INVESTIGATION MACHINE FOR PAVEMENT ACOUSTIC DURABILITY; IMPACT TESTING THE DURABILITY OF LOW NOISE ROAD SURFACE

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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. At present, testing acoustic and mechanical durability of asphalt pavements is only possible by constructing test-sections and monitoring them during loading 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 "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. Noise emission is in the present project calculated the by the mathematical 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. Thus, the test procedure of the present work enables faster development of new low noise road surfaces than conventional approaches. Moreover, IMPACT allows comparison of different products under identical and well-defined conditions.

Keywords: Acoustic durability of asphalt pavements, low noise road surfaces, testing of acoustic and mechanical durability

1. INTRODUCTION

Peace and quiet is one of our most valuable goods, but due to urbanization and increasing road traffic it can no longer be guaranteed everywhere at any time. Human activity leads to an increase in noise levels which pollute our environment. Peace and quiet is becoming an increasingly scarce resource and therefore one well worth protecting.

Unfortunately noise belongs to highly industrialized countries and it is still seen as a necessary evil for keeping our standard of living. This is why the effect of noise on our psychological and social well-being still is trivialised, but more and more studies come to the conclusion that people do not get used to noise. In addition excessive and permanent noise causes physical illness. As a consequence of this people suffer from insomnia, high blood pressure and even heart attacks. Noise also generates follow-up costs running into billions. Apart from the health costs, a very important factor is the depreciation of real estates.
A Swiss survey clearly showed that road traffic noise is rated as one of the major environmental threats compared to other environmental themes - an estimation that corresponds to the situation in most European countries.

2. ROAD TRAFFIC NOISE POLLUTION IN SWITZERLAND

Road traffic in Switzerland produces extensive noise which covers large parts of the country.

- An area of 175 km² by day and 110 km² by night is affected by high road traffic noise emissions.
- Some 1.2 million people are exposed to disturbing road traffic noise during the day (figure 1). This represents 16 % of the Swiss population.
- Noise pollution drops during the night (figure 1). The driving ban at night-time for heavy goods traffic has a very positive effect on the reduction of noise pollution, but road traffic still is the main source of noise during the night: About 10 % of the Swiss population (700.000 people) are exposed to disturbing traffic noise at night.
- Some 600.000 dwellings are affected by disturbing road traffic noise by day, representing 17 % of the Swiss housing stock (figure 1). 350.000 buildings are affected by noise pollution also at night (10 % of all dwellings).
- Over 110.000 buildings are affected by hazardous or disturbing road traffic noise during the day (figure 1). This represents 10 % of all buildings in Switzerland. 6 % of buildings (nearly 65.000) are exposed to night-time road traffic noise.
- Some 420.000 workplaces are exposed to excessive road traffic noise (figure 1), which is 12 % of all workplaces in Switzerland.
- The estimated overall costs for countermeasures to reduce road traffic noise in Switzerland comes to CHF 4.2 billion.

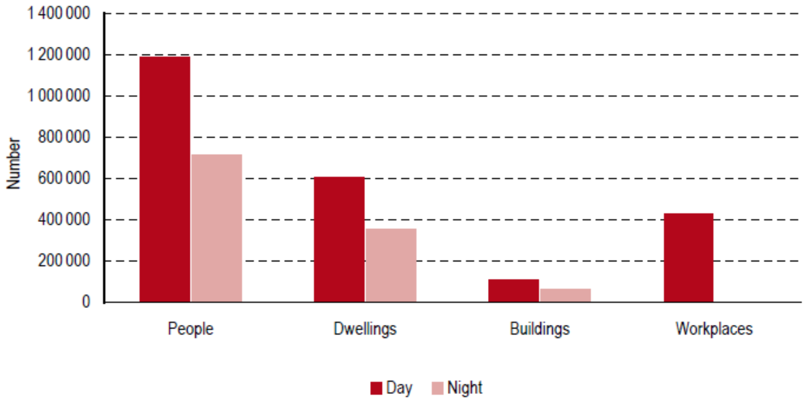


Figure 1: People, dwellings, buildings and workplaces affected by disturbing road traffic noise in Switzerland [1]

3. ABATEMENT OF NOISE STRATEGY IN SWITZERLAND

Switzerland's abatement of noise strategy is based on three fundamental principles: measures at source, precautionary measures and countermeasures. The most important legal basis is the Environmental Protection Act and the Noise Abatement Ordinance. Despite numerous countermeasures, road traffic noise remains a widespread problem. Although the measures implemented or planned up to now do only offer a minimum level of noise protection, they are still inadequate. The objective of the abatement of noise is to reduce the enormous noise pollution to a level which is deemed healthy and as far as possible to protect regions which are still peaceful and keep them free from disturbing noise pollution.

