THIN NOISE-REDUCING ASPHALT PAVEMENTS TOWARDS SUSTAINABLE TRANSPORT IN URBAN AREAS

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ABSTRACT

The objective of the research was development, optimisation, and evaluation of thin noise reducing surface layers in Germany. The mixtures were developed based on an open textured surface and stone mastic asphalt (SMA) aggregate skeleton across the whole thickness of the layer. As a result of this, they might have a slightly lower noise reducing capacity, but a greater durability compared to porous pavements, thus achieving a positive long-term acoustical benefit. The test pavements in Düsseldorf were subjected to continuous close proximity (CPX) method monitoring of the noise emission for more than three years of service, and showed a significant noise reduction and, unlike porous pavements, the measurements indicated a very low influence of pavement age on the acoustical performance, which indicated a stable surface texture. On the basis of the research results and past experience, recommendation on the specifications according to the relevant European standards was developed, thus contributing to the adoption of European specifications for noise-reducing asphalt pavements. The research showed a high noise reduction potential of the considered thin noise-reducing asphalt pavements, thus qualifying them as a good alternative for achieving a sustainable transport in urban areas through a higher level of protection against environmental noise.

Keywords: noise reduction, asphalt pavements, environmental sustainability, stone mastic asphalt (SMA), acoustical properties, close-proximity (CPX) method

1. INTRODUCTION

The growth of transport activity, as an essential component of modern life, raises concerns for its environmental sustainability (European Commision 2009), thus having the potential of improving and eroding public health (Mudu *et al.*2006). Road traffic is also a major contributor to human exposure to air pollution and noise, especially in urban areas where it affects a large number of people. Environmental noise affects people's health and quality of life, as it interferes with basic activities such as sleep, rest, studying, communication, concentration, and cognition — ranking with smoking and diet as one of the most important determinants of health in Europe (European Environment Agency (EEA) 2007, Fyhri and Aasvang 2010, Mudu *et al.*2006). Environmental noise is also a relevant reason for people moving out of cities into the suburban area (e.g. for every third household moving out of Cologne, noise and air pollution in the city was a crucial reason). About half of the citizens in the EU-15 are estimated to live in areas which do not ensure acoustical comfort for residents — 40% of the population is exposed to road traffic noise exceeding 55 dB(A) during daytime, and 20% to levels exceeding 65 dB(A). At night, more than 30% are exposed to sound levels exceeding 55 dB(A), which disturb sleep and are considered increasingly dangerous for public health. (European Commission 2011, Hurtley ed. 2009) The main portion of the road traffic noise is caused by the tyre/road interaction, especially at speeds higher than about 40 km / h (Alenius 200, Reichart 2009).

Having regard to significant disadvantages of porous asphalt, especially considering its long-term acoustical performance, an overall effectiveness of this type of mixture could not be considered satisfactory. Porous pavements have an open structure with connected voids in the whole thickness of the layer. The typical air void content is between 24 and 28% (Arbeitsgruppe Asphaltbauweisen 2008a) and the layer thickness is between 4.5 and 6.0 cm depending on the type of mixture (Arbeitsgruppe Asphaltbauweisen 2008b). If water is poured on a new porous pavement, it disappears down into the porous structure (Bendtsen 2009). This effect keeps the pavement surfaces dry to a certain extent, and through this, reduces splash and spray and improves the visibility for the drivers as well. Unfortunately, these positive effects decrease over time due to the layer pores clogging (Bendtsen *et al.* 2005). Additionally, intensive winter maintenance reduces the cost-effectiveness. Clogging of porous pavements is a problem on highways as well as on roads with lower speeds.

Because of the disadvantages compared to dense mixtures, asphalt concrete (AC) and stone mastic asphalt (SMA), porous pavements have not been used as a measure of noise abatement in some European countries (Miljković and Radenberg 2011), with the exception of places where high noise-reducing effects are required regardless of compromising other requirements. This emphasises the need to develop and evaluate other types of noise-reducing surface layers, changing the focus in mixture design towards thin surface layers which might have a slightly lower noise-reducing capacity than porous asphalt, but a more durable one, so the long-term acoustical benefit will be positive (Bendtsen and Andersen 2008).

