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Traffic/road noise mitigation under modified asphalt pavements

Audrius Vaitkus [a], Donatas Čygas [a], Viktoras Vorobjovas [a], Tadas Andriejauskas [a,]*

[a]*Vilnius Gediminas Technical University, Linkmenu str. 28, 08217 Vilnius, Lithuania*

Abstract

Road traffic noise is one of the largest trend environmental problems, which causes a lot of negative effects to people health and countries' economies. Road traffic noise abatement and mitigation is a huge challenge for NRAs, which, in the context of decreasing budgets, has not only to maintain sufficient level of their road networks, but also to meet the environmental requirements and society needs. Despite the wide experience of noise reducing asphalt mixtures development and application in European countries, the same effective solution cannot be adapted in all countries because of the regional differences of clime and traffic conditions. For these reasons, Lithuania have started a set of research works related with noise reducing asphalt mixtures development for Lithuanian climate conditions, which could be characterized as a harsh climate conditions with a high number of annual frost-thaw cycles. Article presents laboratory research phase of noise reducing asphalt mixtures. Optimization of traditional asphalt mixtures SMA and AC were performed to increase noise reduction properties at the same time retaining sufficient durability. Conventional and innovative laboratory testing methods were applied. Paper provides results of laboratory testing and analytical analysis of the tested asphalt mixtures properties. Summarized research conclusions and recommendations for further activities are presented in the article.

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Keywords: Tyre/road noise; optimized pavements; surface texture

* Corresponding author. Tel.: +370-5-251-2354; fax: +370-5-273-1020.
E-mail address: tadas.andriejauskas@vgtu.lt

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1. Introduction

Environmental noise can be associated with various industrial, transportation and social activities. Sadly, the main noise causal factors are linked with road and railway transport – calculations show that annual socio-economic costs due to road and railway noise are worth around 40 billion EUR and is likely to increase 50% more by 2050. It is important to note, that 90% of these costs are caused by light and heavy road transport (European Commission 2011).

Around 20% of EU inhabitant are exposed to noise level that are higher than 65 dBA at daytime and 40% of EU inhabitants – to noise levels that are higher than 55 dBA at nighttime (Commision… 1996; Jaecker-Cueppers 2002). Negative noise impacts are linked with nuisance, health problems (cardiovascular, mental state, hearing system, central nervous system, autonomous nervous system, sleep disturbance, learning/understanding/communication performance, work efficiency and other disorders or diseases) (Miedema, Oudshoorn 2011). Some animal species are also negatively affected by noise resulting problems in animal population and migration.

Road transport noise is mostly dependent on driving speed: different travelling vehicle noise sources dominate at different speeds, for example vehicle propulsion noise dominates at low speeds (less than 40 km/h), tyre/road noise dominates at the speed range from 40 to 100 km/h and noise due to vehicle aerodynamics dominates at very high speeds (higher than 120 km/h) (Rassmussen et al 2007).

Recent tendency of urbanization requires reshaping transport infrastructure in a way it provides best mobility conditions for people and goods as well as create good living environment. However, the road sector financing is not sufficient to maintain roads at the highest level and at the same time to ensure lowest environmental impacts. Having in mind such challenges, new solutions, which are focused to cost-efficient transport noise reduction, have to be developed and applied in practice.

Despite that traffic noise reduction through optimized or ad hoc developed pavements are known and used in practice for a long time in Europe, Lithuanian and Baltic region experience in that area was low. Therefore, the increased attention to environmental problems in Lithuania encouraged research activities on the development of noise reducing pavements for Lithuanian climate conditions, which are quite specific and different from warm climate countries.

2. Reduction of tyre/road noise generation mechanisms

Tyre/road noise is an important part of overall vehicle noise, especially in the cities or urban environments where the building are close to the road/street and the vehicles are mostly driving at the speed of 50–60 km/h. Tyre/road noise is described by the noise generation mechanisms caused by mechanical tyre vibrations, aerodynamical phenomena and related amplification or reduction mechanisms (Sandberg, Ejsmont 2002). Each of the noise generation mechanism are linked with particular influencing factors (road surface properties, tyre properties, environmental factors, driving behaviors) (Li et al 2009).

It is well researched that tyre/road noise reduction can be achieved by applying 3 main pavement surface optimization techniques: increase of porosity, texture optimization and reduction of mechanical impedance (Sandberg et al 2011; Beckenbauer 2011). Increase of porosity leads to better sound absorption and reduction of tyre/road noise at high frequencies (over 1000 Hz). Such pavements can be characterized by large porosity (at least 20%) with interconnecting voids. Good examples are single or double layer porous asphalt layers which absorbs the sound waves that dissipates from the vehicle above road surface. Noise reduction of such pavements can be achieved by 5–8 dBA (comparing with standard AC mixtures) (Freitas et al 2009), but it loose initial noise reduction properties quite fast (about 1 dBA per year) due to dirt placed in the voids.

Texture optimization is based on the formation of even road surface texture where the road surface plane is with more spaces between the aggregates than irregularities – 'negative' texture. Optimized surface texture reduce tyre rubber thread vibrations and so generated noise levels. For the best result it is recommended to use cubic shape small maximum aggregate size: 4–6 mm for passenger cars' noise reduction and 8–10 mm for heavy duty vehicles' noise reduction. By optimizing surface texture, noise is reduced in low frequencies (under 1000 Hz) (Kuijpers, Van Blokland, 2006). Thin asphalt layers can be highlighted as a positive solutions (noise reduction about 2–5 dBA) of pavements with optimized surface texture (Bendtsen 2008).

