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Low noise pavement development for severe climate conditions

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ABSTRACT

In recent years, increasing road transport noise problem in Lithuania has gained significant attention and induced development of low noise pavements for severe climate countries. Large research programme was initiated with the main purpose to develop low noise asphalt mixtures that considerably reduce road transport noise and are resistant to a large number of frost-thaw cycles in winter. Several AC and SMA mixtures were optimised for tyre/road noise reduction and tested in laboratory together with traditional asphalt mixtures and porous asphalt mixture to compare mixtures' performance in terms of noise reduction, mechanical stability and sensitivity to severe climate conditions. After positive and promising results, test road of noise reducing asphalt mixtures was built on operating highway for further research. Paper presents test road, which consists of 9 different short sections built of low noise and traditional asphalt mixtures. Paper describes research and testing plan of low noise pavement properties under real climate and traffic conditions. Results analysis of measured noise reduction properties after first half year of test road exploitation showed that depending on the mixture type, vehicle speed and mounted tyres, optimised low noise SMA mixtures reduce noise 3-5 dBA comparing with traditional asphalt mixtures.

Keywords: Road traffic noise, Outdoor test sites
I-INCE Classification of Subjects Number(s): 52.3; 73.4

1. INTRODUCTION

Excessive environmental noise is a major health problem, which in a longer term harms people's health and negatively affects the quality of living. It is estimated that around 125 million European inhabitants are exposed to the noise levels greater than 55 dB L_{den}. From a healthcare perspective, environmental noise causes at least 10000 cases of premature death and 43000 hospital admissions every year (1). High noise levels are responsible for sleep disturbance, annoyance, human emotional response, psychological stress reactions that increase the risk factor of various health problems and diseases (2). Negative environmental impacts on wildlife could also be identified as some animal species have migration or reproduction problems due to noise exposure (3). According to EC calculations (4) annual socio-economic costs (healthcare costs, reduced work/learning proficiency, real estate depreciation, abatement costs, etc.) due to noise pollution are approx. 40 billion EUR and expected to increase 50 % by the 2050.

Road transport is a main source of noise in Europe, followed by railways, airports and industry. Road traffic noise is caused by the combination of propulsion noise (engine, exhaust, and transmission), tyre/road noise and aerodynamic noise. While propulsion noise is dominant source at low speeds (up to 40 km/h) and aerodynamic noise at very high speeds (over 100 km/h), tyre-road noise is dominating at the most usual speeds in urban and suburban areas where noise exposure is the highest (5).

Noise pollution is a growing environmental concern and requires effective and efficient noise

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management and abatement actions and solutions. EC is addressing noise problem by setting common official regulations (*Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to assessment and management of environmental noise*), building future transport network strategy (6) and preparing other relevant documents. Road infrastructure owners/managers are also raising the attention to increasing traffic noise problem, which is highlighted in CEDR Strategic Plan 2014-2017 (7) as an important future road infrastructure challenge.

Political ambitions are high with the objective to significantly reduce noise pollution in the EU by 2020 and move closer to WHO recommended noise levels. Only combination of various noise mitigation measures aimed at all noise sources may meet the expectations and bring the highest results. Despite the significant progress which has been achieved through low noise tyre design, better vehicle aerodynamics, reduction of propulsion noise, there is still a lot of room and need for tyre/road noise reduction through development of quieter pavements.

In recent decades development of low noise pavements was mostly oriented for warm and mild climate regions, therefore the transferability of effective low noise solutions (e.g. porous asphalt) to severe climate regions (with high number of frost-thaw cycles and large temperature fluctuations) is unfeasible or complicated (requires comprehensive research and testing).

Recently, Lithuania has initiated large national research programme, which aims to optimize road surface characteristics using holistic approach – reduce road traffic noise and rolling resistance, ensure skid resistance and maintain sufficient durability and resilience to adverse climate conditions. One of the parallel research projects has main focus on road traffic noise reduction through the optimization of conventional stone mastic asphalt (SMA) and asphalt concrete (AC) mixtures.

