POROUS PAVEMENT FOR REDUCED TYRE/ROAD NOISE AND IMPROVED AIR QUALITY – INITIAL RESULTS FROM A CASE STUDY

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One possible solution to reduce noise resulting from tyre-pavement interaction is to use a porous pavement surface. A porous surface will reduce noise by decreasing air pressure gradients in the tyre-pavement contact as well as by decreasing the acoustical impedance of the road surface and reducing the horn effect. While reducing noise, other functional aspects of a pavement such as abrasion wear which impacts on air pollution through generation and suspension of particles, friction and rolling resistance need to be addressed. This paper analyses the acoustical behaviour of a Double Layered Porous Asphalt (DLPA), applied in the city of Linköping, Sweden, as a solution to mitigate noise, compared to a non-porous Stone Mastic Asphalt (SMA) pavement used as reference. The analysis is based on Close Proximity noise measurements, both in absolute value and as frequency spectra, acoustical homogeneity over the surface length and sound absorption measurements. The acoustic analysis is combined with analyses of air quality measurements of PM$_{10}$ (Particulate Matter with aerodynamic diameter < 10 µm) from two Tapered Element Oscillating Microbalance (TEOM) measurement stations placed near each different pavement section. The initial results indicate that the porous pavement results in a noise reduction of up to 5 dB for light vehicles, and up to 4 dB for heavy vehicles. So far, the DPLA shows approximately 52 % lower PM$_{10}$ concentrations than the SMA. It should be noted that PM$_{10}$ is influenced also by meteorological conditions, like humidity, background sources as well as vehicle properties, e.g. use of studded tyres, and that some of the observed decrease can be due to other aspects than porosity e.g. road surface moisture and wind direction. In conclusion, the use of a porous pavement shows promising results from both acoustical and air quality aspects, given the initial, short term results.
Keywords: Tyre, Pavement, Noise, Air Quality, PM$_{10}$

1. **Introduction**

Urban areas face a wide variety of challenges. Amongst these are the environmental problems such as noise and particle emissions, rolling resistance linked to fuel consumption and thus emission of greenhouse gases. Both noise and particulate matter are well known to impact human health [e.g. 1, 2]. To mitigate noise resulting from the interaction between the road surface and tyre, some possible solutions are texture optimization, for instance with horizontal grinding [3] or the use of porous road surfaces [4]. In Sweden and other cold region countries, studded tyres are used to increase friction (50-99 % of vehicles use studded tyres in winter conditions, depending on region in Sweden [5]), while causing durability issues due to the increase of wear rates of pavements. The increased wear rates also increase generation of road dust and PM$_{10}$ (Particulate Matter with an aerodynamic diameter smaller than 10 µm) from road surface tyre interaction, where large-scale tests in a laboratory setting have shown the impact of both the increased use of studded tyre as well as the pavement type and inherent material types and properties [e.g. 6]. Not to mention that it also impacts on tyre/road noise emissions.

To reduce the noise emission, the Linköping municipality replaced an abrasion wear resistant stone mastic asphalt (SMA) with a double layered porous asphalt (DLPA) in August 2018. To gain a more comprehensive knowledge towards a more holistic approach, the effect of the newly laid pavement was studied with regard to noise and air quality.

This paper only reports the set-up of the experiments and the first results; while both noise and particle emissions need to be monitored a longer time to give a full picture.

2. **The road section and its surroundings**

The road section under study consists of a DLPA pavement having a 25 mm thick top layer and 55 mm bottom layer, with maximum aggregate size of 11 and 16 mm respectively, both with a designed air voids content of 25 %. The road section is approximately 600 m long and has average annual daily traffic (AADT) of 14 700 vehicles, of which 7 % are heavy vehicles. In winter conditions, to provide appropriate friction levels even with snow or ice on the surface, it is allowed to use studded tyres in Sweden. This also affects how the road surface wears out, thus affecting wear particle and road dust generation, while also contributing to noise emissions. During the winter season it is estimated that between 51 and 66 % of the light vehicles that drive over this road section do so with studded tyres. As reference for the air quality measurements, the southern part was used, where the old pavement of type SMA was still intact, see Figure 1. For noise, in this paper, the reference is the old pavement (SMA) prior to the DLPA. Measurements suggest that this SMA seems to have a 16 mm maximum aggregate size.
3. Measurement Methods

The measurement campaign includes methods and additional noise and air quality measurements that are not discussed here due to scope and size limitation.

