New concepts for low noise concrete road surfaces

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ABSTRACT

Increasing road traffic requires road surfaces that are simultaneously durable and low noise. Durability could be best provided by concrete roads, but standard concrete road surfaces do not achieve noise reductions better than 2 dB, which is not sufficient to compensate the increase of noise levels due to increasing overall traffic volume. Nevertheless, theoretical investigations considering the mechanisms of tire-road noise generation show a much higher noise reduction potential for concrete roads. In German and international research projects several concepts of low noise concrete road surfaces have been investigated, including the optimization of standard road surfaces like exposed aggregate concrete or the postprocessing of concrete roads by diamond grinding but also porous concrete. In addition, new surface types have been developed from a virtual design, taking into account the deeper understanding of tire-road noise generation: these concepts include specifically designed road surface textures, novel materials for road construction such as ultra high performance concrete or specially designed porous concrete. Some of these surfaces have been built on site to assess the achieved noise reduction capacity in practice. This paper resumes the projects’ outcomes and the respective achievable noise reduction, durability and technical feasibility of the investigated concrete road surfaces.

Keywords: Tire-road noise, concrete road, low noise road surface, I-INCE Classification of Subjects Number(s): 11.7.1, 52.3, 76.1.1

1. INTRODUCTION

1.1 General

For most European countries, road traffic – and especially heavy traffic – is predicted to increase by a substantial percentage within the next few years. Thus, road building authorities in future will have to cope with both the demands of noise control for inhabitants and of high durability of the road. Additionally, safety requirements must be considered.

Concrete is an appropriate material for the construction of highly durable roads, esp. for the construction of motorways. Exposed aggregate concrete roads, however, show only a relatively small noise reduction by about 2 dB compared to the German reference roads - which is not sufficient to compensate the increasing impact of traffic noise due to the predicted traffic growth within the next years. The understanding of the generation mechanisms of tire-road noise gained during the last decade as well as practical observations might help to develop novel concepts for low noise concrete roads.

1.2 Mechanisms of tire-road noise

Theoretical investigations and comprehensive measurements performed in earlier research projects were used to set up the so-called SPERoN model, a calculation model that allows to predict the pass by noise of passenger cars from road surface and tire parameters (1, 2, 3).

The calculation model takes into account the following noise generation mechanisms:

- Tire vibrations and torus resonance noise, induced by road surface roughness and tire pattern,
- Air pumping and horn effect, influenced predominantly by the road surfaces’ acoustic
impedance. The road surface’s absorption coefficient is proportional to the surface’s void content. This allows a rough classification of road surfaces to:

- Dense surfaces: void content below 5 %,
- Semi-porous surfaces: void content approx. 12 %,
- Porous surfaces: void content above 18%.

The influences of the road surface roughness (texture) and of the sound absorption on the noise reducing potential of a road surface are shown in Figure 1, together with the related mechanisms of tire-road noise generation.

![Figure 1](image_url) – Noise reduction capacity of a road surface, depending on void content and road surface roughness (texture).

### 1.3 Possible concepts for low noise roads

As can be seen from Figure 1, both, an optimized texture and increased void content could lead to a better acoustic performance of concrete road surfaces.

For dense surfaces this means to adapt the concrete road’s surface texture to the requirements of low noise roads. In preceding research projects, e.g. “Low noise road traffic 1” (1) and ITARI (4), it was found that dense road surfaces under certain conditions are able to provide a rolling noise reduction capacity of up to 5 dB compared to the German reference road surface. However, this requires a very smooth surface with a fine texture in dimensions of a few millimeters or even less. Producing this kind of road surface texture requires either an appropriate, very fine grain material such as ultra high performance concrete (UHPC) with an adapted method of production (5, 6, 7) or special methods of postprocessing a standard concrete surface, such as diamond grinding (8, 9).

In the case of porous road surfaces, a sufficient amount of open/accessible pores has to be provided by the construction material. For open porous concrete this requires an appropriate material composition with a non-steady grading curve of the coarse grain component and a high quality binder to ensure the road’s long term stability even under heavy traffic.

The construction concepts investigated in several German research projects will be described in detail in the following sections.