2. LOW NOISE ASPHALT MIXTURE DEVELOPMENT

2.1 Tyre/road noise reduction principles

Traffic noise reduction through the road surfaces can be achieved in two ways (8): reduction of tyre vibrations and acoustical absorption of propagating sound waves above the surface. Referring to that, three noise reduction techniques can be applied when developing and optimizing road pavements for noise reduction (5): increase of sound absorption, texture optimization and mechanical impedance reduction.

Increased porosity in the road surface reduces ‘air pumping’ mechanism and increases absorption of sound waves emitted from the tyre/road contact and propagating over the surface (9). While asphalt mixes with air voids higher than 10 % are effective in noise absorption, but good noise absorption properties can be achieved when air void content is at least 15-20 % (5). During the porous asphalt pavement construction it is important to control compaction temperature as the air void content of porous asphalt mixtures mainly depend on it (10). According to (11) superficial porosity, preventing air pumping, is the main factor that explains good acoustic performance of thin layers despite they are not absorbing.

Road surface texture optimisation reduces tyre vibrations which are responsible for a noise generation (12). Texture is also important for splash/spray reduction, rolling resistance and skid resistance. Therefore it is important to find the right balance and compatibility between these characteristics as well as to define relevant geometric descriptors in order to assess the relationships between road surface texture and other parameters (13). Texture optimisation is performed at macrotexture scale by selecting aggregate type, size and mineralogy parameters (5).

Increase of porosity in the asphalt mixture could reduce noise levels at high frequencies (over 1000 Hz) while texture optimisation could reduce noise levels at low frequencies (less than 1000 Hz) (5). Therefore combination of these two noise generation techniques could result highest result.

Main principles to optimize conventional AC and SMA mixtures for noise reduction (5, 11, 14): use of smaller (4-6 mm for passenger cars’ noise reduction, 6-10 mm – for HDVs’ noise reduction), cubic shape, uniform and with sharp edges aggregate; open and ‘negative’ texture; air void content at least 5-6 %.

2.2 Low noise pavements

Porous asphalt pavements are the most popular and effective low noise pavements across the world. Reduction of noise levels, comparing with dense asphalt concrete pavements, can be achieved up to 6 dBA. However, clogging and poor resistance to severe climate (winter damage, ravelling) leads to shorter lifetime, higher life-cycle costs (15), and rapid decrease of acoustical properties (noise level increase by 0.7-1.0 dBA per year (16). Double layer porous asphalt, where the upper layer is constructed with a smaller size of maximum aggregate to protect surface texture from clogging while the bottom layer is constructed using larger size of maximum aggregate to ensure good acoustical absorption, may increase the lifetime of pavements (8), but sensitivity to climatic conditions (frost-thaw cycles, temperature fluctuation) limit the application of porous pavements in severe climate regions.

Another effective low noise pavement solution is thin layers which can be characterised by an optimised surface texture and 10-25 mm thickness. Thin layers are mostly constructed from modified SMA mixtures that has increased porosity and 'negative' texture, which helps to reduce air-pumping noise and the low amplitudes of megatexture, which helps to reduce tyre tread impact noise. Hin layers used as wearing course and may reduce noise levels (comparing with dense asphalt concrete pavements) by 3-4 dBA (17).

Very high noise reduction can be achieved via asphalt rubber or poroelastic (PERS) surfaces, which may reduce noise by 4-10 dBA comparing with dense asphalt concrete pavements. Asphalt rubber mixtures contain 18-22% of crumb rubber by weight of binder. The design air void content for PERS pavements is at least 20% by volume and the design rubber content is at least 20% by weight (5, 18). However, both asphalt rubber mixtures and poroelastic surfaces have lower durability and strength parameters, are more sensitive to abrasion, aging and moisture than traditional asphalt mixtures and require further development.

