this experience, the air flow resistance on the SDA 4 C is bigger than for the SDA 8 B (see Figure 6).

The shape of the curve in Figure 6 (increasing of the airflow resistance with increasing number of wheel passes) corresponds with the experience of several long-term monitoring of low noise asphalt. In a current Swiss long-term monitoring [11] on several test tracks, a similar increasing of the air flow resistance for the first million wheel passes was observed. After 50,000 wheel passes, the airflow resistance had doubled in value; unfortunately, after 2 million wheel passes, the value remains at the same level and did not increase any more.

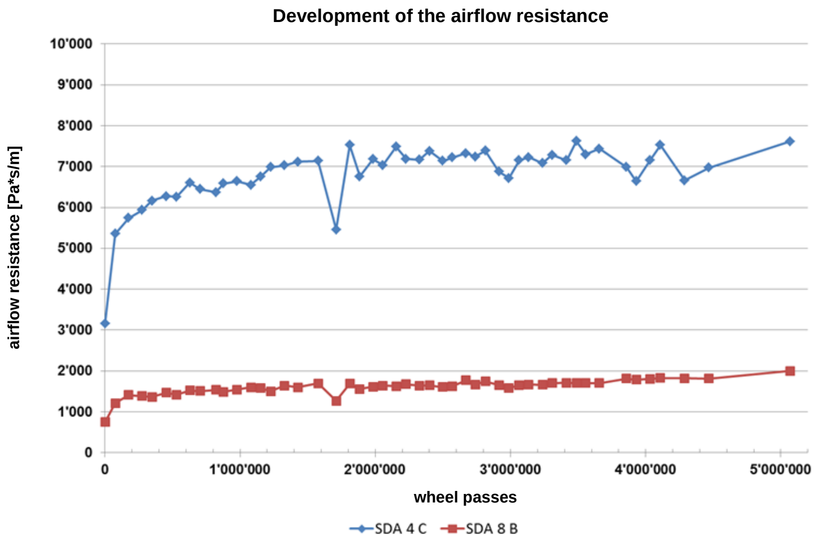


Figure 6: Airflow resistance as a function of wheel passes

The peaks after 1,700,000 wheel passes can be described as a systematic error in the measurements, without any importance for the overall evaluation.

Normalised to the initial value, the laboratory measurements of the air flow resistance of the two test specimens showed similar relative trend (see Figure 7).

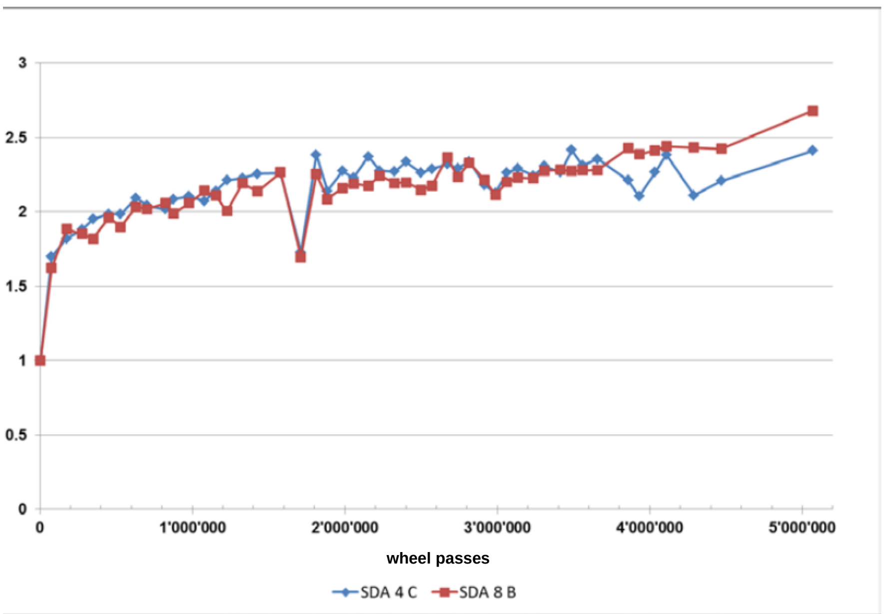


Figure 7: Trend of the airflow resistance

6.2 Development of the shape factor

The measurements showed (see fig. 8) that both samples had an initial shape factor of approximately 80%. The SDA 8 B increased slightly to 85% followed by a slight decrease back to its initial value of 80%. After 4,000,000 wheel passes, the value dropped rapidly to 60%. It is probable that the rapid drop of the value is due to the ravelling of the surface, which started at about 2 million wheel passes and became continually bigger.
In principle, a similar behaviour could be observed for the sample SDA 4 C, except the value started at 80 % and it decreased to 70 %.