2. OPTIMISATION OF NOISE-REDUCING PERFORMANCE OF THE MIXTURE

In contrast to porous pavements that are open across the whole thickness of the layer with connected voids, open textured pavements are open only on the upper part of the surface layer with voids having a depth less than the upper sieve size of the aggregate used for the mixture. The basic approach in design of open-textured pavements for noise reduction is to create a layer structure with voids at the surface of the pavement as big as possible to reduce the noise generated from the air-pumping effect to some extent, and at the same time to ensure a smooth surface, so that the noise generated by the vibrations of the tyres will not be increased. Such a noise-reducing open-textured layer can be thin, as the mechanisms determining the noise generation depend only on the surface structure of the layer (Bendtsen 2009). Figure 1 illustrates two types of layers with open surface texture. The layer with a “positive” texture will increase the noise generated from vibrations in the tyre, whereas the layer with a “negative” texture will reduce it.

Figure 1 : Illustration of the two main types of the open surface texture shapes. (Bendtsen 2009)

To achieve the objective of creating a smooth negative open-textured layer, optimisation was carried out using the following principles:

- Using a small maximum aggregate size of 5.6 mm to achieve an even and smooth pavement surface that could reduce noise generated from vibrations in the tyre;
- Using a high void content (Arbeitsgruppe Asphaltbauweisen 2008a) to achieve an open surface texture that can reduce noise generated from air pumping. The target void content is about 5 to 6 %;
- Using cubic aggregate to achieve an even and smooth pavement surface that can reduce noise generated from vibrations in the tyre;
- Using a low sand content to achieve a highly open porous surface texture and dense structure of the layer.

To ensure that the desired surface texture is achieved, both visual evaluation and optical 3D measurement and analysis of a realised surface texture were performed in the laboratory and on the test pavements. Demands for high noise-reducing capacity are predominantly related to high traffic volume roads and streets. To avoid compromising structural durability and stability of the surface texture, and thus to keep the noise-reducing effect over time, a dense mixture structure with high permanent deformation resistance is required. Therefore, mixture development was based on the SMA aggregate skeleton applied in Germany (Arbeitsgruppe Asphaltbauweisen 2008a) with an additional requirement for noise-reducing properties. With the application of a small upper sieve size, it can be applied in thin surface layers.

In Germany, an abbreviation widely used for this type of surface layer is LOA 5 D. Here, LOA from the German origin “Lärmoptimierter Asphalt” is directly translated as “noise-reducing asphalt”, number “5” designates the upper sieve size of the aggregate used in the mixture of 5.6 mm, and the letter “D” from the German origin “Deckschicht” is directly translated as “surface layer”. Up to now, LOA 5 D thin noise-reducing surface layers, although not nationally standardised, have recently been applied to numerous streets in the Federal State of North Rhine-Westphalia (NRW) and in the whole of Germany. Unlike typical SMA mixtures in Germany where the air void content never exceeds 3 %, for LOA 5 D the air void content is usually between 5 and 6 %, and as mentioned above, the surface texture is very porous with connected pores. The mixture can be paved in a very thin layer with a thickness of 2.0 to 2.5 cm. Small thickness with a substantially SMA aggregate skeleton structure and polymer-modified bitumen as a binder, with proper compaction leads to an excellent permanent deformation resistance. The structure does not allow water to drain through the layer and slightly reduces water removal capacity compared to porous asphalt. However, it suppresses typical problems in winter maintenance and thus extends the service life of the whole pavement. Instead of draining through the layer structure, the rainfall water flows over the surface to the roadside through the very porous texture and still keeps good friction characteristics. Thus, the open porous surface texture reduces splash and spray from the vehicles to the minimum and has a positive effect towards avoiding aquaplaning and improves driving safety. To establish the extent to which surface texture changes over time due to wear by traffic, the mixtures were subjected to sandblasting to simulate the impact of tyres in the first few years of service. The sandblasting was carried out by glass pearls of 100 to 200 mm in diameter. Visual evaluation of the surface showed that, except the removal of the surface bitumen film, no significant changes were noticed, indicating the possibility of long-term texture stability.

