ENDURING TRAFFIC NOISE REDUCTION WITH POROUS ASPHALT IMPROVED BY POLYMER TECHNOLOGY

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ABSTRACT

Porous asphalt is commonly used in Germany in order to reduce traffic noise generated by the tire road contact. Although quite good results have already been achieved, noise-reducing pavements are still subject to a loss of performance over the years. The open pores soil and clog due to road dirt. There have been attempts in the past to clean the porous asphalt layers with water under high pressure, however, with little success. Accordingly, the idea is to prevent the asphalt layer from being plugged with dirt using polymer technology. There are three possible solutions:

1) Coatings which equalise the roughness of the pores.
2) Coatings which do not allow dirt adsorption on the pores' surfaces or which make it easier to flush away adherent dirt with water.
3) Addition of polymers to the ready-mix of asphalt which has the same effect on the pores' surfaces as described in 2) after the asphalt layer is built and cooled down.

Ensuring the performance of noise-reducing pavements with a minimal effort might give rise to an increased use of porous asphalt and thus more people could benefit from this technology protecting them against disturbing road noise.

Within this study microscopy pictures of thin sections of artificially soiled porous asphalt specimen and scanning electron microscopy pictures of the pores' surface and roughness in unmodified condition have been made and examined in order to gain important basic knowledge for the further steps described above. Furthermore, the thin sections were investigated towards typical mechanisms of soiling and clogging of porous asphalt.

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Keywords: porous asphalt, road noise, durability, polymer modification

1. INTRODUCTION

Road noise is basically caused by both the vehicle's engine and the tire road contact. The engine as a source of road noise plays an important role especially at lower vehicle speeds. It will not be considered in this paper. For the rolling noise (caused by the tire road contact) which dominates at higher speeds two possible solutions are obvious: either to improve the tires or to improve the road surface. Different properties of the road surface influence the generated noise in volume and frequency. As a reply endeavours have been undertaken to create noise-optimized road surfaces. Noise-reducing pavements can be for example noise-optimized thin asphalt layers and stone matrix asphalt, portland cement concrete pavement (PCCP), porous or non-porous, with adequate surface properties and - very common - porous asphalt layers. The major problem with these layers, which have also advantages in draining water from the surface, is clogging due to road dirt after a certain time and the (partial) loss of the open surface and the porous structure - accompanied by the mitigation of the noise reducing properties. Experience in Germany with porous asphalt layers has shown that a reduction of 4-5 dB (A) can be reached, but this effect can only be expected for 4-6 years [BMVBW, 2002]. Twinlay porous asphalt, which is a rather new development, even has reduction potentials about 8 dB (A), but long-term experience is not yet available.

Porous asphalt pavement and above all the preservation of its noise reducing ability using strategies to avoid soiling and clogging will be the main subject of this contribution. Microscopy pictures of the inside of the porous structure may give a better idea of what the typical ways of soiling are. As the research is still in progress no final results but conceivable ways of constructing porous asphalt layers in order to keep them «clean» will be presented.

2. NOISE REDUCING EFFECT OF POROUS ASPHALT

2.1 Mechanism of noise reduction

Several effects concerning the interaction between road surface and tires are known and described in literature. However, the contribution of each effect to the entire road noise is very different and still being argued about. There are two main mechanisms emerging noise. First of all, mechanical vibrations of the tire profile and the tire as a whole cause low-frequent noise (< 1 kHz). Secondly, several aerodynamical effects are responsible for noise emergence in frequencies which mainly exceed 1 kHz. One effect is caused by air which is first enclosed between the tire profile and the road surface, gets under pressure and is set free again afterwards. This effect is called air pumping. Furthermore, the so called horn effect can amplify sounds (see figure 1). However, the frequencies and volumes emitted depend on the speed and the type of vehicle – e.g. the noise of lorries is different from that of passenger cars.

Porous asphalt can avoid or at least minimize the aerodynamical effects. Air cannot be compressed between the road surface and the tire because of the open pores at the surface. The open pores, which create a certain surface roughness, can reduce the horn effect as well. Moreover porous asphalt can absorb noise due to the high air void content and the coherence of these voids in the structure.

