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Acoustical characterisation and life-cycle of porous road surfaces

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The German Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt) is developing an assessment procedure to characterize the acoustical properties of porous road surfaces. The final objective is to specify the life-cycle of these pavements with respect to their acoustical performance based on civil engineering properties. In 2007 comprehensive measurements of the acoustically relevant parameters absorption, air flow resistance and surface texture have been performed on a multitude of German motorways with porous asphalt pavements of different types of construction and different ages. Additional measurements of the near-field rolling noise (CPX) as well as measurements of the statistical pass-by – noise (SPB) have been performed.

From precedent projects for the sections under investigation there is an extensive database covering details on asphalt mixtures as well as the results of drill core investigations concerning void content, binder content etc.

The results of the present investigation allow to draw new conclusions with respect to acoustical performance and durability of porous asphalt pavements.

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1 Introduction

Tire road noise over years has been an increasing component of environmental noise exposure. Open porous road surfaces can be a measure of noise control equally effective and compatible to townscape. In contrast there are objections concerning higher cost for construction and maintenance of open porous surfaces as well as shorter life cycles compared to dense surfaces.

As the acoustical performance of open porous road surfaces changes with usage there is strong interest to expand the existing knowledge on the parameters limiting acoustic life-cycles of open porous road surfaces.

2 Scope of work

In the first stage of the present project a data base of the acoustically relevant parameters of selected open porous road surfaces was compiled. Therefore comprehensive measurements of the acoustically relevant parameters absorption, air flow resistance and surface texture have been performed in situ [1]. Additional data on the surfaces is available from earlier work [2].

From this data set correlations concerning acoustical performance and age of the surfaces have been drawn. The limits of the parameters have been drawn arbitrarily though they reflect the state of the art.

3 Methods of investigation

3.1 Sections under investigation

The investigation extended to a total of 17 sections with porous asphalt concrete (PAC) surfaces of different types of construction and of different ages:

- 8 sections PAC 0/8 built between 1995 and 2005
- 3 sections PAC 0/11 built between 1993 and 2005
- 5 sections 2PAC 5/8 11/16 built between 2003 and 2005

(PAC: 1 layer PAC, 2PAC: 2 layer PAC)

For all surfaces under investigation there was extended additional information concerning details on asphalt mixtures, void content, binder type and binder content etc. available from precedent projects.

3.2 Measurements performed

In the current project the acoustical parameters given below have been measured in situ:

- Absorption coefficient α for vertical incidence of sound;
- Air flow resistance R^{*}_{s} at a reference air flow velocity of u = 0,0125 m/s ;
- Road surface texture: effective roughness depth spectra $R_{\mathrm{eff,max}}(f)$ for wavelengths λ between 1,25 mm and 250 mm
- CPX-level: average near field rolling noise according to ISO/CD 11 819-2 at a speed of v = 80 km/h for tyre A and D (survey-method)
- SPB-level: average maximum sound pressure level of the pass-by noise of single vehicles according to ISO 11 819-1 for passenger cars at a velocity of v = 120 km/h

Measurements of the first three parameters listed above were performed on 4 points per section: two points in right wheel track, two points in the middle of the right track. Their respective positions can be seen from Fig. 1.

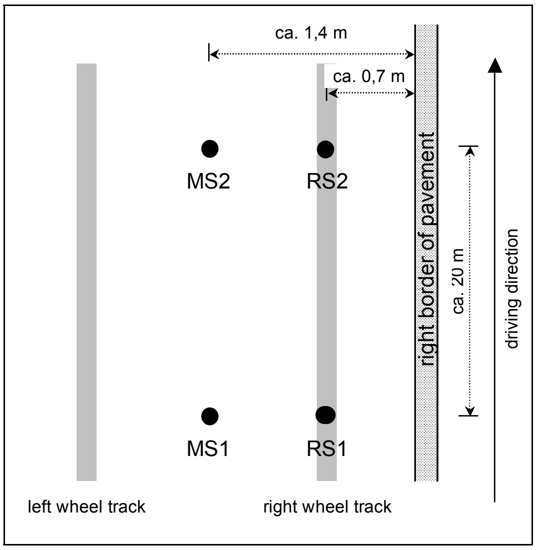

Fig.1. Position of in-situ - measurement points

4 Measurement results

4.1 Absorption coefficient

The absorption coefficients of the open porous road surfaces were measured by applying a deterministic sound signal onto the surface and simultaneously measuring sound pressure and sound velocity directly above the surface. The absorption coefficient α then is calculated from the acoustical impedance of the surface.

