Qualitative criteria and thresholds for low noise asphalt mixture design

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Abstract. Low noise asphalt pavements are cost efficient and cost effective alternative for road traffic noise mitigation comparing with noise barriers, façade insulation and other known noise mitigation measures. However, design of low noise asphalt mixtures strongly depends on climate and traffic peculiarities of different regions. Severe climate regions face problems related with short durability of low noise asphalt mixtures in terms of considerable negative impact of harsh climate conditions (frost-thaw, large temperature fluctuations, hydrological behaviour, etc.) and traffic (traffic loads, traffic volumes, studded tyres, etc.). Thus there is a need to find balance between mechanical and acoustical durability as well as to ensure adequate pavement skid resistance for road safety purposes. Paper presents analysis of the qualitative criteria and design parameters thresholds of low noise asphalt mixtures. Different asphalt mixture composition materials (grading, aggregate, binder, additives, etc.) and relevant asphalt layer properties (air void content, texture, evenness, degree of compaction, etc.) were investigated and assessed according their suitability for durable and effective low noise pavements. Paper concluded with the overview of requirements, qualitative criteria and thresholds for low noise asphalt mixture design for severe climate regions.

1. Introduction

Traffic noise is an increasing environmental problems which is highlighted as a second major environmental problem after the air pollution. Unfortunately, traffic noise is often underestimated as it’s negative impacts affect society not instantly but in a longer term. Exposure to excessive noise levels leads to various health related problems, affects work productivity, sleep quality as well as negatively affects some animal species and countries’ economies.
Calculated approximate EU annual socio-economic costs because of traffic noise are higher than 40 billion EUR and expected to increase 50% by 2050 [1]. Therefore, huge efforts are needed to decrease noise pollution in EU Member States. Implementation of Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to assessment and management of environmental noise is one of the solutions, however implementation needs to be fostered and improved in terms of completeness, comparability and adaptation of highly effective solutions.

From the road infrastructure owners’/managers’ perspective, increased attention was also given to tackle the road traffic noise problem – traffic noise problem was highlighted in CEDR Strategic Plan 2014-2017 [2] as an important future road infrastructure challenge. In-line with EU Noise Directive, National road authorities are developing and implementing strategic noise management plans at national levels. However, in many cases national strategic noise management plans are focused on a narrow set of noise mitigation solutions – mainly related with the construction of noise barriers and façade insulation. Only a holistic approach and combination of different and adapted noise mitigation measures implementation can lead to the highest noise level reduction experience.

Even if noise barrier can achieve high noise level reduction rate, costs for their construction and maintenance are relatively high. Such situations are very common in new road construction and road rehabilitation projects, where it is necessary to apply noise reduction measures in order to meet environmental requirements even if there are single or few properties along the road. Additionally, their implementation is sometimes impossible due to the technical, legislative and landscape related restrictions.

Low noise asphalt pavements are cost-efficient and cost-effective alternative noise mitigation solution, which implementation has a big potential, especially in urban areas or in highways. Various research and feasibility studies has shown that low noise pavements are much more cost efficient solution comparing with noise barriers and façade insulation for every single reduced dBA or per treated km (Fig.1) [3]. Some other examples show that it is less expensive to achieve required noise reduction effect by using combination of low noise pavements and noise barriers than only barriers in a longer treated distance.

![Figure 1. Costs of three noise abatement measures for three typical cases [3].](image)

### 2. Low noise asphalt mixture design prerequisites

Optimisation of asphalt mixtures for tyre/road noise reduction largely depends on the potential application area of these mixtures – where it will be used, under what traffic and what climate conditions. Various conditions can be related with different set of tyre/road noise influencing factors that has to be taken into account when modelling and optimising low noise asphalt mixtures.