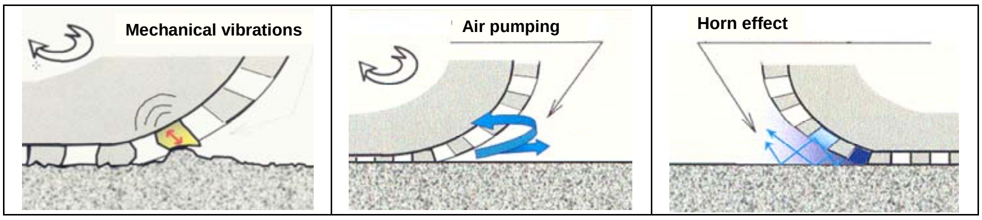

Figure 1 Main noise generating effects: Mechanical vibrations, air pumping and horn effect [Sandberg et al., 2002]

2.2 Loss of noise reduction effect due to clogging

Besides all these positive effects, porous asphalt also impacts negative aspects like higher costs, stronger oxidation and ageing of the bituminous binder as well as problems with winter road clearance. The major disadvantage, however, is soiling and clogging of the porous structure and thus the (partial) loss of the noise-reducing effect and other advantages (e.g. drainage) within few years. This is caused by tire abrasion, road abrasion, salt from winter road clearance and further dirt from the vehicles and the environment which partly clog the pores after a certain time (several years) whereby the properties of the porous asphalt become more and more similar to a conventional non-porous road surface.

Soiling and clogging affect the noise reducing abilities in different ways. Basically, there is a creeping loss of void content because the pores are filled with dirt step by step. A decrease in void content leads to a worsening of the sound absorbing effect. However, the amount of dirt which is flushed into the surface during years is not supposed to be that high that the whole porous structure is filled with dirt. Therefore another effect seems to influence noise reduction. The connection between two or more pores can be blocked by dirt particles. Therefore, some pores are isolated and cannot contribute in absorbing noise.

The major influences causing the mitigation of noise reduction thus seem to be the loss of void content and the loss of coherence of the porous structure. These and other effects of soiling should be made visible and explained in detail in chapter 3.

3. TYPICAL MECHANIMS OF SOILING AND CLOGGING

There are several possible mechanisms of soiling and clogging of porous asphalt over the years. In order to get a better impression of soiling effects, thin sections of artificially soiled porous asphalt (gradation 0/8) have been prepared and examined by microscopy (see figures 2 and 3). Furthermore, scanning electron microscopy is used to analyze soiling effects in drill cores of porous asphalt which were derived from a motorway and thus have been soiled under reality conditions (see figure 4).

Different ways of soiling can be recognized: Some pores just get filled with dirt (completely) over the years. Dirt is flushed into the porous structure, one part is carried through the porous structure to the edge of the road by water. The other part reaches the pores where dirt is accumulated. Possibile explanations for accumulation are clogging effects (so that dirt cannot be flushed through any more) or pores which only have one aperture (so that dirt cannot escape any more). The dirt is trapped and fills up the pores by the time. A loss of void content and thus a reduction of sound absorbing qualities are the obvious consequences of the "filling mechanism" (see figure 2).

A second phenomenon is the adhesion of dirt on the bituminous surface in the pores. Bitumen itself is a gluey material also due to its viscous behavior. Thus dirt particles can be adhered easily, mainly in areas with little water flow (see figure 3,a). Adhesion itself is not the major problem but adherent dirt can constrict narrow channels and connections between bigger pores. The more narrow a channel is the easier it will be plugged. Adherent dirt accelerates this development (see figure 3). Clogged interconnections mean a further loss of sound-absorbing effects (and draining properties) – although the void content is almost not influenced. That means that porous asphalt may lose its noise absorbing qualities not only due to a loss of void content but as well due to the closure of interconnections between the pores, while the void content stays nearly constant.

A third soiling mechanism theory can be developed. Apart from the mineral particles of the dirt small black-colored bitumous particles can be recognized (see figure 2,b and 3,b). That indicates that small bitumen particles or filler particles covered with bitumen break out of the asphalt by abrasion. These particles support soiling which means a kind of self-soiling. Bituminous particles may also lead to a further development of dirt agglomerations because of the adhesive properties of bitumen.