### 2. DENSE CONCRETE ROAD SURFACES

#### 2.1 Exposed aggregate concrete

Roads built in exposed aggregate concrete are the only low noise road surface in concrete being included in German road construction standard. Their noise reduction capacity is given by 2 dB compared to the German standard road surface. Though the construction of exposed aggregate
concrete roads is described in detail in technical guidelines being an integral part of the construction contract, the actual noise reduction capacity of exposed aggregate concrete roads shows a wide spread. This indicates that the parameters relevant to noise generation on exposed aggregate concrete surfaces are not considered sufficiently in the regulations and/or that the available machinery is not suitable to build low noise road surfaces on target.

In a research project on behalf of the German Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASf) the parameters relevant for noise generation on exposed aggregate concrete roads were identified. Additionally, the respective optimization potential considering noise reduction of exposed aggregate concrete road surfaces was investigated in detail (10).

This resulted in the following set of construction parameters for a good acoustic performance of exposed aggregate concrete roads surfaces:

- Max. aggregate size ≤ 8 mm,
- Steady grading of coarse material,
- Grain shape \( S_{15} \),
- Profile peaks count ≥ 50 peaks in 2500 mm\(^2\),
- Texture depth should be kept as small as possible, but the surface must ensure sufficient grip.

Nevertheless, the project showed as well, that even in case of an optimum choice of the parameters mentioned above, the potential noise level reduction of exposed aggregate concrete road surfaces is limited to values not much better than the 2 dB given in the German standard.

### 2.2 Diamond grinding

Another possibility to influence evenness and micro texture of concrete road surfaces is diamond grinding the road surface. In a comprehensive study on behalf of the German Federal Highway Research Institute (8, 9) the influence of material composition and grinding parameters such as the width and distance of grinding discs and the depth of grinding on the acoustic performance of a concrete road surface has been investigated.

In the first project step, different diamond grinding patterns were generated by calculation and then used as input for SPERO calculations to identify grinding parameter sets achieving low noise values. In a second step, laboratory samples with different material compositions were treated with the grinding patterns selected in step 1. On these samples air flow resistance and surface texture profiles were measured, the measurement results again were used as input for SPERO calculations to estimate the acoustical performance for the different combinations of material and grinding pattern that could be achieved on real roads.

As can be seen from Figure 2, depending on the material composition and esp. on the coarse aggregate type, the appearance of the grinded surface can be very different even for identical grinding parameters.

![Figure 2 – 3 different concrete samples treated with the identical grinding pattern (photos: TU Munich)](image)

As a result acoustically optimized combinations of material and grinding parameters were found, which allow to obtain low noise road surfaces from diamond grinding of existing concrete road surfaces.

In a subsequent, still ongoing project, selected sets of grinding parameters were applied to existing and newly built concrete roads, an example is shown in Figure 3. First acoustical measurements on test tracks have shown promising results, but evaluations are not finished yet.
2.3 **UHPCroad**

A completely new approach to build low noise concrete roads was chosen in the project “Multi-function whitetopping road in nanooptimized ultra high performance concrete (UHPC) - Design and production of a low noise surface texture” funded by the German Ministry of Research (5).

In preceding research projects (1), dense low noise road surface textures with level reductions up to 5 dB have been designed by starting from pass-by noise calculations. An example for such an artificially generated low noise surface is shown in Figure 4:

Within the ITARI project (4), controlled pass by (CPB) measurements were performed on a test track, which proved a substantial pass by noise level reduction by this artificially designed surface.

As the special characteristic of the ITARI surface is its very smooth surface with narrow funnels in only a few millimeters distance, an appropriate fine grain material had to be chosen for building this low noise road surface on a bigger scale, such as ultra high-performance concrete (UHPC) – a fine grain material providing strength and durability as well.

Within the UHPCroad project a sensitivity analysis was performed with several modifications of the original texture to find a texture design adapted to the specific properties of UHPC and to the chosen texturing method without affecting the noise reduction of the road surface. An adapted recipe
for UHPC and an appropriate surface texturing method were developed for the implementation of a two-layer UHPC road, consisting of a lower bearing layer with a textured wear layer on top.

![Figure 5 – small scale test of low noise surface in UHPC](image)

Tests on a small scale (cf. Figure 5) have shown, that in case of an optimal implementation of the newly designed road surface pass-by level reductions up to 6 dB can be reached, actually large-scale productions should achieve level reductions of 3 dB to 4 dB. As a drawback, there is a need to adapt the construction technology for the upper layer, as the working and compacting of the UHPC mortar on site requires modifications in machinery.