Design of the low noise asphalt mixtures is even more complicated for severe and cold climate regions where large temperature fluctuations and large number of frost-thaw cycles occur. In such cases, it is essential to take design low noise pavements with sufficient durability and resistance to climate conditions. To address this challenge, national research project NOPE on the design of low noise asphalt mixtures for severe climate conditions has been started in December 2017 in Lithuania.
This paper presents first stage of this project aiming to assess tyre/road noise influencing factors and their impact on the tyre/road noise generation and to combine these influencing factors with set of requirements, criteria and particular recommendations low noise asphalt mixture design. Previous research projects on this topic [4] showed that optimised thin asphalt layer mixtures of modified AC and SMA pavements have highest potential in colder climate regions, therefore this paper focuses mainly on this type of pavements.

2.1. Tyre/road noise influencing factors

Influencing factors for tyre/road noise generation can be distinguished into 4 major groups [5,6]: Road surface characteristics (road surface texture, aggregate properties, air void content, pavement stiffness, pavement colour, pavement age and deterioration), Tyre characteristics (number of tyres, tyre dimensions, tyre internal structure, tyre inequality, rubber hardness, tread pattern and structure, age and wear, tyre type, studded tyres), Environmental factors (moisture, wind, temperature, water on the surface, dust) and Factors controlled by driver (driving speed, tangential forces and acceleration, tyre load and pressure). Set of influencing factors affect noise generation mechanisms related with noise due to tyre vibrations, aerodynamic effects and amplification/reduction effects. Each of the influencing factor can be associated with specific noise frequency range.

Main criteria that needs to be evaluated before selecting appropriate low noise pavement solution in particular location are allowable speed limits, traffic volumes and composition as well as possibility to use studded tyres. With the increasing driving speed, tyre/road noise levels intend to increase too, thus it is necessary to know the speed limits for particular locations. Some low noise asphalt solutions are recommended to be used only at higher speeds (e.g. porous asphalt) due to the self-cleaning effects while at the lower speeds such solutions might not be acoustically durable due to fast clogging [7]. Since road surface texture and surface porosity are the main road pavement influencing factors that have major impact on induced tyre vibrations and air pumping noise generation mechanisms, it should be also noted that at higher speeds for smooth pavements air pumping mechanisms are more dominant than tyre vibration related mechanisms [8].

Traffic volumes (AADT) and traffic composition (percentage of heavy duty vehicles in the whole traffic flow) are also important to take into account when modelling low noise pavements. There are differences between the noise frequencies and noise generation mechanisms for passenger and heavy vehicles tyres, therefore, surface texture needs to be optimized using different maximum aggregate size. Additionally, high traffic volumes and use of studded tyres might lead to faster road surface texture deterioration and polishing what can also be linked with increasing noise levels.

2.2. Asphalt mixture optimization for tyre/road noise reduction

After the initial analysis of the traffic related influencing factors, next step is design and optimisation of asphalt mixture with its relevant characteristics for tyre/road noise reduction.

Asphalt mixture porosity and flow resistance are very important factors that impact air-flow induced noise generation mechanisms such as air pumping. High porosity also increases sound absorption properties of asphalt mixtures. It is known that air void content of at least 10% makes road surface acoustically absorbing [5]. However, the surface will be acoustically efficient only when air void content is >20%. According to the air void content and potential for tyre/road noise reduction, asphalt mixtures can be grouped to dense pavements (4-9% air void content), semi-dense (10-14% air void content), semi-porous (15-19% air void content) and porous (>19% air void content) as shown in Figure 2 [9]. The design goal is to obtain the maximum amount of sound absorption at a frequency of 1000 Hz for high speed roads and of 600 Hz for low speed roads [10] as well as to ensure the frequency spectrum bandwidth of the absorption coefficient as broad as possible. Moreover, it is desirable that the pores in the surface layer should be interconnected in order to ensure good water and air drainage [5]. Shape of the air voids may have also a significant effect on mixture fatigue, stiffness and clogging. Thus, it is recommended to design mixture with circular shape air voids rather than polygonal [11].
Figure 2. Noise reduction potential according to the surface type (adapted from [9]).