3.1 Noise

The acoustical performance of the DLPA was evaluated with the Close Proximity (CPX) method. Additionally, the noise absorbing properties of this porous pavement was evaluated with sound absorption tests.

3.1.1 Tyre/road noise

Noise resulting from the tyre/road interaction was evaluated by the Close Proximity (CPX) method in accordance with ISO 11819-2 [7]. The measurements were performed by the Gdański University of Technology (TUG) using the Tiresonic MK4 trailer presented in Figure 2. The reference tyre P1 was used to represent light vehicles and the reference tyre H1 was used to represent heavy vehicles [8]. Two different test speeds were used, namely 50 and 70 km/h and all the lanes (designated as K) were evaluated, namely both southbound lanes, K1S and K2S, and the single northbound lane, K1N. While K1S and K2S were evaluated in the right wheel track, K1N was evaluated both in left and right wheel tracks.

The tyre/road noise was evaluated at two different occasions, the first one being approximately a month before the porous pavement was laid, i.e. on the previously existing dense pavement, named measurement M0, and the second one approximately 45 days after the porous pavement was laid, named M1.
Figure 2: The CPX measurement trailer from TUG used to evaluate tyre/pavement noise. Photo: Tiago Vieira.

3.1.2 Sound absorption

To evaluate the sound absorption on the porous pavement a total of 6 core samples having a diameter of 100 mm were drilled from the road structure in two different sections, both in the K1N direction of the porous pavement. Three samples were extracted per section, one for each wheel track (left and right) and one between the wheel tracks. The samples were then analysed according to ISO 10534-2 [9].

3.2 Air Quality

To evaluate air quality (AQ), two air quality monitoring stations were placed at the southern and northern position in Figure 1, respectively. These stations are equipped with TEOMs (Tapered Element Oscillating Microbalance), measuring PM$_{10}$. The northern site has a model 1400, while the southern site has a model 1405, both from ThermoFisher. The TEOMs principle of operation is that the aerosol (particles + air) enter the PM$_{10}$ inlet. The aerosol is then led down, heated to 50 °C, into the measurement chamber where a heated filter is positioned on a glass staff, which oscillates with a given frequency. When the mass of the filter increases due to deposition of particles, the frequency changes and from this change the mass concentration of particles in the air is calculated.

At the southern site, a smaller weather station is located, sampling wind speed and direction, rain precipitation, air temperature and the relative humidity of the air. The station on the southern site is shown in Figure 3.

Figure 3: The southern AQ station. The green container is equipped with a TEOM 1405. The open grey box contains the PM$_{10}$ inlet, as well as temperature and humidity measurement. The uppermost part of the station is the meteorological measurement equipment, where rain precipitation, relative humidity, temperature, as well as wind speed and direction are measured. Photo: Joacim Lundberg.
4. Results and discussion

4.1 Tyre/road noise

The average CPX levels for each measurement, reference tyre and test speed are presented in Table 1. It appears that the average noise level decreased 5 dB for both reference tyres when comparing the new pavement (DLPA, M1) with the old one (SMA, M0) for the speed of 70 km/h, which is the maximum legal speed for the analysed road section. For the speed of 50 km/h the noise reduction was 3 dB for the reference tyre H1 and 4 dB for the reference tyre P1.

Noise spectra for each measurement, tyre and test speed are shown in Figure 4. Note that the noise reduction occurs mainly for frequencies higher than 630 Hz. The spectra for the porous pavement does not present a significant flattening for frequencies around 800 Hz, which usually is found for porous pavements in new condition and is attributed to the noise absorbing properties of the porous layers.