Measurements were performed for vertical incidence of sound. The results can be interpreted as the absorption coefficient for spherical sound waves.

The measurement results for absorption coefficients $\alpha_{0°}$ of the open porous road surfaces are shown in Fig. 2 for all types of open porous surfaces under investigation.

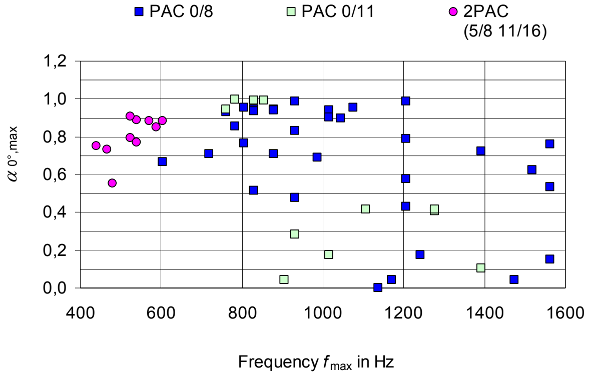

Fig.2. Absorption coefficient $\alpha_{0°}$:
absolute value and frequency at 1st maximum

For newly built open porous surfaces we expect values of the absorption coefficient between 0.8 and 1.0, depending on layer thickness, air flow resistance and void content.

The frequency of the 1st maximum f_{max} is determined mainly by the layer thickness of the surface. Typical frequencies are between 500 Hz and 1kHz for one-layer PAC surfaces with an average thickness of 4 cm. For two-layer surfaces the frequencies in the 1st maximum sometimes are even below 500 Hz. Under standard traffic conditions the absorption coefficient α decreases in absolute value.

Fig. 2 shows a wide spread in absorption coefficients specially for the one layer surfaces. This mostly may be due to the different ages of the surfaces under investigation but also to the differences in construction, binder type etc.

Fig. 3 shows the absorption coefficients measured in 2007 drawn vs. the age of the surfaces under investigation.

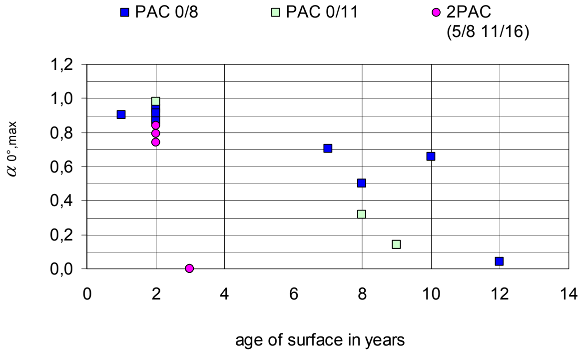

Fig.3. Absorption coefficient $\alpha_{0°}$: Measurement results 2007 vs. age of surface

Note: For one three year old 2PAC surface no absorption can be found any more ($\alpha = 0$). This is probably due to a nearby construction site causing excessive clogging of the surface.

If we set an arbitrary limit for the acoustical effectivity of PAC surfaces at $\alpha_{0°} = 0.6$ then from Fig. 3 we would get a life cycle of 8 - 9 years for one layer porous asphalt concrete surfaces. For two layer surfaces there are no surfaces at the end of their life cycle so no conclusions can be drawn for this case.

4.2 Air flow resistance

Air flow resistance is measured in situ with a steady-flow device measuring the overpressure necessary to maintain a steady air flow through the porous surface. Air flow resistance R^*_s is calculated from the overpressure Δp and the air flow velocity u by

$$R^*_s = \frac{\Delta p}{u} \tag{1}$$

The given measurement results are the values of air flow resistance at a reference air flow velocity $u_{ref} = 0{,}0125$ m/s. The results of the air flow resistance measurements in general permit conclusions on the possible evacuation of the contact patch between tire and road surface and thus the prediction of air pumping noise. In the present case the results are used to draw conclusions specially on the clogging of the open porous road surfaces under investigation.