Despite intensive efforts to fight noise, numerous people remain exposed to noise emissions which are above the legally required maximum levels. The Environmental Protection Act defines the limitation of noise emissions at source as a basic principle. It is therefore essential to intensify measures such as low-noise road pavements and the use of more silent tires to protect the population against noise pollution.

4. MOTIVATION FOR LOW-NOISE ROAD PAVEMENTS

The sound emission of modern passenger cars is dominated by the noise of the rolling tires on the pavement. Only under conditions of strong acceleration or speeds below 30 km/h propulsion noise can dominate. Also for heavy goods vehicles at speeds above 60 km/h, rolling noise starts to become the major source. In 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 due to road traffic. The placement of a low-noise road pavement may represent a measure which is both, effective and economical for reducing road noise. Anywhere the placement of a low-noise pavement is possible, and it has no negative effect compared to other measures. For example, noise barriers disturb the landscape and site; sound-proof windows, require considerable investment costs in buildings.

These 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 ore façade insulation. Finally, these pavements are often the only measures which can be applied on roads in urban areas.

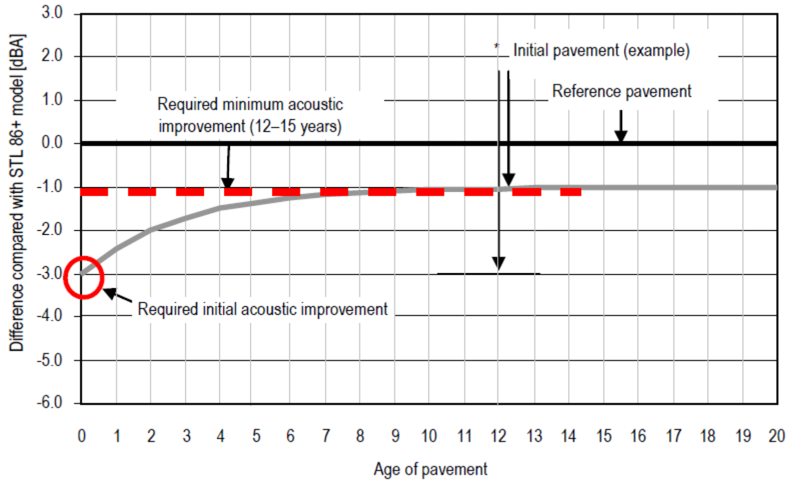
The technical possibilities of low-noise pavements are well known on highways. In general, corresponding solutions are also available for urban roads. However, until now they only have been employed to a very limited extent.

Yet, especially in urban areas the use of low-noise pavements is of great importance. Here, structural measures such as sound-absorbing barriers or embankments are feasible only in exceptional cases, due to limited space or the need to guarantee access. In many cases, topographical reasons militate against such measures, and operational measures such as speed limits or restrictions on traffic are generally impossible to implement on urban roads with heavy traffic.

5. DURABILITY OF LOW-NOISE PAVEMENTS

The main problem of low-noise urban road pavements is the durability of its acoustic features. Measurements indicate that it is absolutely possible to achieve an initial acoustic improvement of 3 dB(A) or more compared to the reference bituminous pavement (figure 2). 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.