### 2.4 UHPC-F

After the experiences made within the UHPCroad project, the focus of the subsequent project “Low noise road from prefabricated slabs in UHPC” was to develop a method to reproduce the predefined surface texture as precise as possible in prefabricated parts from UHPC for the use as a durable and low noise road surface. The production of prefabricated parts overcomes most of the technological difficulties encountered in the UHPCroad project, as the technology of mixing and moulding UHPC in this case is performed under controlled conditions.

As there were only minor modifications of the UHPC recipe required, the adapted texture design for the low noise surface could be easily adopted from the UHPCroad project. The main focus was to obtain the fine grain surface and a precise reproduction of the predefined texture also for the top-down casting method used for production of the elements.

The second task was to develop an appropriate laying technology to ensure long-term stability, which included dowelling of the single elements and setting up an appropriate method for grouting the elements in place (cf. Figure 6).
To ensure sufficient load, the test track was built in the driveway of a parking lot of a motorway (Figure 7), which is predominantly used by trucks. So, constructional and acoustical long-term stability of the test track can be monitored under realistic load and wear conditions.

The acoustic performance of the UHPC test track from precast elements was tested by CPB- and CPX-measurements as well as by measurements of surface texture and of air flow resistance. The situation during CPB measurements is shown in Figure 8.
Figure 8 – test track of UHPC precast elements during CPB measurements

As can be seen from Figures 7 and 8, due to technical difficulties during casting and laying the precast parts, in some areas minor surface irregularities in the surface such as wavy steps in the joints are observed. These are due to the fact, that the elements’ die-plate had to be composed from several small tiles. It must be mentioned that these difficulties are due to the limited budget within the research project to build a demonstrator and can be easily handled in a large scale production.

For the controlled pass-by measurements an optimum track as shown in Figure 8 was found to avoid the above mentioned steps in the measurements.

Driving speed in the CPB measurements ranged between 40 kmph and 75 kmph, the measurements were performed with 3 different sets of tires. Under the given circumstances, the measurements were performed for the optimum and the non-optimum tracks on the UHPC road surface respectively. The results for the optimum tracks are drawn in red in Figure 9, whereas the results for the non-optimum tracks are drawn in black.

Figure 9 – CPB measurement results for test track of UHPC precast elements. Red: optimum track, black: non-optimum track

In the CPB-measurements, the UHPC-F road surface from precast elements achieved a noise level reduction of about 3 dB for the non-optimum state and up to 5 dB for the optimum state of the surface. Parallel measurements with an SRT pendulum have shown a sufficient wet grip of the surface. So, the UHPC-F road surface from precast elements can be considered a new approach to low noise concrete roads.
3. POROUS CONCRETE SURFACE

3.1 Low noise concrete block pavement

A successful realization of porous concrete road surfaces has been achieved within the joint project “Low noise block pavement in concrete” performed on behalf of the German Federal Highway Research Institute by sf-Kooperation, Munich Technical University and Müller-BBM (11).

Concrete block pavements are used mainly in dwelling areas with a low driving speed.

In this project theoretical investigations on optimum material packing density for a maximum degree of absorption at the given velocity of 30 kmph were combined with laboratory measurements of absorption coefficient and air flow resistance (cf. Figure 10).

![Figure 10](image1.png)

Figure 10 – Calculation of absorption coefficient as a function of void content

In further steps performed in collaboration with the manufacturer, the production process of the block pavement was adapted to the special requirements of porous concrete. The challenge was to achieve an adapted stability of the coarse aggregate matrix and the binder and at the same time provide a sufficiently high percentage of open voids to guarantee noise reduction.

![Figure 11](image2.png)

Figure 11 – Drill cores of porous concrete block pavement for laboratory tests
On a test track built within the project, measurements of statistical pass-by noise (SPB measurements, cf. Figure 12) yielded a noise level reduction by approx. 7 dB for passenger cars at 30 km/h (11).

Figure 12 – Test track of porous concrete block pavement during SPB measurements

4. CONCLUSIONS

Concrete road surfaces have a potential to optimize their acoustic performance, but this requires the use of novel materials and of concepts beyond standard road construction. Therefore, there is a high need for an intense collaboration between planners, construction companies and acousticians to achieve the full potential of concrete roads considering safety, noise reduction, and durability.

But – as the examples of the UHPC road from precast elements and of the low noise concrete block pavement show – a well-planned collaboration from the very beginning of a road construction project can achieve excellent results considering noise reduction, which might be conserved over a long time due to the concrete material’s stability.

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The responsibility for this publication lies exclusively with the authors.

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