The behaviour of the laboratory measurements correspond in principal with the in situ measurements of a Swiss long-term monitoring of low noise pavement [3]. After 4 years of monitoring, 7 of the 13 low-noise pavements showed a shape factor below 65 %. This value is known as the threshold for low-noise asphalt surfaces.

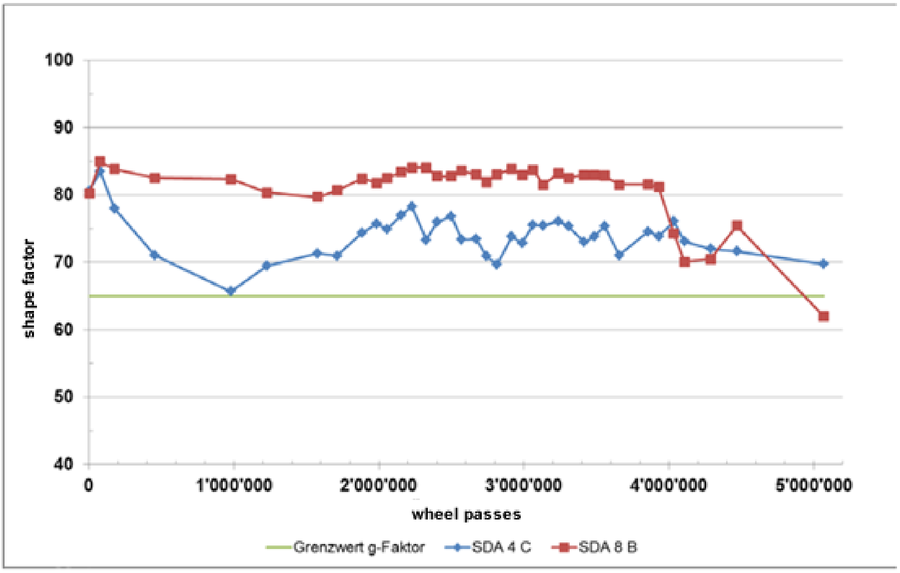


Figure 8: Development of the shape factor

6.3 Development of roughness depth Reff,max and wavelength λmax

Sandberg [9] showed that, under traffic, the roughness depth Reff,max decreases while the wavelength λmax increases.

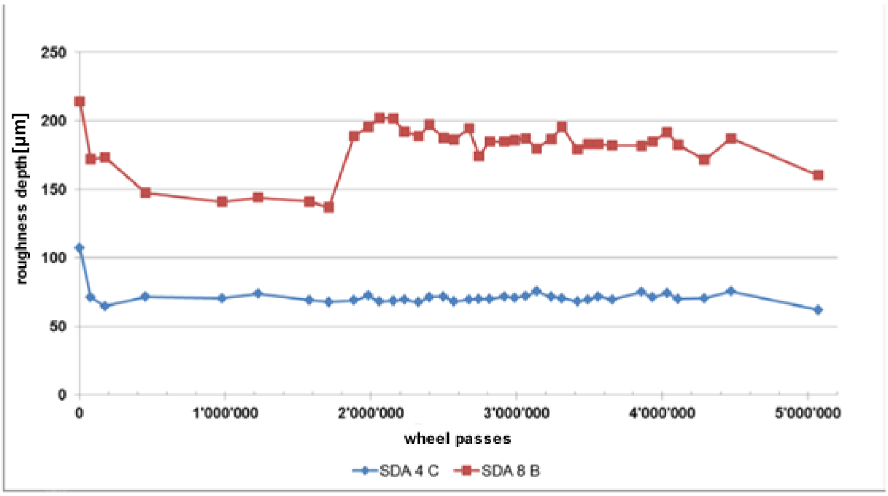


Figure 9: Development of the roughness depth Reff,max.

For both asphalt mixtures, the roughness depth decreased rapidly and then remained at the reduced level. The jump of the value for the SDA 8 at 1,750,000 wheel passes is due to ravelling. The ravelling was observed in 3-d measurements as shown in Figure 10.