2.3 Lithuanian experience

As Lithuania did not have much experience on development or either application of low noise pavements, part of larger research programme was development of low nose asphalt pavements for regional climate conditions. Application of porous asphalt pavements is questionable due to their poor resistance to colder climate conditions (Lithuanian climate conditions could be characterized as severe conditions for road infrastructure (60−80 frost-thaw cycles annually)), it was decided to work on the optimization of the standard SMA and AC mixtures, so the mixtures would reduce tyre/road noise and at the same time retain sufficient durability and climate resistance.

Development was started in the Road Research Institute (RRI) of Vilnius Gediminas Technical University (VGTU). Conventional SMA and AC mixtures were modified for noise reduction by optimising their surface texture (smaller max. aggregate size (5 mm for passenger cars' noise reduction and 8 mm for HDVs' noise reduction, 'negative' texture) for tyre vibrations reduction and increasing air void content for better sound absorption (19). Optimised low noise asphalt mixtures SMA 5 TM, SMA 8 TM and TMOA 5 were tested and compared with conventional asphalt mixtures SMA 8 S, SMA 11 S, AC 8 VS, AC 11 VS, AC 8 PAS-H, porous asphalt PA 8 and special patented noise reduction pavement (20). Laboratory testing included determination of:

- standard physical and mechanical properties;
- noise reduction properties - mean texture depth (MTD) and sound absorption;
- Durability properties and resistance to climate conditions – laboratory simulation of 50 frost-thaw cycles and testing indirect tensile strength and particle mass losses after 0, 12, 25, 35 and 50 cycles.

3. TEST ROAD OF LOW NOISE PAVEMENTS

Based on the positive and promising laboratory testing results, which estimated that developed low noise asphalt mixtures for regional climate conditions should reduce noise by 2-4 dBA, it was decided to perform further research on the optimized low noise asphalt mixtures by constructing test sections on the operated road. The aim is to increase quality of living of the population by testing low noise pavements in real traffic and environmental conditions, evaluating noise reduction characteristics dependent on asphalt mixture type and duration and level of exploitation.

Construction of the Test Road of Low Noise Pavements is important for the whole region as there were no experience of testing low noise pavements under region climate conditions. The results as well as optimised low noise asphalt mixtures will be valuable and transferable to other region countries.

3.1 Construction of test road

For the selection of the potential locations for construction of the Test Road of Low Noise Pavements several location criteria were defined:

- Test road should not be on a curve, longitudinal slope less than 1%.

- Length of the each Test Road section should be at least 60 m, for high speed roads – at least 100 m. However, in all cases, the recommended length is 100-200 m.
- Each test section should be constructed homogenously (of the same materials) in all section length and width.
- In 25 m distance from the roadway cannot be any traffic barriers, building facades, noise screens, embankments or noise walls.
- Annual average daily traffic (AADT) should be at least 2000 vehicles per day, of which more than 10% should be heavy traffic. Statistical data about AADT in the test road should be collected continuously.
- Traffic flow should consist of passenger vehicles, light duty vehicles (two axle) and heavy duty vehicles (more than two axles).
- Traffic flow in the section should be consistent and without any obstacles for the driving speed (e.g. intersections, speed limits, acceleration/deceleration lanes, etc.).
- Background noise (generated not by the vehicles and reflecting from the near surfaces) should be at least 10 dB lower that direct noise level from the vehicles.

According to the selection criteria, location for the Test Road of Low Noise Pavements was selected on a Lithuanian highwayA2 Vilnius-Panevėžys. A2 is a two lane dual carriageway road which connects two large cities – Vilnius and Panevėžys. Average annual daily traffic (AADT) in different parts of this highway varies from 7000 to 10000 vehicles per day. Speed limit is 110 km/h.

Test Road of Low Noise Pavements was constructed in September, 2015 on a right side (both lanes) of the highway in the direction to Panevėžys at 56.07-57.57 km. Test Road is 1.5 km in length and consists of 9 short sections where asphalt wearing layer was constructed using different asphalt mixtures. Those mixtures include 3 noise reducing asphalt mixtures (TMOA 5, SMA 5 TM, SMA 8 TM) developed by VGTU RRI for Lithuanian climate conditions, 1 porous asphalt mixture (PA 8), 1 special pavement and 4 traditional asphalt mixtures (SMA 8 S, SMA 11 S, AC 11 VS, AC 8 PAS-H). Main characteristics of the sections are presented in (Table 1).