3. ACOUSTICAL PROPERTIES OF THE NOISE-REDUCING LAYERS FROM THE TEST PAVEMENTS

3.1 Method of Measuring Acoustical Properties

The measurements of acoustical properties of the test pavements were based upon the close-proximity (CPX) method according to the working draft of the standard ISO/CD 11819-2 (International Organization for Standardization (ISO) 2000). They were carried out between 2007 and 2010 by a closed CPX trailer with two tyres, a picture of which is shown in Figure 2. Each tyre is equipped with at least two microphones close to the contact between the tyre and the test pavement surface. The measurements were accomplished using standardised reference tyre types A and D, which relate to passenger cars (light vehicles) and trucks (heavy vehicles), respectively. Unlike the statistical pass-by method, the CPX method gives a continuous measurement of the whole test section. Reference speeds for the noise measurements were 30 and 50 km / h. In Germany, speed limit of 30 km / h is usual only in residential streets, near schools, etc. which slightly differs depending on the federal state. Therefore, the acoustic properties of pavements regarding heavy vehicles in these areas were considered irrelevant due to their relatively rare presence, and the measurements were carried out just for light vehicles. The noise data were processed to give A-weighted noise levels. The results from two reference tyres were averaged to CPX indices. On all sections, the measurements were collected in both directions. All results were normalised to a reference temperature of 20 ºC.

Figure 2 : Towing vehicle with the measuring trailer used for the CPX measurements. (Miljković 2011)

3.2 Results of the CPX Measurements and Development of the Acoustical Properties over Time

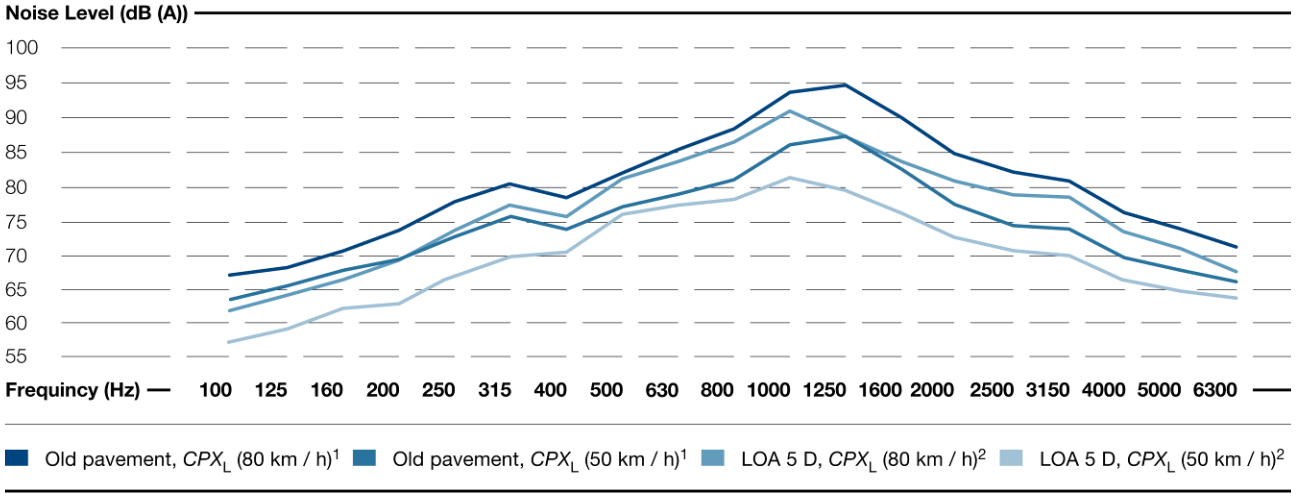
The noise emission over time was continuously monitored at test pavements in two streets in Düsseldorf where this type of mixture was first applied, and thus, where the longest measurement history is available. As the other pavements have been recently constructed, no long-term data were available for these pavements. Figure 3 shows one-third-octave band frequency spectra for the test pavements in Mecumstraße and Kennedydamm in Düsseldorf and Figure 4 shows the equivalent noise levels over time. The frequency spectra are displayed in the frequency range from 100 to 6300 Hz.