To minimize tyre vibration induced noise generation mechanisms road surface texture must be optimized. Texture parameters are also not only important for tyre/road noise reduction but also to minimize splash and spray, rolling resistance, reflection, glare and ensure skid resistance. Therefore, it is important to find the right balance and compatibility between these characteristics. Texture optimization is performed mostly at macrotexture scale [5] by selecting aggregate type, size and mineralogy parameters. According to [5, 12], megatexture and macrotexture is positively correlated with low frequency noise (less than 1000 Hz) while microtexture is negatively correlated with high frequency noise (more than 1000 Hz). Main principles of texture optimization are [5]:

- Macrotextures should have high amplitudes in the 1–8 mm wavelength range and low amplitudes in the 10–50 mm wavelength range for light vehicles' noise reduction.
- Macrotexture should have high amplitudes in the 0.5–12 mm wavelength range and low amplitudes in the 16–50 mm wavelength range for heavy duty vehicles' noise reduction.
- Small size maximum aggregate should be used to achieve smooth surface and reduce tyre vibrations. Max. aggregate size of 4–6 mm for light vehicle tyre noise reduction and max. aggregate size of 6–10 mm for heavy duty vehicle tyre noise reduction.
- Open and ‘negative’ texture that is characterized by a large amount of narrow and small spaces between the particles not like ‘positive’ texture that have large amount of irregularities.
- Megatexture should be minimized by avoiding large aggregate sizes and ensuring homogeneous macrotexture. Otherwise “missing aggregates” or large spaces between the aggregates will cause megatexture to increase.

Both to achieve optimised surface texture and ensure durable performance of low noise asphalt wearing layer it is essential to select proper aggregate and materials. As it was written above, selection of aggregate size is important to form “negative” macrotexture. Main recommendations for the aggregates for low noise asphalt mixtures are:

- Select aggregates with sharp edges and of a polishing resistant material to retain the sharpness as long as possible. Polishing reduce aggregate sharpness and the amplitude in general at short texture wavelengths resulting in decrease of the air drainage between the tyre tread rubber and the road surface [5, 13].
- Select cubic shape, uniform and with sharp edges aggregate to ensure even and smooth surface. It is also desirable to pack aggregates close together in surface texture [5, 14].
- Petrography of the materials is of importance as different mineralogical composition could have an impact on the durability of an asphalt mixture [13].
- Specific requirements to assess when selecting granular materials for SMA mixtures [15]: Los Angeles abrasion (<30 %), fractured faces (>90 % for particles with two faces, 100 for
particles with one face), flat and elongated particles (<5 and 20 % (ratios 5:1 and 3:1 respectively)), fine aggregate angularity (FAA) (>45).

- Polishing resistance materials are recommended to avoid polished surfaces. Microtexture of the crushed stone is therefore of great influence on the skid resistance, particularly in rainy weather.

- Parameters that have significant impact on surface wear resistance [16]:
  - Aggregate quality. On a descending quality scale: Porphyry, quartzite, granite, gneiss
  - Use of mixed aggregate qualities. Wear resistance is given by proportional contributions from each aggregate source

Main recommendations for the grading of low noise asphalt mixtures [5, 17]:

- Since it is necessary to create open and “negative” type surface textures specific grading should be used – sand content has to be minimized and aggregate size should not be larger than 8 mm (for light vehicles) or 12 mm (for heavy vehicles). Texture openness between the particles will provide better air drainage, which reduces air-pumping noise generation

- In order to reduce both the vibration generated tyre-road noise at frequencies below 1500 Hz and the aerodynamic noise at higher frequencies a “steep” aggregate grading curve where filler and very small aggregates are combined with large aggregates but without aggregates of the sizes in between should be used.