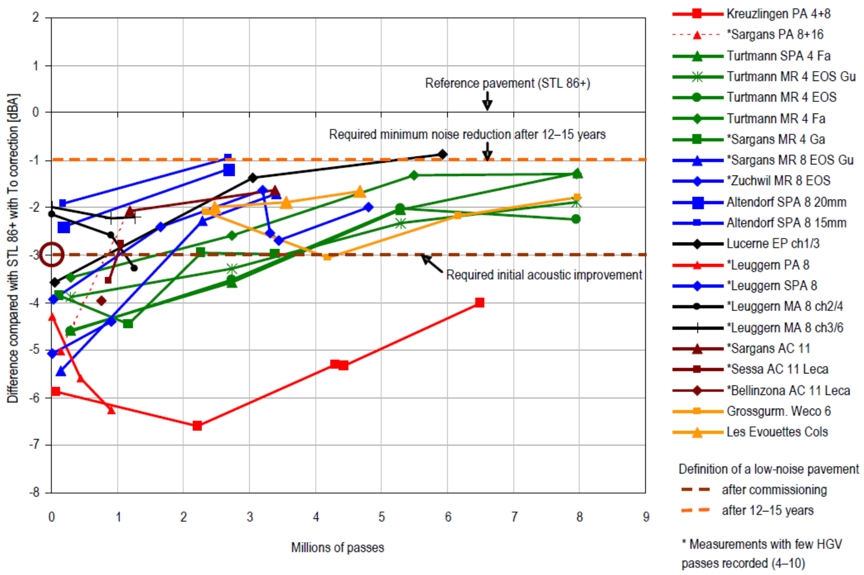


Deviation from the national reference pavement of the StL86+ noise calculation model. A pavement is defined as long-term low noise if the initial acoustic improvement is equal to -3 dBA and if the reduction is maintained at -1 dBA for least the 12 – 15 years of its useful life.

Figure 2: Definition of long-term low-noise urban pavements [2]

During the first Swiss research program on low-noise road surfaces in urban areas [2, 3], 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 involves a wide range of noise-reducing asphalt mixtures, including semi-dense macro rough asphalt AC MR and porous asphalt PA. The characteristics of the decrease 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 [4].

In correlation to 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 3). From figure 3 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.
With regard to figure 3, all examined road surfaces take a similar course.



The number of vehicle passes since commissioning was calculated on the basis of average daily traffic.
porous pavements*. : *grain size 4 pavements*. : *grain size 8 pavements*. : *grain size 11 pavements
***gravel*. : *special pavements*.**

Figure 3: Acoustic performance of pavements as a function of the cumulative traffic load [3]

6. BACKGROUND OF IMPACT

In 2011 a second multiannual research program was initiated by the two Swiss Federal Offices FOEN and FEDRO with the aim of further investigation of the promising outcome of the first phase. Considering the fact that on-site track testing over several years 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 while using a software model to predict its acoustic decrease. Thus, with IMPACT there will be a method at hand that provides fast, reproducible and cost-effective testing and development of new low-noise pavement products. Furthermore, the method will be used to perform certification procedures and additionally it will help pavement manufacturers to meet future demands on the part of road authorities.

7. THE IDEA OF IMPACT

Up to now the development of low-noise asphalt has been time consuming, and it hasn't been economical. The reasons for this are that the development itself is expensive, because of the fact that a test track has to be built, a suitable place for building the test track has to be found and several years of measuring are necessary. Additionally it is important to meet the following test section requirements:

- 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 (if the statistical pass-by SBP method is used) where there are no sound reflections of walls or buildings

In order to study the durability of a pavement the test track has to be observed for several years (data of the test track has to be collected for several years). Additionally it is not allowed to damage the pavement by, for example, digging holes (no road construction work). This would possibly influence the comparability of the measuring data of several years.
Since we know that the acoustic aging of a pavement mainly depends on the number of the roll-over cycles and not on its age, we developed a laboratory based testing device, called IMPACT (Investigation Machine for Pavement ACousTic Durability). The aim is to gain information about the acoustic durability within a month.

Since 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 [5], 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.
Within only a few weeks of testing, the obtained data enable us to make an assessment of the durability of the tested pavement. In contrast to conventional approaches the test method of the available work enables us to develop new, low noise pavements even faster.
Moreover the new test method IMPACT makes it possible to compare different products under identical and well defined conditions. IMPACT also allows for taking samples from the road and testing them in the laboratory.

8. THE CONCEPT OF IMPACT

The aim of IMPACT is to put pavement samples to the test in order to gain an insight into the acoustic durability.