Table 1 – Main characteristics of the Test Road of Low Noise Pavements

Pavement type	Layer thickness [mm]	Section length [m]	Pavement width [m]
PA 8	40	100	11.25-11.60
SMA 8 S	30	175	8.55-8.75
SMA 11 S	30	175	8.55-8.75
AC 11 VS	30	175	8.55-8.75
AC 8 PAS-H	25	175	8.55-8.75
TMOA 5	25	175	8.55-8.75
SMA 8 TM	25	175	11.25-11.60
SMA 5 TM	25	175	11.25-11.60
Special pavement	25	175	11.25-11.60

Since the constructed asphalt mixtures have different air void content resulting different water drainability and related problems, wearing layers of emergency lane were constructed of the same asphalt mixtures as on the traffic lanes for mixtures with higher air void content (PA 8, SMA 5 TM, SMA 8 TM) and for special product to ensure that water could be easily drained from the traffic lanes. For all other sections, constructed of less porous mixtures, emergency lane was constructed of AC 8 VN mixture.

To minimize probability of future asphalt cracks at the joints (between the lanes and different asphalt mixtures), both lanes and emergency lane was constructed at the same time, using three asphalt pavers (Figure 1).

After laying the test sections, no surface treatment (that are usually used for SMA mixtures to ensure sufficient friction) were applied as it may have negative impact on surface texture resulting worse noise reduction properties.

3.2 Research plan

Large set of periodic measurements in the Test Road of Low Noise Pavements are planned for the next three years:

- Acoustical measurements:
  - Noise level measurements of passing vehicles using Statistical Pass-By (SPB) method (EN ISO 11819-1) (Figure 1). Measurements at different driving speeds: passenger cars – 50 km/h, 80 km/h and 110 km/h; LDV and HDV – 50 km/h, 70 km/h, 85 km/h.
  - Tyre/road noise measurements using Close-ProXimity (CPX) method (ISO/DIS 11819-2) (Figure 1). Measurements at different driving speeds: 40 km/h, 50 km/h, 80 km/h, 100 km/h. Measurements using two sets of tyres – representing passenger cars (Standard reference test tyre (SRTT)) and HDVs (Avon Supervan AV4 tyres (AAV4)).
  - Sound absorption measurements in impedance tube using standing wave ratio (EN ISO 10534-1). Drilled cores from the road are tested in the laboratory.
- Surface texture measurements:
  - Mean texture depth (MTD) measurements using volumetric patch method (EN 13036-1).
  - Mean profile depth (MPD) measurements using laser texture measurement devices, including measurements of RMS and skewness parameters;
  - IRI measurements.
  - Skid resistance measurements using pendulum SRT device.
- Other measurements:
  - Air void content and layer thickness measurements in laboratory (from the drilled cores);
  - Visual condition assessment.

Measurements are performed annually: twice in spring (when average daily temperature is higher than 5^{o}C and when average daily temperature is 10-15^{o}C) and once in autumn (before the winter season). Before noise measurements, every section of the Test Road are being visually inspected to evaluate road pavement condition, identify pavement deterioration and all distresses.

Most of the testing are performed on the both traffic lanes, except SPB measurements. Measurements on both traffic lanes will allow to monitor acoustical and durability properties variation depending on the traffic volumes, traffic composition (on the 1st traffic lane – mixed traffic of passenger cars and HDVs, on the 2nd traffic lane – mostly passenger cars), level of exploitation and climate conditions.