- Once a mix has been designed with a given grading curve and the performance of this mix has been demonstrated, there is little margin for variations, and a need to keep the grading as constant as possible, because mixes with a stony skeleton are very sensitive to this. Changes in grading could disrupt the stony skeleton and lead to a loss of stability or a loss of cohesion.

Binder in the low noise asphalt mixtures also has a significant role for the mixture durability and performance. Specific binder recommendations for low noise asphalt mixtures [5]:

- The choice of binder can influence the ageing properties of the surface. The significant influence is on the initial porosity and clogging rate of porous surfaces. Therefore, it is recommended to use a binder that makes possible the highest initial porosity (communicating air voids) and that makes the surface as resistant to clogging as possible.

- The susceptibility to clogging is higher porous and semi-porous mixtures are made with higher binder contents. However, higher binder contents implicate mixtures with thicker binder film coating, making the mixture more resistant to weathering hence more durable [18].

- Avoid a binder that gives a very stiff surface (tentatively).

- The design binder content is obtained by adding the amount of binder drain down to the provisional binder content.

- Binders that include crumb rubber powder don’t give lower noise due to reduced stiffness. However, asphalt mixtures, including crumb rubber in the binder has less problems with binder drain down (e.g. SMA mix with crumb rubber binder had 0% drain-down at 162°C and 177°C indicative of the crumb rubber’s behaviour as a stabilising agent, and thus improving the resistance of SMA mix towards drain down [19])

- Major surface distress type for low noise asphalt surfaces is ravelling which is mostly a low temperature phenomenon. Adhesive failure commonly occurs at low temperatures (mostly, moisture induced damage) and cohesive failure at intermediate temperatures. The latter mechanism is caused by failure due to slow demixing (segregation) of the mastic and ageing of the binder [13]. It is recommended to assess adhesion and cohesion behaviour when selecting binder for low noise asphalt mixtures.

To improve properties and performance of low noise asphalt mixtures, various additives and modifiers can be used such as ground tyre rubber, styrene-butadiene-styrene (SBS) and styrene-butadiene-rubber for durability improvement by increasing the stiffness and ductility of the binder. If modified appropriately, the binder may prevent short-term ravelling that is caused by the shear forces between the tyre/road interface.
Additionally, cellulose fibre, hydrated lime and minerals (0.3 to 0.5 percent by mass) might be used to prevent drain down problems during transport and placing and reinforce the film thickness of the asphalt binder [20].

3. **Low noise asphalt layer thickness, laboratory testing and paving techniques**

Acoustical performance and noise reduction potential of semi-porous and porous low noise surfaces largely depends on the layer thickness. For the thin asphalt layers, it is recommended that layer thickness should be between 2.5 and 4 times the nominal maximum aggregate size (NMAS) [16]:

- If layer thickness is smaller than 2.5 times NMAS then there is a chance to experience problems in achieving the sufficient and desired level of compaction and thereby endangering the durability of the pavement.
- If layer thickness is larger than 4 times NMAS then there is a risk that the traffic loads will generate permanent deformation (rutting) in the layer.

In order to obtain a frequency-optimised absorption of the porous asphalt mixtures, it is recommended that [5]:

- Layer thickness should be 38 mm for high speed roads and 63 mm for low speed roads
- Layer thickness should be at least 40 mm, and preferably as high as possible.

**Recommendation for the compaction of the low noise asphalt mixtures** [15, 21]:

- During the compaction, aggregate particles may disintegrate due to the impact of the hammer, confining pressure, inter-particle friction, and applied boundary conditions. Among all the compaction methods used, Marshall compaction approach is more susceptible for aggregate degradation. Due to this degradation of the aggregates the actual mixture properties could be different from the designed/calculated properties such as air voids, voids in mineral aggregates, etc. Therefore, it is recommended to use gyratory compaction in the laboratory.
- For thin asphalt layers, air voids are less important than for thicker (porous) asphalt layers to border effects and its open texture. Therefore, it is more relevant to control compaction level for the thin asphalt layers.
- Inadequate compaction should be avoided as it may cause large variations in tyre/road noise levels and might foster surface layer acoustical and structural degradation.