Air flow resistance measurements on PAC 0/8 surfaces yield values between 240 and 11.000 Pa s/m in the middle of the track and between 380 and 21.000 Pa s/m in the wheel track – depending on the age of the surface and on the degree of clogging. The lowest values measured are found on a 2 year old surface (2PAC, constr. in 2005), the maximum value was found on a 10 year old surface having reached the end of it's life-cycle (PAC, constr. in 1998). Even in this latter case the surface shows a certain content of accesible voids though: the reference value for a dense surface of maximum aggregate size 8 mm (SMA 0/8) lies much higher at approx. 36.000 Pa s/m. The same holds for the PAC 0/11 surfaces: older surfaces show higher values of R^*_s due to clogging of the pores.

For 2PAC surfaces the measured values of the air flow resistance R^*_s do not exceed 2000 Pa s/m. For newly built surfaces of this type we expect values below

R^*_s = 100 Pa s/m, under traffic conditions this value increases rapidly though.

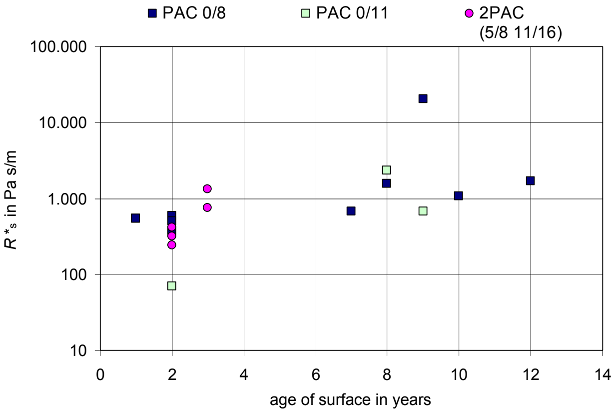

Fig.4. Air flow resistance R^*_s vs. age of surface

If we set the upper limit for the air flow resistance of an open porous surface to R^*_s = 1.000 Pa s/m for single layer surfaces from the air flow resistance measurement results we find a life-cycle of approx. 9 - 10 years.

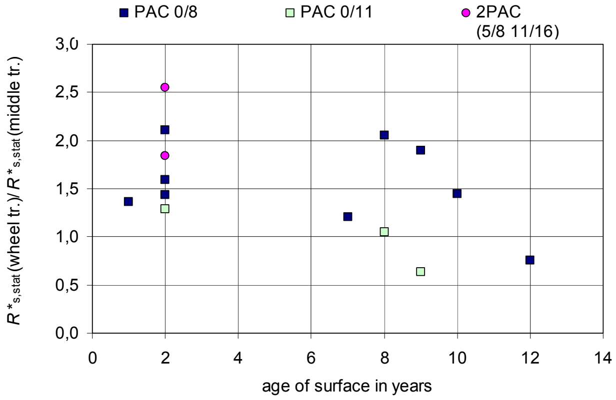

Fig.5. Air flow resistance R^*_s in wheel track / R^*_s in middle track

Comparing the measurement results in the wheel track to those from the middle of the track (cf. Fig. 5) there is no distinct trend with increasing age of the surface. In most cases however air flow resistance values in the wheel track exceed those measured in the middle of the track. This might be a hint to review the common opinion that the pulsating pressure in the wheel track surface under traffic conditions helps to prevent clogging of the pores – though the database used here is too small to confirm or reject this finding.

4.3 Surface texture spectra

Roughness profiles of the surfaces under investigation were measured by means of a laser triangulation device. From the measured profiles spectra of the effective roughness depth $R_{\mathrm{eff,max}}$(f) were calculated by FFT for wavelengths between 1,25 mm and 250 mm.