Figure 1 – Fragment from CPX (left) and SPB (right) noise level measurements

4. ACOUSTIC TESTING RESULTS

Since the Test Road of Low Noise Pavements already passed half year of exploitation, acoustical testing of optimized low noise asphalt mixtures performance has been performed several times using different methodologies: CPX, SPB and acoustical absorption. Combination of three acoustical testing methods enables opportunities to conduct comprehensive analysis of acoustical performance of various road surfaces and to identify mixtures properties influence on noise generation mechanisms.

4.1 CPX measurements

As it was expected, the lowest noise levels were measured for the sections, constructed of porous asphalt PA 8 and from optimized low noise asphalt mixtures SMA 8 TM, SMA 5 TM, TMOA 5. At the 50 km/h speed best performing sections are PA 8, SMA 5 TM and SMA 8 TM (Figure 2). At the 80 km/h speed best performing sections are PA 8, SMA 5 TM and SMA 8 TM (Figure 3).

Slight differences (under 1.5 dBA) of CPX noise levels between the traffic lanes were identified almost in all sections except the sections constructed of asphalt mixtures with higher air void content – PA 8, SMA 8 TM, SMA5 TM. For these sections, differences between the traffic lanes are higher than 1.5 dBA. Reasons of such differences can be associated with the construction processes: over or under compaction. This was verified by the laboratory testing of drilled cores – air void content for SMA 8 TM surface between the traffic lanes differs by 3.0 % (11.3 % on the 1st lane and 8.3 % on the 2nd traffic lane), level of compaction differs by 3.1 % (94.7 % on the 1st lane and 97.8 % on the 2nd lane). However, unplanned differences between the lanes enabled opportunity to monitor the progress of durability and acoustical properties with relevance to construction problems, different compaction and aid void contents.

Comparing CPX noise level differences with the measurements which were performed right after the construction, it was seen that noise levels have slightly increased (by 0.5-1.0 dBA). Conversely, the differences between the traffic lanes have reduced and may be associated with the bitumen oxidation processes and traffic impact.

SMA 5 TM and TMOA 5 mixtures were optimized with the focus to reduce passenger cars' noise while SMA 8 TM heavy duty vehicles' noise levels. This was also noticed when analyzing noise levels measured with different tyre sets. For SMA 5 TM and TMOA 5 mixtures the noise levels when measuring with SRTT tyre were approx. 2 dBA lower than comparing with the results of CPX noise levels measured with AAV4 tyres.