Table 1: CPX levels for each measurement, reference tyre and speed.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>M0 (old SMA pavement)</th>
<th>M1 (new DLPA pavement)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H1</td>
<td>P1</td>
</tr>
<tr>
<td>Speed [km/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>CPX Level [dB]</td>
<td>92</td>
<td>98</td>
</tr>
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</table>
Homogeneity was evaluated for the road section in measurement M1 (DLPA), and is presented in Figure 5 as the mean sound pressure level (SPL) for each 20 m segment, both test speeds and the reference tyres. Additionally, the parameter $S_t$, which represents the sound pressure level variability, was calculated according to ISO 11819-2:2017, annex H.2, case A [7] and presented in Table 2. The $S_t$ values are relatively high when compared, for instance, to those reported by Mioduszewski and Gardziejczyk [10] and regions along the road section where the SPL increases substantially are visible in Figure 5.

![Figure 5: Mean Sound Pressure Level (SPL) for all runs at both speeds and with both reference tyres.](image)

**Table 2: Surface homogeneity indicated as the sound pressure level variability ($S_t$).**

<table>
<thead>
<tr>
<th>Number of Runs</th>
<th>Speed [km/h]</th>
<th>Tyre</th>
<th>$S_t$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>50</td>
<td>H1</td>
<td>1.4</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
<td>P1</td>
<td>1.3</td>
</tr>
<tr>
<td>8</td>
<td>70</td>
<td>H1</td>
<td>1.5</td>
</tr>
<tr>
<td>8</td>
<td>70</td>
<td>P1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Sound absorption results are presented in Figure 6 in one-third octave bands as the mean value for the six samples extracted from the porous pavement. The results indicate that sound absorption increases for higher frequencies, for instance for 1.25 and 1.6 kHz, even though the values are no higher than 0.25. The lack of a substantial increase in noise absorption around 800 Hz explains the obtained CPX frequency spectra, which show a clear peak for such mid-frequencies rather than the plateau which is usually the result of sound absorption.
4.2 Air Quality

The air quality results are presented in Figure 7, showing a clear difference between the two locations, where the DLPA site has clearly lower PM$_{10}$ compared to the SMA, especially at occasions with high particle concentrations. On average, the quotient between the DLPA and the SMA was about 52%. This shows that the DPLA location demonstrates a large decrease of PM$_{10}$ compared to the SMA site. This is potentially due to the storage capability of dust inside the porous pavement, thus trapping particles otherwise suspended by traffic at the dense pavement and clogging the DLPA. Note that particle emissions are affected by several aspects such as surface moisture, precipitation and wind influence. This influence the interpretation of the results, possible impacting both stations, but given the assumption of similar conditions at both sites, primarily the magnitude of the difference between the location is affected.

5. Conclusions

The use of a porous pavement to reduce noise and its further implications on air quality were analysed in this preliminary study. It was observed that the porous pavement indeed reduced the average noise levels by 5 dB at the maximum legal speed allowed for that road section (70 km/h). The frequency spectra and noise absorption analysis indicate that the porous pavement does not have enough inter-connected
air voids on both layers, which results in just a small reduction of the peak around 800-1000 Hz in the rather sharp frequency spectra. Therefore, a possible way to reach even higher noise reduction would be to increase the amount of interconnected air voids both in the top and bottom layers during the pavement construction.

The initial air quality investigation showed that the PM_{10} levels were lower in the porous pavement region, near the northern air quality station, when compared to the non-porous pavement, near the southern air quality station. Further investigations will indicate if this positive trend both with respect to noise and air-quality will be extended, both over the especially dusty spring period, possibly affecting the noise reduction through clogging, but also over the pavement life-cycle. It should be emphasized that a longer-term analysis might lead to different conclusions.

As this paper indicates, noise and PM_{10} emissions should be co-analysed, since both seemingly are influenced by the pavement characteristics such as the interconnected air voids, where particles likely cause clogging, thus reducing emissions to air while compromising noise reduction capabilities. This is currently studied in more detail by the authors.

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REFERENCES