The acoustical performance of the surface is characterized by the effective roughness depth $R_{\mathrm{eff,max}}$ and the wavelength at maximal roughness depth λ_{max}. In general an increase of the maximum aggregate size will increase the maximum wavelength λ_{max} as well as the effective roughness depth $R_{\mathrm{eff,max}}$ thus yielding a stronger excitation of tire vibrations and consequently an exceeding radiation of rolling noise.

Horizontal resolution of the measurement device is approx. 0,2 mm, the vertical resolution is 8 µm.

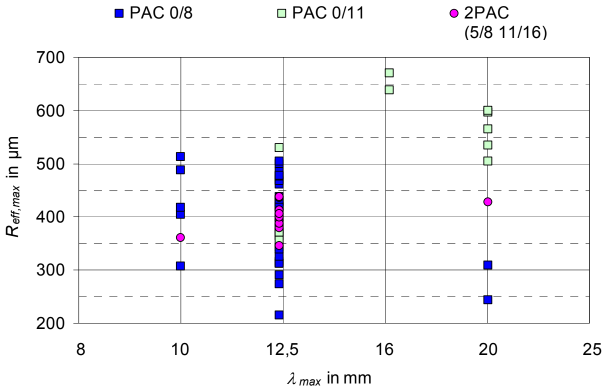

Fig.6. Surface texture measurements: Effective roughness depth $R_{\mathrm{eff,max}}$ vs. wavelength λ_{max} at maximum roughness depth.

The spectra of the effective roughness depth show a wide maximum at 12,5 mm wavelength. Higher wavelengths are found mostly on PAC 0/11 surfaces. Mean values for the effective roughness depth for the different types of surfaces are shown in Fig. 7.

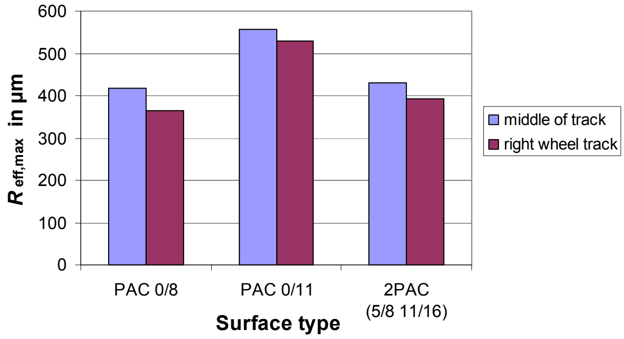

Fig.7. Mean values of effective roughness depth $R_{\mathrm{eff,max}}$ in middle of track and right wheel track for different types of surface.

4.4 Close Proximity Method (CPX)

The **C**lose **P**roximity **M**ethod (CPX) allows measurements of the average near field rolling noise without impacts of external air flow or propulsion noise of the drawing vehicle. Thus from the CPX-level direct conclusions to the tire road noise characteristics of the surface can be drawn.

CPX-measurements can be carried out continuously over a longer stretch of way. So this method is specially appropriate to characterize the (acoustical) homogeneity of road surfaces.

The measurements of the average near field rolling noise (CPX-level) have been carried out according to ISO 11 819-2 (draft 2002) at a speed of v = 80 km/h with tires A and D (survey-method). The measurements were performed on the right lane of the test sections on a total length of 200 m (i. e. locations measured in situ ± 100 m).

Data analysis was carried out for sections of 5 m length, mean values for each section are given in Fig. 8.

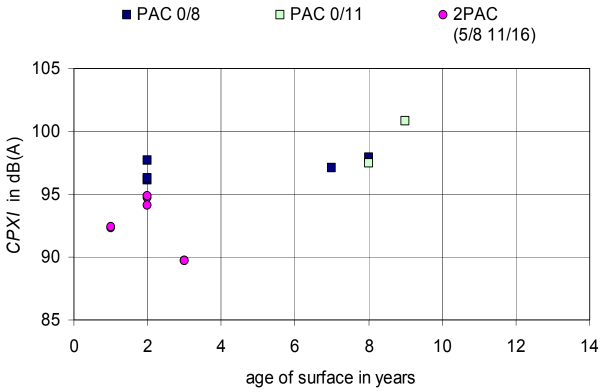

Fig.8. CPX-level measurements: CPXI values measured by survey method at a speed of v = 80 km/h. The values given are mean values for a length of 200 m.