The development of such compact agglomerations is a fourth mechanism of soiling. The agglomerations are supposably based on the use of salt in winter road clearance and the impact of temperature during hot summers. The scanning electron microscopy pictures in figure 4 show such agglomerations (marked with circles). The left one on picture (1) may be caused by temperature because of the close bonding between dirt and bitumen in the pores, which almost show a homogenous structure. Picture (3) shows a possible way of bonding between bitumen and a dirt particle. The particle is to a certain extent embedded into the bitumen film. This may be caused by higher temperature exposure during summer months or may just a be matter of time due to the viscous properties of bitumen. The agglomeration in picture (2) (which is enlarged from picture (1)) shows a different structure. In this case the intensive bond seems to appear only between dirt particles without the involvement of the bituminous surface. The bitumen is only a linking part to the surface but does not seem to be part of the agglomeration. The use of road salt ($NaCl$ and $CaCl_2$) in winter could be a possible explanation for the development of such agglomerations due to the hygroscopic properties of salt and the ability to create stable crystal lattices.

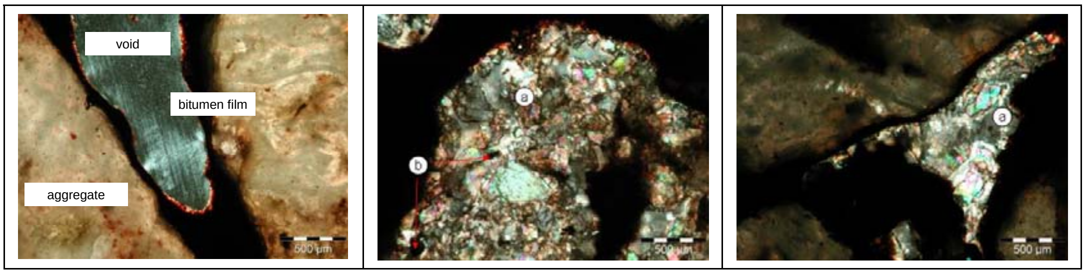

Figure 2 Filling mechanism of pores; dirt deposit (a) resulting in lower void content of porous asphalt, bituminous dirt particles (b) [Maróthy, 2006; Kuti, 2006]

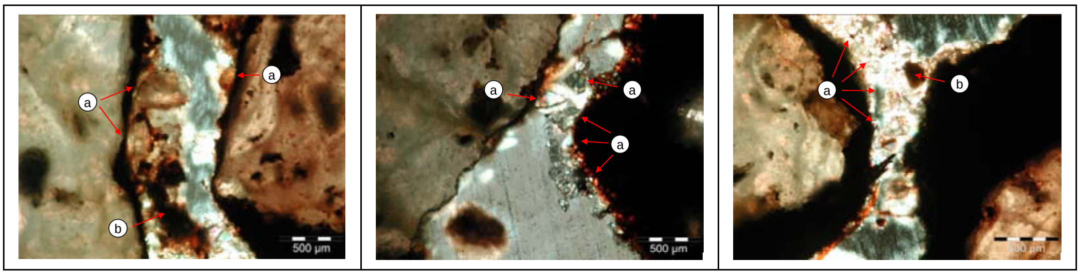

Figure 3 Clogging of pores; dirt adhesion at bottlenecks showing the tendency of clogging (a), bituminous dirt particles (b) [Maróthy, 2006; Kuti, 2006]

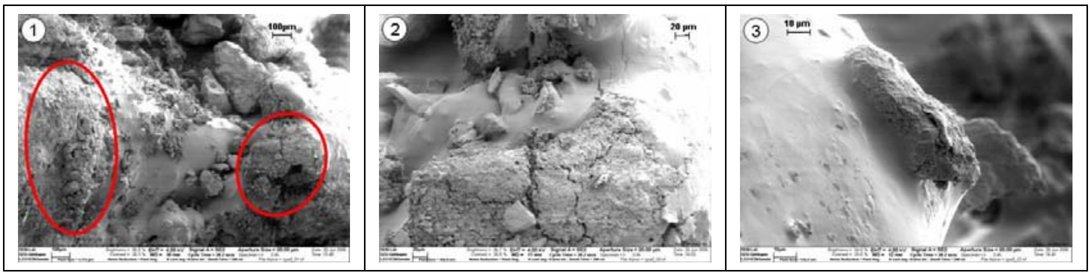

Figure 4 Dirt adhesion and development of dirt agglomerate (marked with circles) (1); enlarged image of dirt agglomerate (2); dirt adhesion on bitumen (3) [Maróthy, 2006; Kuti, 2006]

4. REDUCING SOILING AND CLOGGING

4.1 Artificial cleaning with water

There have been several attempts in the past to clean porous asphalt layers with high-pressure cleaning equipment installed on a special truck. Water is pressed in the porous structure and afterwards removed by suction so that the dirt is flushed out of the pores, collected and thus can be disposed. However, the results concerning the recovery of noise-reducing properties of the porous asphalt have been rather poor. The frequency of cleaning should have been very high to achieve a proper effect towards noise reduction. This, however, is not cost-effective at all.