IMPACT allows changing the following parameters:

- increase in temperature; from 30 to 50 °C
- wheel spin; - 5% (braking) to 5 % (acceleration); it is also possible to adjust a clearly larger spin but it doesn't make sense for the given task. There are suitable test methods which make it possilble to investigate the loss of grain (raveling) of an ashalt surface, for example prEN 12697-50 " Resistance to Scuffing" prEN 12695-50; Bituminous mixtures – Test method for hot mix asphalt – Part 50: Resitance to Scuffing [6]. With regard to IMPACT spin should lead to wear out the surface without destroying it.
- load up to 4000 N - this corresponds to the wheel load of a mid-range car
- the number of roll-over cycles (unlimited, only for economic reasons they can be limited)
- different sorts of tires (compounds, tread pattern)
- tire pressure

In order to be able to produce a test specimen with ordinary compaction instruments from the laboratory a certain length was chosen.

By using a roller compactor (a method where a smooth steel roller is used, EN 12697-35) [7], test specimen with a length of 500 mm by 180 mm can be compacted. Because the roll-over of longer test specimen is desired, two plates where fixed on a mat, one behind the other, in such a way that possible difference 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 also makes it possible to take test specimen from existing roads in order to test them. In a first step a small diameter of a tire was chosen. The emphasis was on the width of the tire, according to the intention to stress the asphalt test specimen surface as much as possible. When the tire was fixed, one had to pay attention that the camber and the track were equal to zero. Our intention was to avoid additional shear stresses between the tire and the test specimen.
In order to keep the temperature constant during the test, the whole testing device is put under a covering (see Figure 5 and 6).

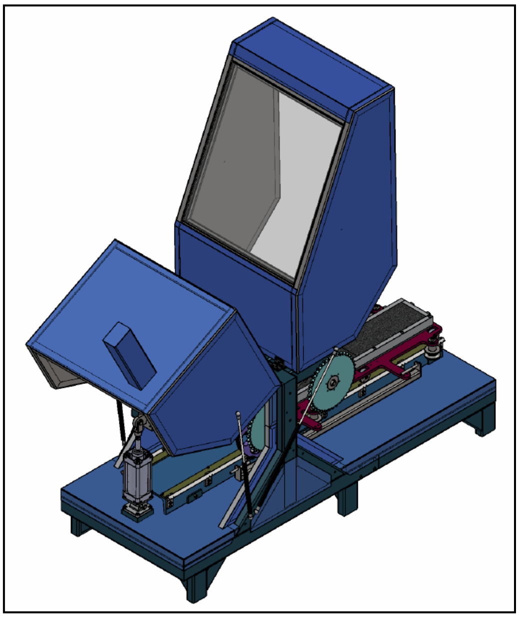


Figure 5: Drawing of IMPACT

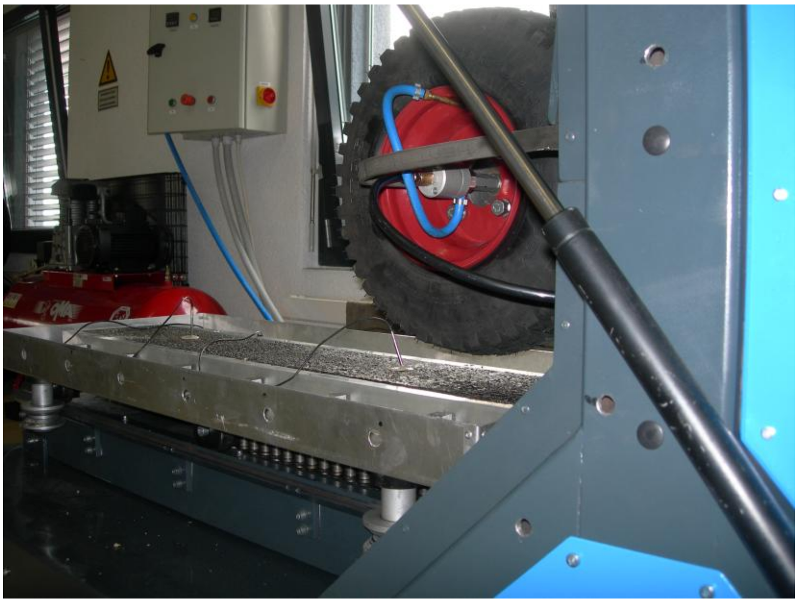


Figure 6: Picture of IMPACT

The driving speed was determined in accordance to the rutting test (EN-12697-22) [8] to 0.94 m/s. The duration of a load cycle (backwards and forwards) consequently is 2 seconds.
In order to measure the surface characteristics for the prediction model SPERoN, the test specimen can be driven out of the testing apparatus.
The roll-over of the surface of test specimen causes a change of the surface characteristics. In order to measure the different parameters which are needed as the basic data for the SPERoN Model, an even surface of the test specimen - also after the load test - is obligatory. The test conditions have to be chosen in a way that the test specimen doesn't get deformed (for example rut).