The results of the CPXI measurements show a wide spread as can be expected from the differences in construction, age etc. Values are ranging between *CPXI* = 89,7 dB(A) on a section of 2PAC 5/8 11/16, constructed in 2005 and *CPXI* = 100,8 dB(A) on a section of PAC 0/11, constructed in 1998. This last value is probably caused by the characteristics of construction – especially by the maximum aggregate size of 11 mm – and by the age of this surface.

The measurement results in Fig. 8 do not show any clear dependence between the *CPXI*-values and the age of the surface. The 1 year values have been measured in 2006 on the same section as the 2 year values in 2007: this section in the right lane thus has suffered an increase of it's *CPXI*-value by 2 dB in one year. This is probably due to the traffic volume and especially to the high fraction trucks in the right lane (average daily traffic volume is 112.000 vehicles in 24 h, overall fraction of trucks is 7,3 %).

4.5 Statistical pass-by noise (SPB)

The measurement of statistical pass-by noise (SPB-method) allows the acquisition and assessment of the acoustical characteristics of road traffic in common and of the road surface in particular. Here the maximum sound pressure level of single vehicles passing by is measured at a height of 1,2 m above the surface and a lateral distance of 7,5 m beside the lane.

Results given in Fig. 9 show the average maximum sound pressure levels of the pass-by noise of passenger cars at a velocity of v = 120 km/h measured according to ISO 11 819-1 (SPB-level).

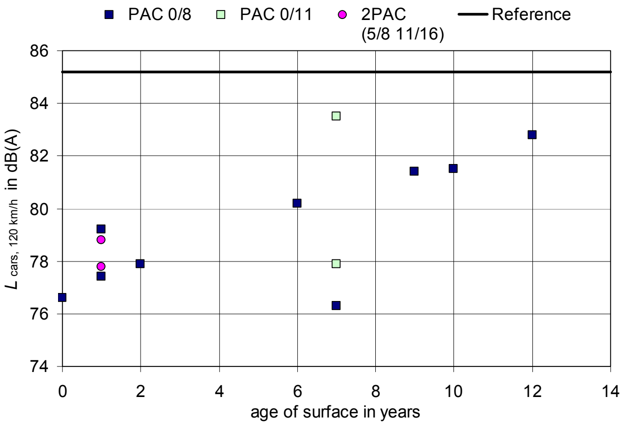

Fig.9. SPB-level measurement results: SPB values for passenger cars at a speed of v = 120 km/h over the age of the surface.

For the PAC 0/8 surfaces a clear dependence can be seen between the SPB-Level for passenger cars at a speed of v = 120 km/h and the age of the surface.

According to the German Standard RLS-90 the reference level is 85,2 dB(A) (this corresponds to the SPB level $\text{SPB}_{\text{cars,120 km/h}}$ on a standard gussasphalt road surface) [3, 4]. Open porous surfaces of type PAC 0/8 are given in this standard with a specific rolling noise level reduction of D_{StrO} = -5 dB over a period of at least 6 years on motorways [5]. This can be confirmed by the results of the SPB measurements shown in Fig. 9.

For other types of surface under investigation no reliable conclusions can be drawn due to the small number of available data.

5 Conclusion

The absorption coefficients determined in this study are rather heterogeneous due to differences in material mix and methods of construction. Thus the measurement results of different surfaces cannot be compared easily. Nevertheless if we set the lower limit of the acoustical effectiveness of porous asphalt concretes to an arbitrary value of $\alpha_{0°} = 0.6$ then from Fig. 3 we could find a rough estimate for the acoustical life-cycle of open porous surfaces of about 8 - 9 years.

Similar results can be obtained when regarding the measurement results of air flow resistance R^*_s. The results of the SPB measurements give a duration of acoustic effectivity of at least 6 years.

Due to the rather small database the results given here cannot be more than a hint to probable longer life cycles of open porous road surfaces. Further work should extend to a continuous monitoring of selected surfaces – as is performed for some test sections in Bavaria. Also the continuing development of these surfaces requires to periodically review the estimated life cycles

Acknowledgements

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