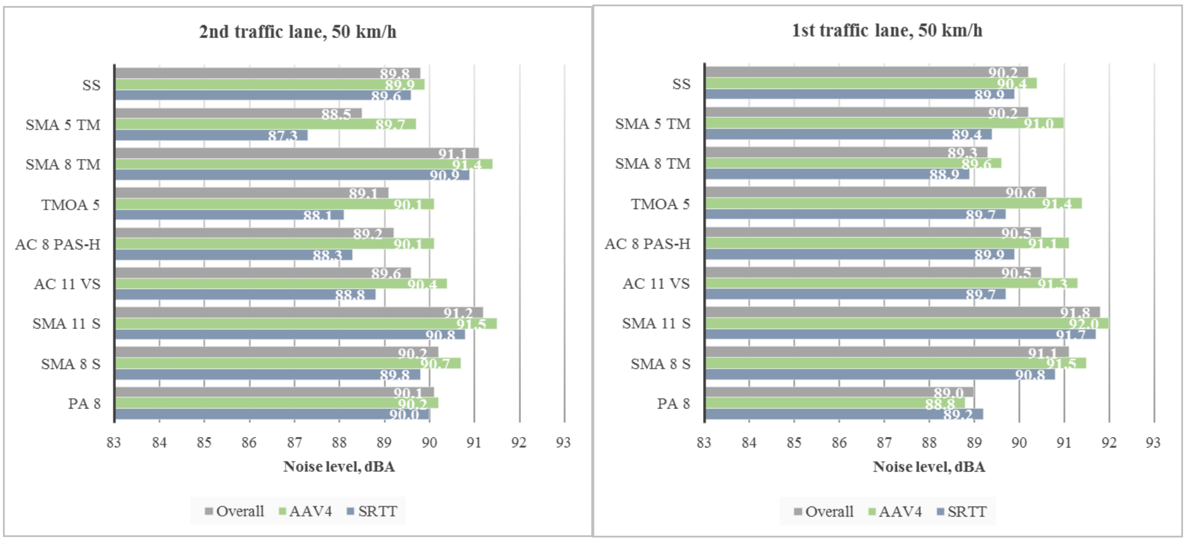


Figure 2 – CPX noise level measurements at driving speed of 50 km/h

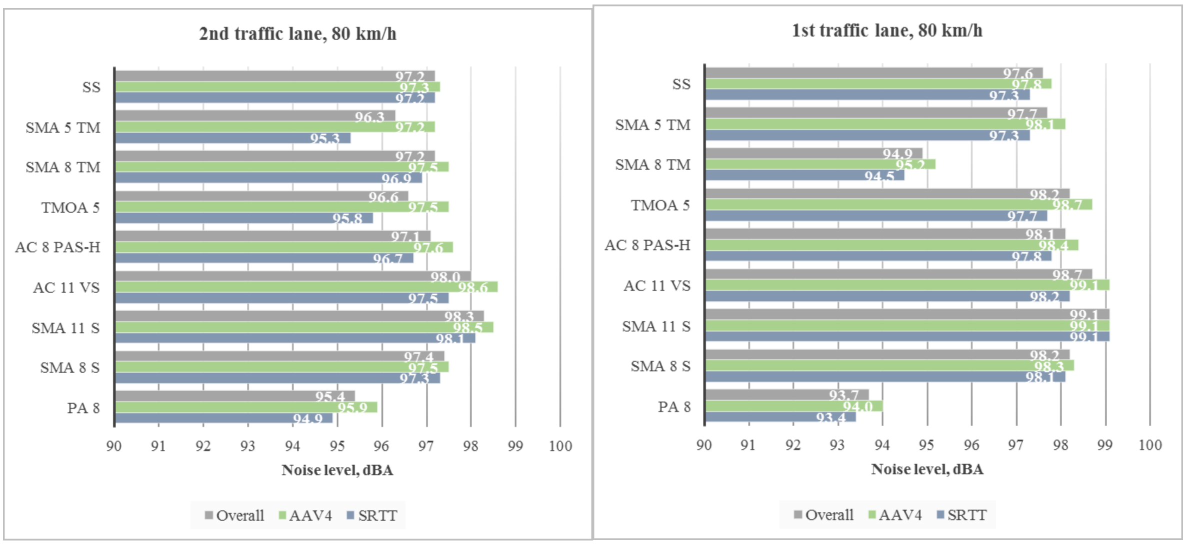


Figure 3 – CPX noise level measurements for two traffic lanes at 80 km/h

4.2 SPB measurements

SPB noise level measurements have showed similar results to CPX noise level measurements (Figure 4). Measured noise levels at 50 km/h speed were lowest in the sections constructed of porous asphalt PA 8 – 65.0 dBA, and optimized low noise asphalt mixtures SMA 8 TM – 65.0 dBA, SMA 5 TM – 66.5 dBA and TMOA 5 – 67.3 dBA. Comparing with the traditional AC 11 VS and SMA 8 S, SMA 11 S mixtures, the difference is 1.5-4.1 dBA (depending on the compared mixtures).At the 80 km/h speed lowest noise levels were measured for PA 8 – 73.3 dBA, SMA8 TM – 73.3 dBA, SMA 5 TM – 75.4 dBA and TMOA 5 – 75.9 dBA. Comparing with the traditional AC 11 VS and SMA 8 S, SMA 11 S mixtures, the difference is 1.2-5.6 dBA (depending on the compared mixtures).

Comparing SPB noise level differences with the measurements that were performed right after the construction, it was seen that noise levels have slightly increased (by 0-0.2 dBA) and may be associated with the bitumen oxidation processes and traffic impact.