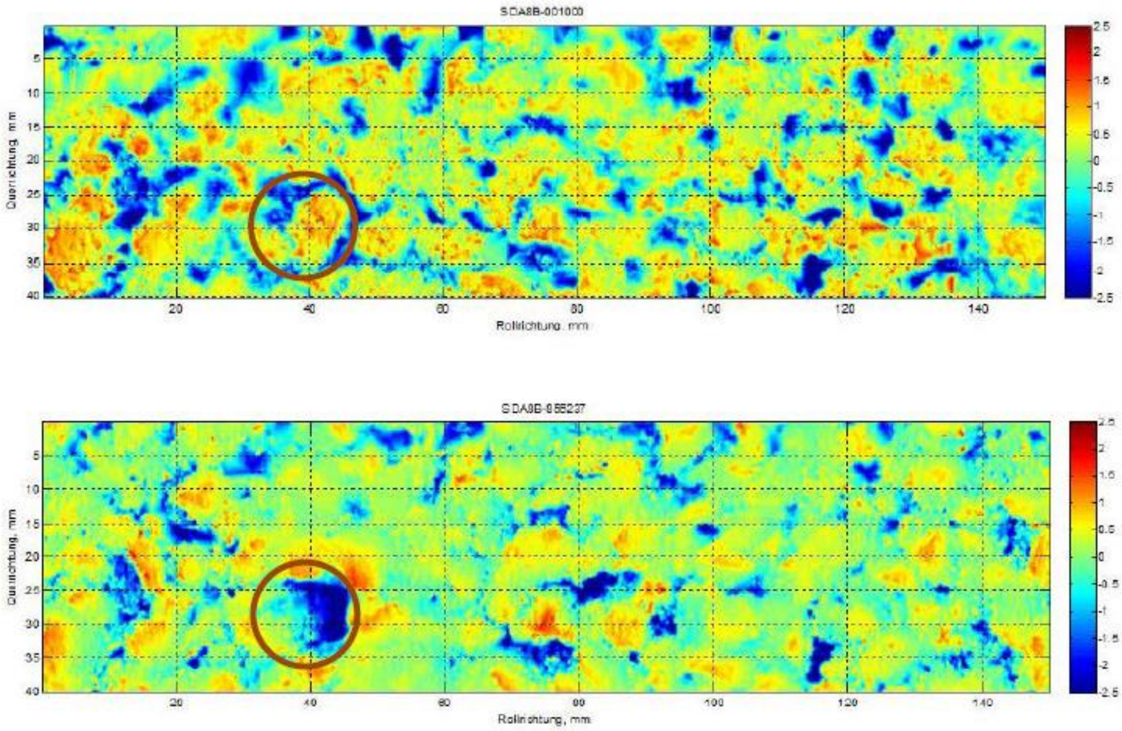


Figure 10: Comparison of 3D-pictures after 2 000 (above) and 1 750 000 wheel paesses (below). The marked spot is yellow at 2 000 wheel passes, which means that there are "small mountains". After 1 750 000 wheel passes, the marked spot is dark blue, which means that there are deep valleys.

Concerning the development of the wavelength, the following can be said:

- On the sample with the SDA 8 mixture, the λ_{max} value increased from the terzband-class 10 to 12.5 mm. The sample in the IMPACT-machine behaved similar to the one in practice.
- On the sample with the SDA 4 mixture, the λ_{max} value fluctuates between the initial (8 mm) and final value (10 mm), which can be explained by the fact that fine-grained surfaces have a flat spectrum which caused a random value for the wavelength λmax at which the maximum amplitude is measured.

6.4 Modelling the tyre/road noise

For modelling of the tyre/road noise, the profile of the surface, the airflow resistance and the acoustic absorption were required of which the profile and the airflow are the main parameters. Therefore, the acoustic absorption was not measured as often as either of the other values. The predictions of the noise level was done using the SPERoN (**S**tatistical **P**hysical **E**xplanation of **Ro**lling **N**oise) approach developed by the Müller-BBM Group, Munich, Germany and the Chalmers University, Division of Applied Acoustic, Gothenburg Sweden [5,8].