9. FIRST RESULTS

9.1 Parameter - Study

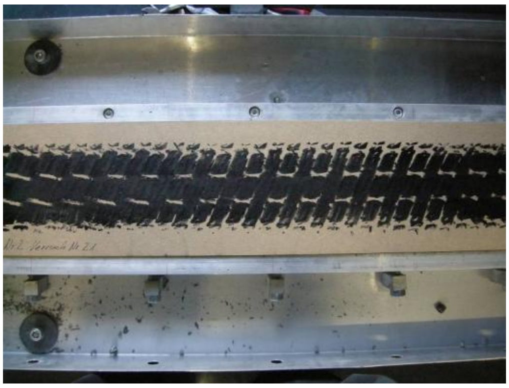
In the first step the parameters, which are temperature, interior tire pressure, load, tread pattern and spin were investigated, with the following aim (table 1):

Table 1:

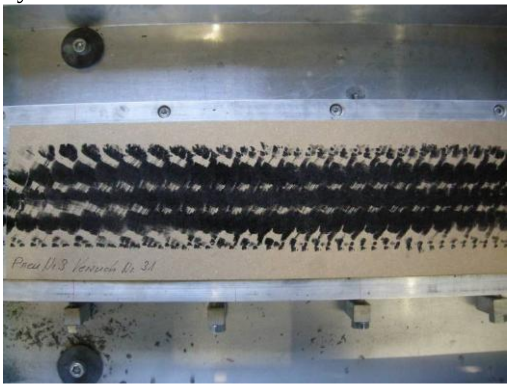
aim	investigated parameters
regular stress of the whole surface	tread pattern, spin, interior tire pressure and load
high, intensive stress without deformation, if possible	temperature, number of cycles, spin

In order to check the steadiness of the surface stress, different tires were painted with printing colour and their print was taken at different testing conditions. In figure 7 some typical prints are shown.

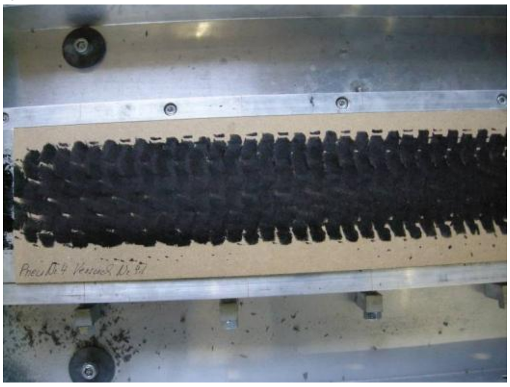
tyre 1



tyre 2



tyre 3



tyre 4

Figure 7: Typical prints of different tread pattern and different spin

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

- load : 4000 N
- inflation pressure of the tire: 300 kPa
- spin : + 5 %
- choice of the tread pattern : the chosen tires had a regular coarse tread pattern with a regular division of tread blocks.

In order to detect the possible cause for deformations a transverse profile measurement was made. The figure 8 shows exemplarily the measuring of asphalt AC MR 8 with a polymer modified bitumen PmB (CH) E 45/80-65. The measurements were made at temperatures of 30, 40 and 50°C after 10.000, 20.000 and 100.000 cycles.
At temperatures of 30 and 40°C no deformation could be detected, but at a temperature of 50° C a rut depth of 2 mm was measured. This doesn't seem much but, even such a small deformation can have the effect of an uncontrolled influence on the determination of the airflow resistance.
In addition at a testing temperature of 50° C raveling was detected.