Both streets have a speed limit of 50 km / h. Mecumstraße is a section of the German federal road B326, whereas Kennedydamm is a section of the German federal road B1. Both are six-lane central city streets. Additionally, Mecumstraße also has a bus lane along the greater part of its length. The annual average daily traffic (AADT) in Mecumstraße is around 40,400 vehicles and the portion of heavy vehicles is around 1.7 %. The surface layer in Mecumstraße was constructed in April 2007 replacing an old asphalt concrete pavement. Kennedydamm is a highly trafficked street with an AADT of around 59,600 vehicles of which heavy vehicles make up around 3.6 %, and is one of the major streets in Düsseldorf having an important role in the traffic network of the city. Because of the high traffic loading and the importance in the street network, one side of the pavement structure in Kennedydamm was constructed in July 2007, whereas the other side was constructed a year later replacing the old concrete pavement. The data in Figures 3 and 4 refer to the part of the street built in 2007. The CPX data for the old asphalt pavements in both streets are also provided.

It can be seen that the frequencies corresponding to the highest noise levels were 1250 Hz for the old and 1000 Hz for LOA 5 pavements. For Kennedydamm, at the frequency of 1000 Hz, the noise reduction at the higher reference speed of 80 km / h of about 4 dB(A) was lower than for the lower reference speed of 50 km / h which was about 6 dB(A). However, the frequency spectrum data for the old pavement in Mecumstraße were not available.

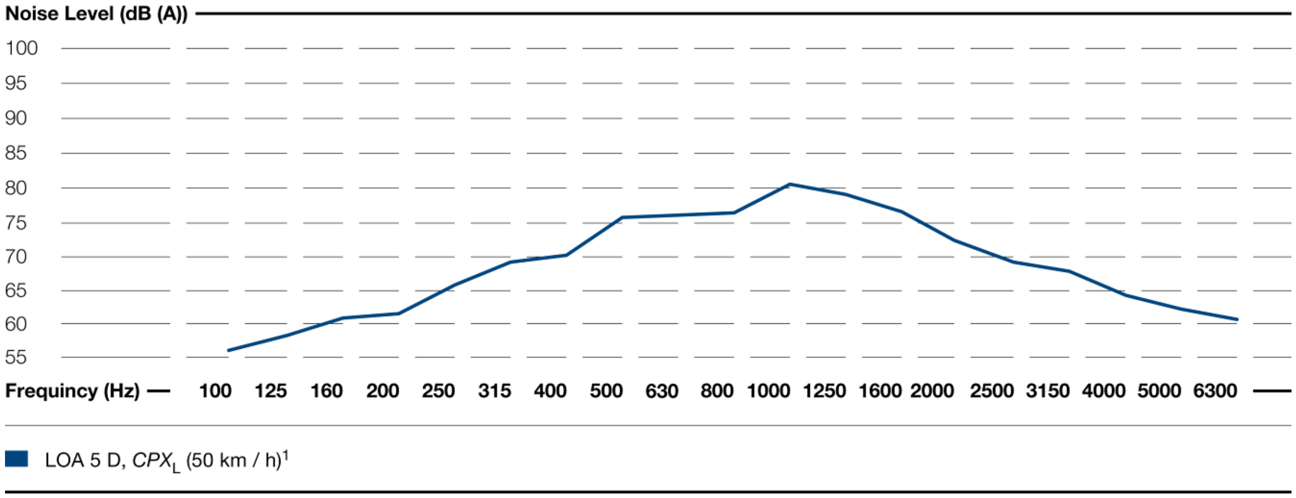
According the data on the noise development over time, the average CPX values are between 86.5 and 88.9 dB(A). The initial noise reductions compared to the old pavements are 6.7 and 4.3 dB(A). For both pavements, the range between maximum and minimum CPX value during approximately 3 years of service is no more than 1.3 dB(A). This indicates a very stable surface texture. Thus, Figure 4 shows that the influence of pavement age on the acoustical performance of LOA 5 D is very low. This is very different from porous asphalt pavements where the average increase in noise level for light vehicles in streets with low traffic speed is expected to be approximately 0.9 dB(A) per year, where most of that increase occurs in the first year of service (Bendtsen et al. 2009, ViaNova Plan og Trafikk 2009).