The modelling was done for 24 different numbers of wheel passes. The SPERoN-Model allows a choice of traffic speed for which the noise will be predicted; the modelling was run for a speed of 50 km/h. The precision of the result of the modelling is ± 0.5 dB(A); which means, that a change of the predicted noise of less than 1 dB(A) is statistically not relevant.

For the SDA 8, the modelling has showed a difference between the initial and the final noise-level after 5,000,000 wheel passes of 2.0 dB(A) (see Figure 10). The stress in the investigation machine creates a reduction of the acoustic performance of the surface, as it can be observed in practise. Initially, a higher change had been expected after a lower number of wheel passes.

On the finer SDA 4, the final noise level and the initial level do not differ in a statistically relevant way.

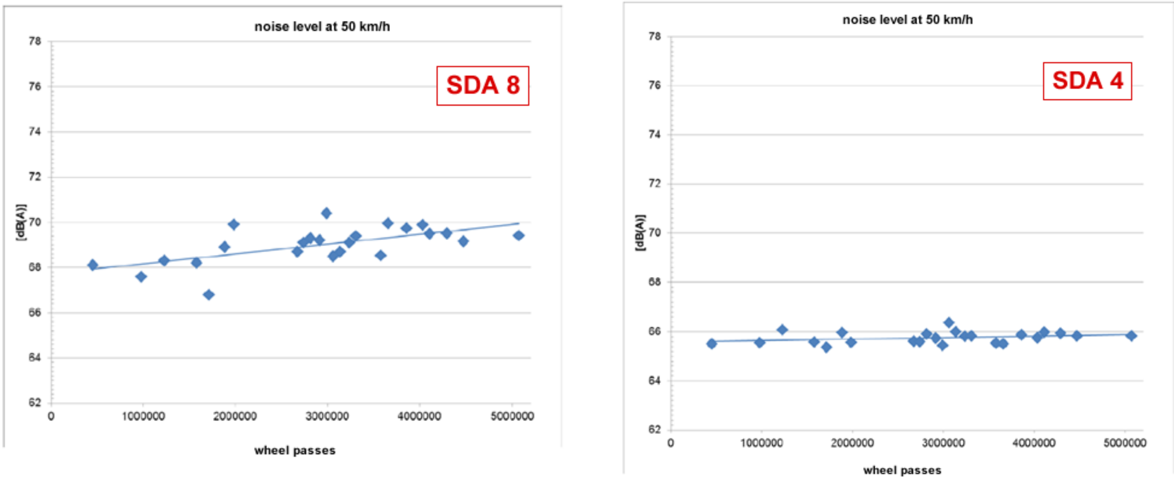


Figure 11: Noise level of the tested asphalt mixtures

7. Summary

The preparation of samples in the laboratory gave satisfactory results in comparison with the surfaces from in situ laid mixtures. The use of a smooth steel roller compactor is a good solution to preparing samples for testing the acoustic behaviour of the surface.

The developed machine for testing the acoustic durability of asphalt surfaces creates similar changes to the surface as can be observed in long-term monitoring of low-noise asphalt test sections. The changes in the surface were measured by different characteristics of the texture such as shape factor, mean depth, spectral analysis, by the airflow resistance and by the acoustic absorption.

The calculation of the tyre/road noise by using a modelling tool at different numbers of wheel passes showed a reduction in the acoustic performance for the sample with a 8-mm asphalt mixture of 2 dB(A). For the 4-mm mixture, the measured decrease is statistically not relevant.

The desired magnitude of the changes in the acoustic performance could not be reached as yet. The measured changes of the surface texture in the laboratory test method correspond to a service life in practice of about 2 years. The required number of wheel passes is too big for a use in daily business.

8. Conclusion

The results show clearly, that the developed investigation machine IMPACT (**I**nvestigation **M**achine for **P**avement **AC**ous**T**ic durability) provides similar changes to the acoustic performance than are observed in practice. This implies that it should be possible to predict the acoustic durability of an asphalt pavement in a laboratory test. Within this context, it must be clearly stated that the results are only valid for semi-dense and dense asphalt mixtures. Porous asphalts behave in a different way due to the clogging effect of the voids.

The amount of the reduction reached in the acoustic performance is, as yet, too small and the required number of wheel passes is too big. Further works has to be done to reduce the number of wheel passes and to increase the noise level. It is believed that the test method can be improved by introducing weather and climatic parameters in the test procedure.

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