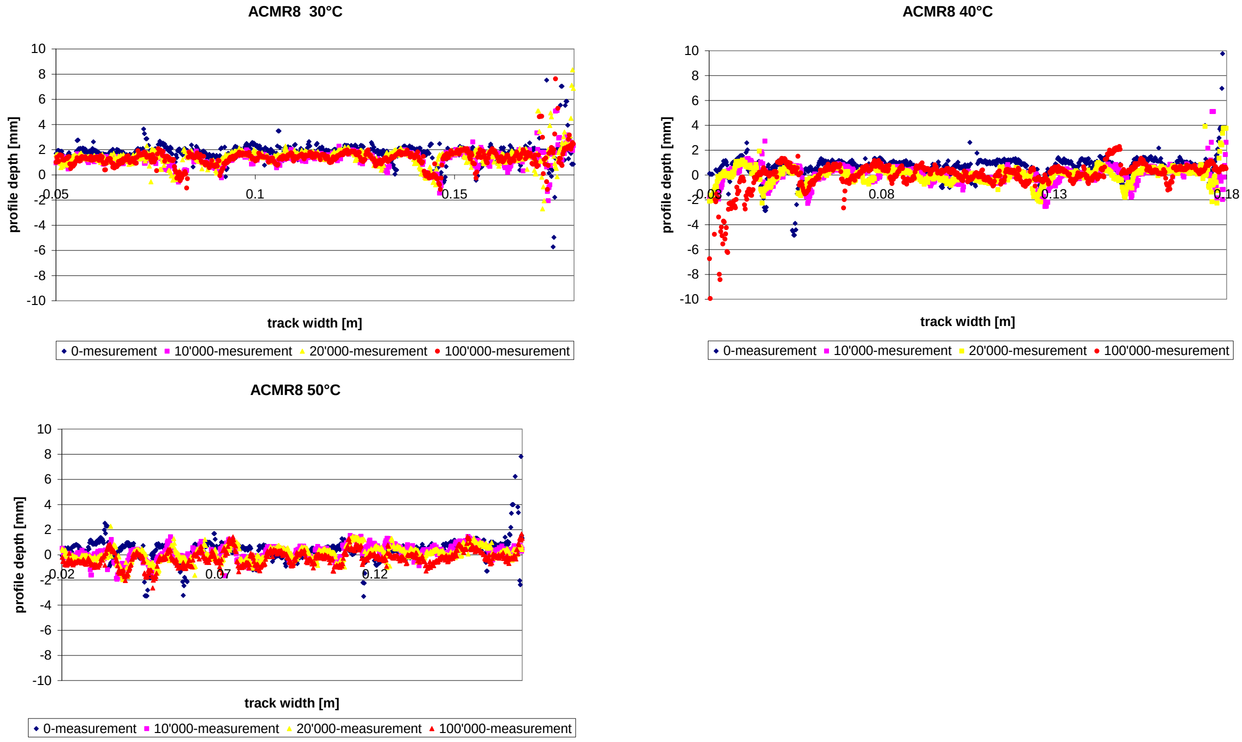


Figure 8: transverse profile measurement at different testing conditions with respect to temperature..

The determination of the degree of compaction according to EN 12697-33 [9], before and after the loading cycles, emphasizes the observation that a temperature of 50° C seems to be too high; as shown in table 2 the degree of compaction increases.

Table 2: degree of compaction increases after 100.000 cycles at different testing temperatures

Temperature [°C]	30	40	50
degree of compaction increases [%]	0.3	0.6	1.2

The choosing of the test temperature has not only to be seen from the point of view of deformation. Much more important are the experiences gained during the previous research work [10]. We came to the conclusion that the road traffic leads to changes in the texture of the pavement due to the roll-over cycles. The surface undergoes irreversible changes because of rearrangements, abrasion and kneading, smearing. Therefore, it is obvious that the structure of the pavement-surface undergoes changes, first and foremost at warm weather conditions.
Even though, also in Switzerland, temperatures can rise above 50° C, a temperature of 30 or 40°C is more common for the time of the year where changes of the textures can be observed.

It was planned to examine different kinds of rubber compounds. Within the framework of preliminary investigations, we got the impression that it should be possible to get different types of rubber compounds for the chosen tire size, or rather to have different types of tires being produced, at least in small amounts.
The intension was to investigate the influence of different sorts of tires, such as winter and summer tires, and truck tires. Unfortunately, we had to see that the manufacturers of tires - because of permanent optimization of the rubber compounds - are not able to guarantee a constant quality for years. In addition it is not possible to produce tires with different tread patterns in small amounts at affordable prices. The parameter study was carried out with a relatively soft compound, normally used for farm vehicles.
The parameter study made it possible to fix the testing conditions. After defining the testing conditions a test series with, for Switzerland typical low-noise asphalt (AC MR 8) was carried out, in order to define whether the change of the surface texture (pavement characteristics) measured under laboratory conditions are equal to results of the practical experience. The ideal case would have been to take the data of the measurements because the data are necessary for the prediction of the tire/road noise in the SPERoN model. Unfortunately, this has not been possible up to now because the SPERoN model and the methods for determining the basic data have to be adjusted to the laboratory conditions.
The prediction model was worked out on the basis of taken measurements on real road surfaces and that's why some modifications concerning the test method and the algorithms have to be made. The modifications are necessary in order to apply the prediction model to laboratory test specimen. The contribution of Beckenbauer and Angst (E&E 2012) [11] gives explanations related to this study.
Nonetheless, in order to give a first statement about the changes of the texture, a laser texture measurement according to