4.2 Modification of the pores' surface

Periodical cleaning could be a solution to avoid clogging but the results achieved by cleaning with high-pressure cleaning equipment are not satisfactory yet. Therefore, another way to deal with clogging will be tried. The material itself should be made resistant to dirt adsorption which means that either dirt cannot be adhered on the pores' surface or can be at least easily washed out again with water. The surface of the pores has to deliver these dirt-resistant properties. There are three strategies which will be tried to prevent dirt adsorption in the pores:

The first one is a rather simple equalisation of pores' roughness with a polymer coating (1), the second one is the creation of a very hydrophilic surface (2) and the third one is the creation of a micro-structured hydrophobic surface (3). Figure 5 shows the basic mechanisms and effects on the bituminous binder surface. In case (1) the smoothened surface in the pores should bar the dirt from adhering to the surface. In case (2) a thin water film spreads completely on a "superhydrophilic" surface with extremely low contact angle and is able to undercreep dirt particles. This kind of surface cannot avoid dirt adhesion but could make it easier to flush away the dirt – by rain or artificial cleaning. The third possibility (3) is a combination of two surface effects, a very hydrophobic surface which is additionally micro-structured. This combination is copied from nature and known as "lotus self-cleaning effect". Dirt can only adhere to the surface with little contact points because of the micro-structure. Water cannot intrude into the hydrophobic micro-structure, it can only move on top of the micro-structure with minimal contact area and thus pick up well the accumulated dirt particles. This method can diminish dirt adhesion and enables the surface to be cleaned with water in an easier way.

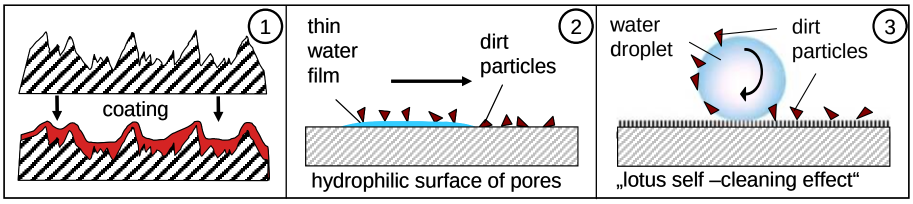

Figure 5 Alternatives to create dirt-resistant surfaces in the pores; equalisation of pores' roughness (1), very hydrophilic surface (2), hydrophobic, micro-structured surface ("lotus self-cleaning effect") (3)

The surface modifications in the pores may be achieved by means of coating the porous asphalt layer (post-paving) or adding special polymers to the asphalt ready-mix before paving (pre-paving). This polymer phase is first distributed equally in the bitumen and after the completion of paving these polymers should move to the bituminous surface of the pores (self-stratifying effect) and according to their composition should make the surface either hydrophobic or hydrophilic (see figure 6).

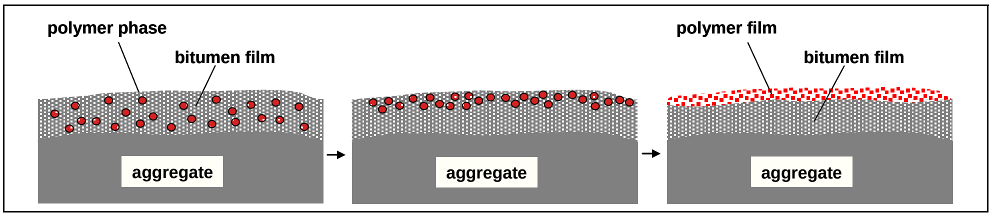

Figure 6 Self-stratifying effect of polymer creating a dirt-resistant surface

The pre-paving method has advantages in practical realization because the addition to the bituminous binder or the asphalt mixture in plant is a procedure which is rather easy to handle. A disadvantage may be that the added polymers could change chemical attributes and thus affect other properties of the porous asphalt such as stability. Using coatings is a difficult and complex manufacturing process realizing that roads are constructions with a very big surface area. However, the danger that asphalt properties are affected decreases because it is only a (physical) change in surface behaviour which should not influence chemical behaviour of the asphalt mixture as a whole. Many different investigations will have to be conducted to find the most appropriate method (see also chapter 5).