Noise Levels of LOA 5 D Surface Layer in Kennedydamm, Düsseldorf



[1] Measured in June 2007.
[2] Measured in September 2007.

Noise Levels of LOA 5 D Surface Layer in Mecumstraße, Düsseldorf



[1] Measured in June 2007.

Figure 3 : A-weighted one-third octave band CPX_L spectra for passenger cars at reference speeds of 50 and 80 km / h in Mecumstraße and Kennedydamm in Düsseldorf.

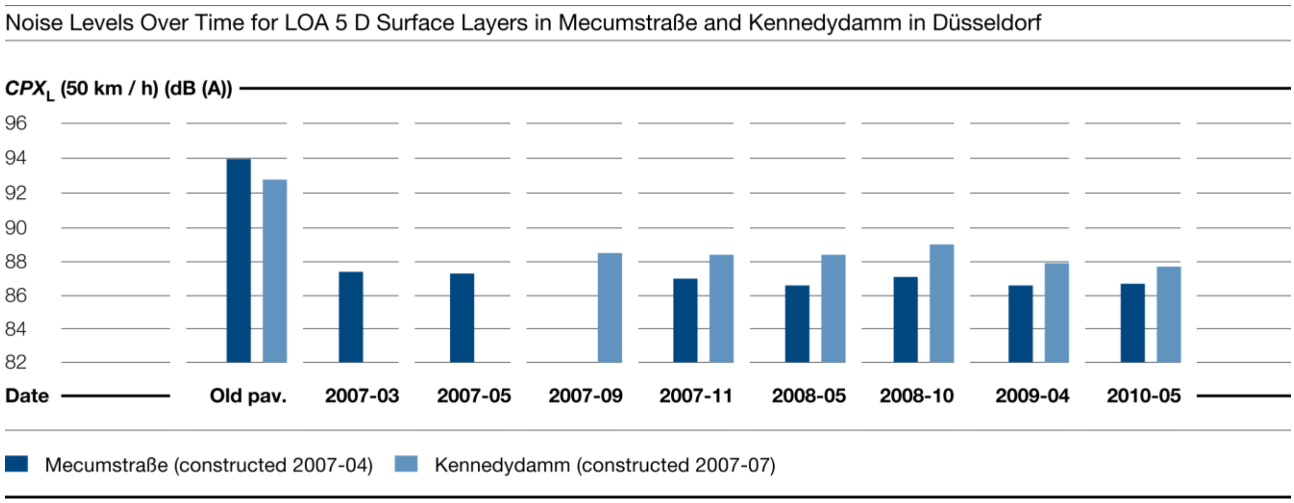


Figure 4 : The CPX noise measurement results over time for LOA 5 D pavements in Mecumstraße and Kennedydamm in Düsseldorf for the light vehicles at the reference speed of 50 km / h. (Miljković and Radenberg 2011)

4. RECOMMENDATION ON SPECIFICATIONS FOR THIN NOISE-REDUCING SURFACE LAYERS

On the basis of the results presented here and experience after more than 3 years of monitoring the performance of test pavements in Germany, the specifications of the thin noise-reducing LOA 5 D are recommended. The requirements refer to constituent materials, mixture composition, asphalt mixture and constructed asphalt layer, as described in Table 4. These requirements are in accordance with the European standards for material specifications for asphalt mixtures, EN 13108-5:2006 (European Committee for Standardization (CEN) 2006a) and EN 13108-20:2006 (European Committee for Standardization (CEN) 2006b). Some of the properties are outside these specifications but are also required due to by the German national specifications for asphalt mixtures (Arbeitsgruppe Asphaltbauweisen 2008a). The only deviation is in the percentage passing a 0.063 mm sieve, as LOA 5 D requires slightly higher filler content. The layer in Mecumstraße was the first to be constructed and was the initial reference for optimisation. Therefore, some of the mixture properties presented in Table 1 differ slightly from these recommended values.