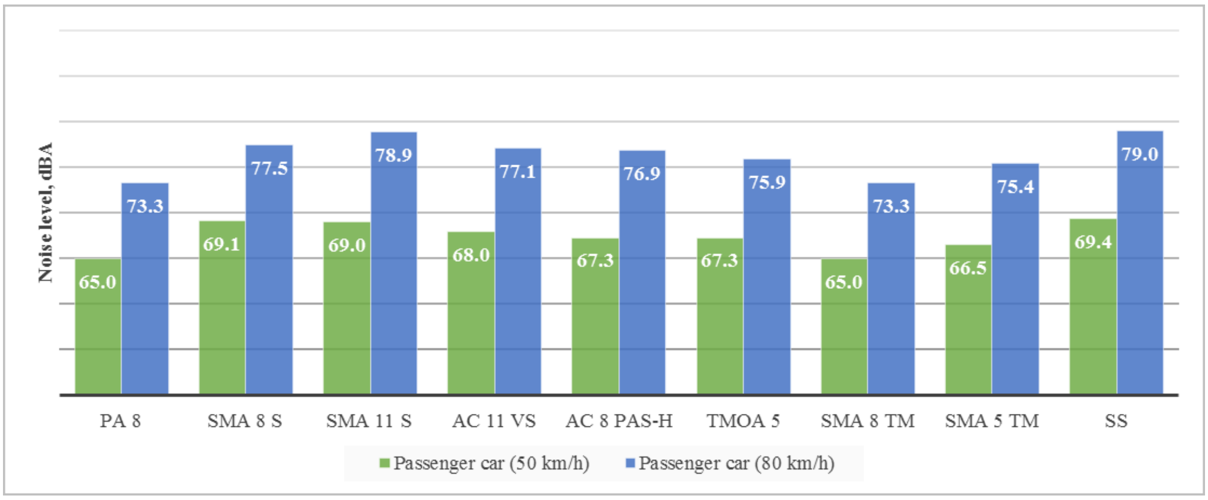
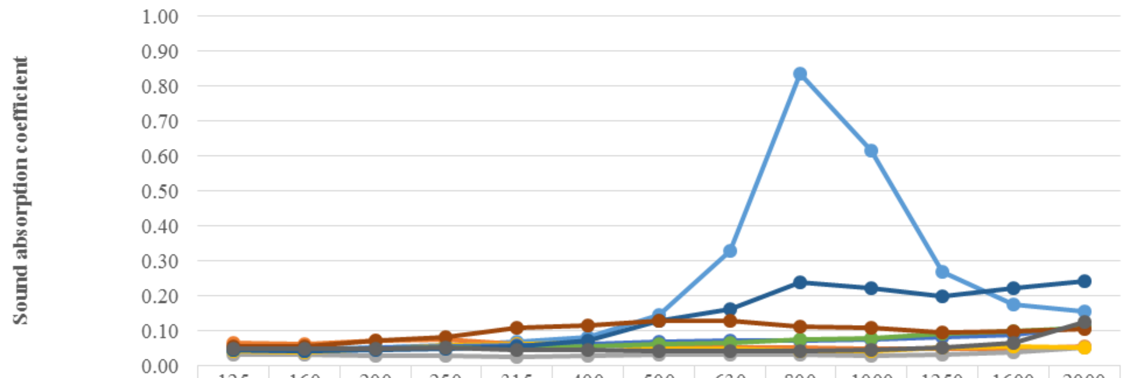


Figure 4 – SPB noise level measurements for passenger cars at two driving speeds

4.3 Acoustical absorption

Sound absorption measurements (Figure 5) showed that very high sound absorption has porous asphalt pavement PA 8 which can be associated with the high air void content (measured air void content from the drilled core – 38.9 %; measured air void content from the asphalt mixture sample – 21.4 %) and wearing layer thickness (approx. 40 mm). Optimised low noise asphalt mixtures SMA 8 TM and SMA 5 TM have also showed better sound absorption than conventional SMA 8 S, SMA 11 S and AC 11 VS mixtures. For PA 8 mixture highest sound absorption (sound absorption coefficient higher than 0.6) was measured in 700-1000 Hz frequency range, while SMA 5 TM relatively good absorption (sound absorption coefficient around 0.15) in 400-600 Hz frequency, SMA 8 TM has highest sound absorption (sound absorption coefficient around 0.25) in 800-2000 frequency range.