5. INVESTIGATION OF EFFICIENCY AND FEASIBILITY OF THE PROPOSED SOLUTIONS

5.1 Feasibility of coating strategy

Knowing the surface characteristics and roughness in the pores is important to be able to choose an adequate coating. Research on the pores' surface has been conducted using scanning electronic microscopy (see figure 7). The micro-roughness shows a very inhomogenous structure, regular roughness parameters cannot be determined. The major influences on the micro-roughness in the pores seem to have their origin in filler particles (a), cellulose fibers (b) and the micro roughness of the aggregate (c). These components can either be covered by bitumen or not, which creates different roughness elements. The roughness in the pores can be characterized by unsteady, little roughness peaks mainly caused by filler material and wide « roughness valleys » (d) with a smooth, pure bitumen surface (see figure 7). There was no observable difference between the roughness of a laboratory specimen and drill cores taken from a motorway.

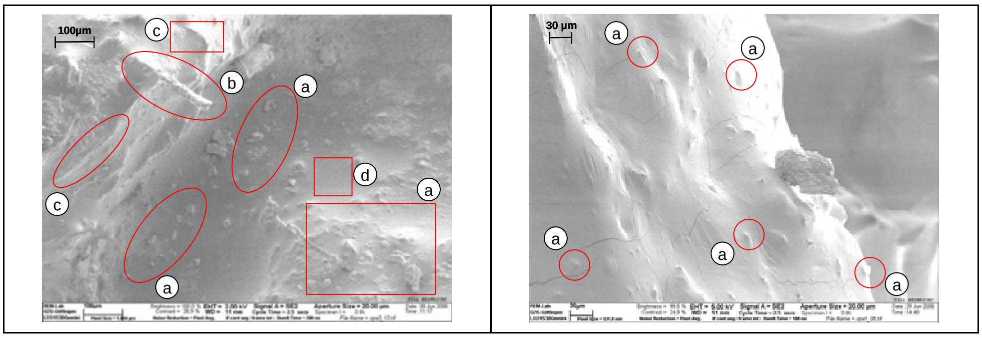

Figure 7 Roughness of pores' surfaces in porous asphalt (0/8) showing different roughness elements: filler particles (a), cellulose fibers (b), micro roughness of the aggregate (c) and smooth bitumen surface (d) [Maróthy, 2006; Kuti, 2006]

The knowledge of the roughness is one of the basic information for further decisions about the adequate material and thickness of the coating.

Furthermore the coating must be tested for the best application temperature, the adhesive strength to the bituminous binder has to be proved and last but not least the coating should cover the predominant area of the pores to achieve the best efficiency possible – a question of viscosity of the coating and application method.

A closer view is also necessary towards skid resistance after the application of the coating. Although the coating should only cover the pores' surfaces inside the layer it will not be avoidable that also the road surface is covered. Accordant tests with the Wehner/ Schulze testing method [FGSV, 1999; Huschek, 2002] will show the influence of the coating on skid resistance. No additional measures improving skid resistance will be necessary if the behavior of the coated asphalt is similar to the one of common asphalt surfaces as far as the abrasion of the surface and an increase in skid resistance in the first weeks is concerned.

Viscosity and application method also play an important role for keeping the pores open. The coating must not fill the pores as a whole and thus clog the porous structure. Fulfilling all conditions – reaching as many pores as possible while avoiding clogging by the coating itself and ensuring adequate skid resistance – will be the most important demand within the coating task.

5.2 Feasibilty of polymer addition to the asphalt ready-mix

The knowledge of bitumen film thicknesses occuring in « real » porous asphalt is important to be able to prove the self-stratifying effect with the according bitumen film thicknesses in laboratory testings. The analysis of thin sections (of porous asphalt with a gradation 0/8) has given a first idea of film thicknesses in the pores' surface in reality. The measured thicknesses of bitumen films spread very strongly, of course. An average of about 150 µm with a standard deviation of 120 µm has been detected. Most of the considered film thicknesses are less than 200 µm, the 75 %-quartile is 192 µm. Only film thicknesses with a contact surface to air are part of that analysis, film thicknesses between aggreagte have been neglected.