Table 1 : Recommendation of the specifications for the thin noise-reducing LOA 5 D surface layer. (Miljković and Radenberg 2011)

Subject	Property	Test method	Requirement
Constituent materials	Percentage of crushed and broken surfaces in coarse aggregates	EN 933-5:1998	$C_{90/1}$ 1)
	Resistance to fragmentation of coarse aggregate	EN 1097-2:2010	LA_{20}, SZ_{18}
	Resistance to polishing of coarse aggregate for asphalt surfaces	EN 1097-8:2009	PSV_{51} 2)
	Class of bitumen	EN 14023:2010	Polymer modified bitumen 25/55-55
Mixture composition	Percentage by mass passing 8 mm sieve	EN 933-1:1997/A1:2005	100 %
	Percentage by mass passing 5.6 mm sieve		90 to 100 %
	Percentage by mass passing 2 mm sieve		30 to 40 %
	Percentage by mass passing 0.125 mm sieve		12 to 18 %
	Percentage by mass passing 0.063 mm sieve		10 to 13 %
	Bitumen content by volume	— 3)	12.5 to 13.5 %
Asphalt mixture	Minimum void content	EN 12697-8:2003	V_{min5}
	Maximum void content		V_{max6}
	Minimum voids filled with bitumen		VFB_{min65}
	Maximum voids filled with bitumen		VFB_{max75}
	Resistance to permanent deformation	EN 12697-22:2003+A1:2007	$PRD_{AIR\ 4,0}$ 4)
	Mean texture depth, *MTD* 5)	EN 13036-1:2010	0.6 to 0.7 mm
	Shape factor, *g*	NA	NR, To be determined 6)
	Shape length, *g*L	NA	NR, To be determined
Constructed asphalt layer	Layer thickness	EN 12697:2003	2.0 to 2.5 cm
	Compaction degree	EN 13108-20:2006	≥ 97 %
	Profile irregularity (by 4 m straightedge)	EN 13036-7:2003	≤ 3 mm

NA = Not available; NR = No requirement

1) Aggregates obtained from crushing rock shall be assumed to be category $C_{100/0}$ and do not require further testing.

2) The requirement for a polished stone value of 51 is specified in accordance with the German national specification document (Arbeitsgruppe Asphaltbauweisen 2008a), but is not provided with EN 13108-5:2006 (European Committee for Standardization (CEN) 2006a). Therefore, when specifying in accordance with the EN standard, the category PSV_{50} is recommended.

3) Determined from bitumen content by mass, bitumen specific gravity (EN 15326:2007+A1:2009), and bulk density of the specimen (EN 12697-6:2003+A1:2007).

4) Although the specification of the proportional rut depth of 4.0 % is not in accordance with EN 13108-5:2006 (European Committee for Standardization (CEN) 2006a), this value is considered from the research to be the most suitable.

5) Because of the testing simplicity and widespread usage, mean texture depth, *MTD*, is specified instead of the mean profile depth, *MPD*.

6) It is strongly recommended that values greater than 80 % should be achieved.

5. CONCLUSION

The development and optimisation of thin noise-reducing surface layers in Germany were based on achieving a smooth open-textured surface with an SMA-based aggregate skeleton across the whole thickness of the layer. The surface layers in the highly trafficked test pavements in Düsseldorf were subjected to CPX method measurements of noise emission, and very good noise-reducing properties were indicated due to low surface texture changes. Also, no signs of ravelling and structural defects such as cracking have been registered, up to now. On the basis of the research results and the experience after more than 3 years of monitoring the performance of the test pavements in Germany, the specifications of the thin noise-reducing LOA 5 D surface layers were recommended, thus facilitating the wider application.

To get a better understanding of long-term changes of acoustical properties over time, further research should be focused on monitoring noise emission data from the test pavements throughout the whole service life and models of any changes developed. Additionally, as surface texture parameters have the highest influence on the acoustical performance of the surface layers, further research on the influence of the optical 3D measurement-based parameters on the noise reduction potential of a pavement surface would be very useful. This would enable estimation of noise-reducing capacity in laboratory conditions, and thus, enable more efficient mixture optimisation. Finally, this should result in the adoption of the requirements in terms of the surface texture parameters and their implementation to the recommended specification.

The results reported here and future research on thin noise-reducing surface layers, together with experience from other European countries should lead to the adoption of European specifications for noise-reducing asphalt pavements, thereby contributing to achieving a high level of environmental sustainability of transport sector in Europe.

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