Even if the noise absorption for optimized low noise asphalt mixtures SMA 5 TM and SMA 8 TM are not high enough to reduce significantly air pumping or to absorb the sound waves that propagates above the road surface like it is possible to do with porous asphalt surface, higher sound absorption (comparing with traditional SMA and AC mixtures) contributes to noise reduction mechanisms.



	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
PA 8	0.05	0.05	0.05	0.06	0.07	0.08	0.14	0.33	0.84	0.62	0.27	0.17	0.15
SMA 8 S	0.07	0.06	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05
SMA 11 S	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.05
AC 11 VS	0.04	0.04	0.05	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.05	0.05	0.05
AC 8 PAS-H	0.05	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.09	0.11
TMOA 5	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.11
SMA 8 TM	0.04	0.04	0.04	0.05	0.06	0.07	0.13	0.16	0.24	0.22	0.20	0.22	0.24
SMA 5 TM	0.05	0.06	0.07	0.08	0.11	0.12	0.13	0.13	0.11	0.11	0.09	0.10	0.11
SS	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.06	0.13

Frequency, Hz

Figure 5 – Sound absorption coefficient of different asphalt mixtures (measures from the drilled cores)

5. DISCUSSION

Environmental noise is an increasing environmental problem, which has significant impact on people health and well-being. Excessive noise exposure in urban areas requires effective and efficient noise management and abatement solutions, preferably complex solutions – combination of noise barriers, traffic management and low noise pavements.

Low noise pavements is very effective solution on traffic noise reduction, but low noise pavement experience and potential application vary across the regions. Effective solutions, such as porous asphalt, is not very well suitable for severe climate countries where asphalt pavements have to be highly resistant to intensive frosting and thawing and high temperature fluctuation.

Based on the positive and promising results of laboratory development of low noise asphalt mixtures for severe climate conditions, Test Road of Low Noise Pavements was built in Lithuania for further assessment of region optimized low noise pavements.

Since the Test Road of Low Noise Pavements is in its first year of exploitation, initial assessment of acoustical performance can be performed. Optimized low noise asphalt mixture SMA 8 TM have showed similar acoustical properties (according to CPX and SPB noise level measurements) to PA 8. Comparing optimized low noise mixtures SMA 8 TM, SMA 5 TM and TMOA 5 with conventional SMA 8 S, SMA 11 S and AC 11 VS, it can be said that optimized low noise asphalt mixtures reduce noise by 2-5 dBA (depending on the driving speed).

Optimized surface texture for passenger cars' noise reduction for SMA 5 TM and TMOA 5 mixtures was successful – CPX measurement results with different tyres showed that the SRTT tyres generate approx. 2 dBA lower noise levels than AAV4 tyres when driving on SMA 5 TM and TMOA 5 pavements.

From a sound absorption perspective, it can be stated that road surface constructed of PA 8 reduce noise levels the most, but comparing sound absorption, CPX and SPB noise level measurements, it can be stated that main noise reduction feature of PA 8 is air void content and for SMA 8 TM and SMA 5 TM mixtures – combination of increased air void content and optimized surface texture.

More detailed analysis of low noise asphalt mixtures and their performance need to be performed regarding noise spectrum analysis and interconnection with texture parameters (MPD, RMS, skewness).

From the CPX noise level results, large differences between the traffic lanes were identified and can be associated with the construction issues. This leads to necessity of establishing strict requirements for low noise pavement construction.

After half year of exploitation optimised low noise pavements retained sufficient stability and strength properties – no distresses were identified. Good pavement quality and resistance to traffic and climate impacts was guaranteed by a special low noise asphalt mixtures design.

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