Measurements of contact angles of water on the thin bitumen films with modified surfaces will prove the controlled decomposition of polymer and asphalt and the changing of surface properties. In the case of a hydrophilic surface the contact angle will decrease while for a hydrophobic surface an increase is to be expected.

Testings concerning asphalt technology have to be conducted with the modified asphalt to ensure that no negative effects on other important properties of the pavement appear, e.g. skid resistance, stability or accelerated ageing. The polymer might change the viscous behavior of bitumen, which could affect stability at high and low temperatures. In fact, penetration and softening points of the modified bitumen must be controlled carefully.

Standard stability tests with the ready asphalt (Marshall specimen), which are obligatory anyway, will complement the test series.

5.3 Efficiency of strategies

Tests with bitumen films and laboratory asphalt samples will give a first impression of the efficiency of the modified surfaces concerning dirt resistance properties and the possibilities of dirt removal.

In first trials bitumen films (with added filler) will represent the surface of the pores. The thickness of the films is derived from the analysis of bitumen film thicknesses (see chapter 5.2) They are easier to handle and the non-soiling effect of the surface can be verified in a more easy way than inside an asphalt specimen. The (modified) bitumen samples are treated with dirt which is tried to wash away again with as little effort as possible

The dirt used for the investigations is a mixture of mineral aggregate in different sizes and shares, real tire abrasion material, additional organic material and road salt. The composition concerning organic and mineral fraction as well as the gradation is based on former literature about road dirt and special studies about dirt which is gained by cleaning porous asphalt surfaces. These studies are conducted by a partner (« Orgalab ») in the research network of « Leiser Straßenverkehr 2 ».

Of course the efficiency has also to be tested in porous asphalt specimen, first trial will be done with small samples (26 x 32 cm) where dirt is applied onto the surface and flushed into the porous structure with water. The water running through the asphalt is collected and the amount of dirt in the runoff is analyzed. The more dirt is found in the discharge the better the efficiency of the applied measure.

After those basic tests the "ready pavement" will be tested under simulated soiling and rain impact on 2.5 m² asphalt samples in order to learn more about the achieved effects under real conditions concerning rain, soiling and pavement runoff (transversal slope 2.5 %). Artificial rainfall is applied on the porous asphalt layers, which are different in gradation, thickness (4 cm, respectively twin-lay 7 cm) and modification. The dirt is flushed into the pores, the runoff can be collected, the amounts of water and dirt in the runoff are measured. The gradation of the dirt in the runoff will be analyzed aditionally by « Orgalab ». The input and output of dirt can thus be compared and deliver conclusions about the soiling tendency of the porous asphalt. Acoustical measurements of the asphalt samples will accompany the soiling experiments.

Traffic impact, however, which is supposed to have a positive effect against soiling and clogging cannot be simulated within these tests.

6. CONCLUSIONS

Porous asphalt pavements must be improved towards durable noise reduction. The durability concerning noise is endangered by soiling and clogging of the porous structure. The creeping loss of void content and the loss of interconnections of the network of pores leads to the decline of the absorbing effect and thus the noise reduction. This problem is well-known but could not be solved adequately yet. The mechanisms how dirt is accumulated in the porous asphalt layer are manifold. Some pores are just filled with dirt, (narrow) interconnections are being clogged after certain time; dirt which adheres to the bituminous surface supports clogging tendencies. Trials to clean porous asphalt layers with high pressure cleaning equipment have not led to the desired success in the past. In fact, this research project tries to look for alternative solutions. The surface of the pores within the pavement should be made dirt-resistant or at least washable in a more easy way with surface technology using polymers. Possible solutions are e.g. very hydrophilic as well as very hydrophobic, micro-structured (« lotus self-cleaning effect ») surfaces of the pores. These dirt resistant properties of the pores could be reached either by coating which are applied after building the porous asphalt layer or the addition of special polymers in the ready-mix before building the layer. Different approaches are examined and tried to bring to road construction practice. The manifold tests and investigations with bitumen films and asphalt samples should show the most efficient, feasible and practicable way to improve porous asphalt towards lifelong noise reduction properties at last.

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