In order to guarantee the quality and durability of low noise asphalt mixtures, the designed mixtures should be validated with respect to the performance of the low noise asphalt mixture. Asphalt mixture permeability, binder drain down, macrotexture and resistance to wear are the key performance based characteristics for low noise asphalt mixtures to be controlled [15]:

- Asphalt mixture permeability is important to evaluate both volumetric composition of the mixture and air and water drainage capabilities what has significant impact on layer acoustical performance.
- Cantabro test (for dry and moisture samples) is recommended to evaluate ageing processes and resistance to abrasion after stiffening (oxidation) of the binder.
- Resistance against wear from the tyres are recommended on high-volume roads in countries and regions with a substantial proportion of studded tyres. Resistance to wear from studded tyres could be evaluated using the Nordic abrasion test (EN 1097-9).
- Surface macrotexture are necessary to evaluate because of macrotexture’s direct impact on tyre/road noise levels. Mean profile depth (MPD) and mean texture depth (MTD) are the main parameters that are recommended to be assessed during the laboratory development of low noise asphalt mixtures.
- Resistance to rutting tests are done not only evaluate the rutting resistance, but rather for the evolution of the surface texture durability after a number of wheel passes.
- As it was mentioned in previous chapter, binder drain down is an important factor that characterizes durability of the low noise asphalt mixtures, therefore it is necessary to test this parameter in the laboratory.
• Since low noise asphalt layers are design with a stony skeleton (stone-on-stone contact of the coarse aggregate), permanent deformation is not generally considered as main issue for thin low noise asphalt layers and porous asphalt mixtures. Special attention has to be given for low noise asphalt mixture paving techniques [5, 15, 17]:
  • Thin asphalt layers tend to cool faster than thicker pavements, therefore paving temperature should be controlled with higher attention than for thicker pavements. This means, that thin asphalt layers should be compacted faster. Additionally, restrictions for thin asphalt laying under low air temperatures should be made too.
  • It is recommended to use vibratory screed which width is adjusted with auger’s width in order to ensure the homogenous paving conditions. To eliminate risk of mixture segregation during the paving, it is necessary to use transporters/mixers.
  • To ensure homogeneous, open and “negative” surface texture, paving process should be seamless, continuous and at the constant speed.
  • Cold joints should be avoided.
  • It is not recommended to use vibrational and pneumatic compaction rollers because it may have negative impact on surface texture and layer structure. It is recommended to use steel rollers, heavier than 6 t. Use of rollers heavier than 11 t. is not recommended because it may damage surface particles and surface texture.
  • One of the most important factors is to ensure that low noise asphalt mixture is not over compacted.

4. Conclusions and recommendations
Analysis of tyre/road noise influencing factors and assessment of typical traffic and environmental conditions first step for the selection of low noise asphalt mixture solution. Such background information allows to select proper criteria for specific low noise asphalt mixture design.

Overviewed and analysed worldwide experience and best practice of low noise asphalt mixture design, testing and construction revealed main low noise asphalt mixture design criteria for severe climate regions. Taking into account structural and acoustical ageing peculiarity of various low noise asphalt pavements and relevant influencing factors, it can be stated that thin low noise asphalt layers are the most promising cost effective low noise pavement solution for colder regions. However, specific attention should be given for these mixtures design and exploitation.

In comparison to traditional asphalt mixtures additional properties must be controlled for low noise asphalt mixtures’ design: binder drain down, resistance to ravelling, surface texture evolution and permeability.

This paper presents an initial stage of low noise asphalt mixture design for severe climate regions. Based on the performed assessment of various tyre/road noise influencing factors and low noise asphalt mixture design peculiarities, further step will include design and modelling of low noise asphalt mixtures.

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