[12] was made on an asphalt ACMR 8. The analysis took place according to the suggestions of Sandberg [12]. The surface texture was measured after 10,000, 20,000, 50,000 and 100,000 roll-over cycles. The evaluation of the data is shown in figure 9. With a growing number of cycles, the maximum amplitude increases as well as as the wavelength at which the maximum amplitude is reported. This development was also detected at various test tracks (see [10]).

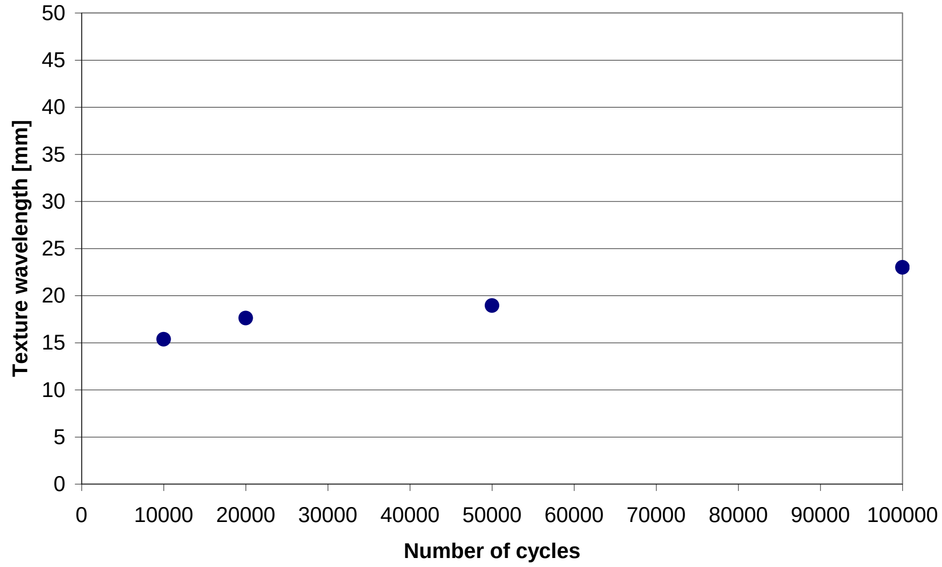


Figure 9: wavelength at which the maximum amplitude is reported as function of the number of loading cycles

10. CONCLUSIONS AND OUTLOOK

The first results show that the testing device IMPACT creates changes of the surface texture of asphalt test specimen similar to those observed in practice. In order to make further investigations, it is necessary to calculate the tire/road noise by means of the prediction model SPERoN depending on the number of roll-over cycles. Nonetheless, appropriate adjustments of the test method and the algorithms of the model are necessary.
It has been proven that a further step of development is necessary in order to be able to examine the influence of the tire tread pattern and its rubber compound, too. To make this possible, the testing device is modified in a way that a commercially available tire of a passenger car can be used (165/65 R 13). After having spoken with tire manufacturers, we got to know that the rubber compounds are changed year by year. On the other hand, the stripes which are needed to retreat a tire, can be produced with any kind of rubber compound, because only a very small amount is needed.

The length of the track on the test stand is defined once again so that more than one rotation of the tire diameter is possible. Because of that, deformations of a tire - which occur when the diameter of the tire gets partly stressed - can be avoided. By the choice of a test specimen length of about 120% of the diameter of the tire it is additionally guaranteed, that the joint inside the tire is stressed. This is crucial for a steady shape of a tire. A larger diameter of a tire means that the area where the tire is in contact with the pavement is larger too and therefore the stress of the test specimen is higher.

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