Third noise reduction techniques is modification of surface mechanical impedance, for instance, added rubber or any similar material in asphalt mixture result more flexible road surface texture and better interaction of pavement and tyre – the difference between surface and tyre stiffness is reduced and so less tyre vibrations. Reduction of mechanical impedance reduce noise levels at medium frequency range (800–1200 Hz). Poroelastic (PERS) pavements or rubber asphalt is a good example of such pavement types (Biligiri et al 2009). However, their durability and lifetime is less than comparing with standard AC mixtures.

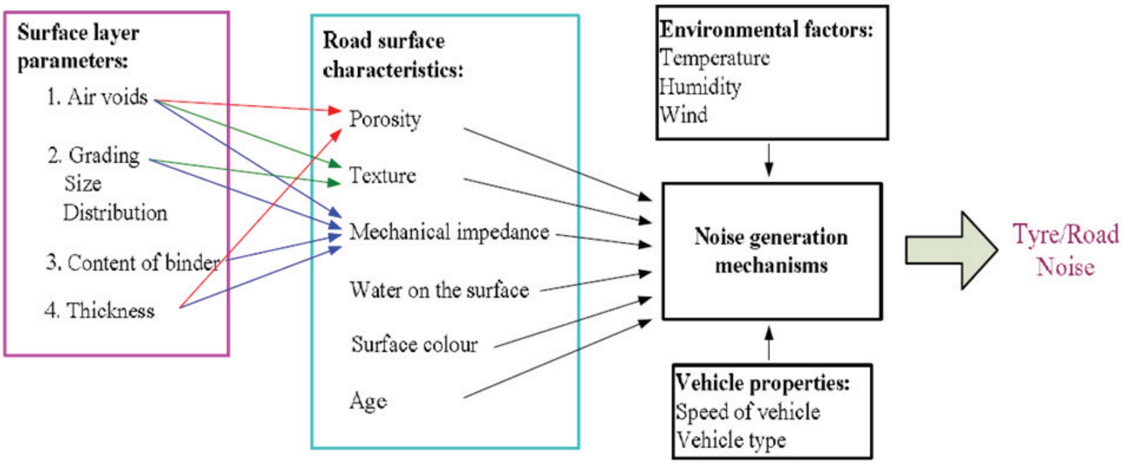

Fig. 1. Major influencing factors on tyre/road noise (Li et al 2009).

3. Laboratory development of optimized low noise pavements

As Lithuania didn't have much experience on development or either application of low noise pavements, a set of research work recently was initiated to develop noise reducing asphalt pavements for Lithuanian climate conditions. Despite that some low noise pavement solutions like porous asphalt are very popular and effective in many countries, in Lithuania their feasible and cost-efficiency is questionable due to their poor resistance to colder climate conditions (which could be characterized as severe conditions for road infrastructure (60−80 frost-thaw cycles annually (Ratkevičius et al. 2013)). 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.

3.1. Methodology

Optimization of SMA and AC asphalt mixtures was performed in a Road Research Institute of Vilnius Gediminas Technical University. A combination of two main noise reduction techniques, texture optimization and increase of porosity, was applied when designing the mixtures. Two conceptual noise reducing SMA mixtures were designed – SMA 5 TM and SMA 8 TM, with the maximum aggregate size 5 mm and 8 mm respectively. Another conceptual noise reducing AC mixture was developed – TMOA 5. Besides these conceptual asphalt mixtures, 3 standard (not noise reducing) and usually applied Lithuanian SMA 8 S, SMA 11 S and AC 11 VS mixtures were selected for further comparison of physical, mechanical, durability and acoustical properties. Parameters of designed mixtures are provided in Table 1.

At first, all of the asphalt mixtures were designed and manufactured with 3 different bitumen binder content with purpose to select the optimal and close to optimal bitumen binder contents in the mixtures. Standard set of physical and mechanical properties (Marshall stability and flow, air void content, indirect tensile strength, indirect tensile strength ratio etc.) of the mixtures were tested in the laboratory.

In the laboratory there were also performed climate resistance tests – particle mass loses after frost/thaw cycles. One cycle – prepared asphalt samples (cylindrical Marshall samples, made by 50 blows per side) were sunk into water bath with 20±5 °C water temperature where samples were kept until becoming fully saturated; then samples were put into the plastic bags and stored in the freezer where they frosted in –18±3 °C temperature for at least 4 hours; hereafter the samples were taken out from the freezer and thawed for 2 hours in the water bath. The described frosting-thawing process was repeated 50 times to simulate 50 frost-thaw cycles. Laboratory tests were performed before the frost-thaw cycles and after 12, 25, 38 and 50 frost-thaw cycles. Particle mass losses were measured according to standard *LST EN 12697-17+A1:2007 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 17: Particle Loss of Porous Asphalt Specimen* and testing samples using the Los Angeles machine (by standard *LST EN 1097-2:2010 Tests for Mechanical and Physical Properties of Aggregates –Part 2: Methods for the Determination of Resistance to Fragmentation*).

From noise reduction point of view, acoustical absorption tests were performed to evaluate how the mixtures absorb sound waves. This was the first time in Lithuanian when this method was performed in asphalt mixtures testing. Sound absorption coefficient was determined in impedance tube using standing wave ratio (according to the standard *LST EN 10534-1: 2002 Acoustics – Determination of Sound Absorption Coefficient and Impedance in Impedances Tubes – Part 1: Method Using Standing Wave Ratio (ISO 10534-1:1996)*). Sound absorption coefficient was measured at different frequencies.

Table 1. Parameters of designed asphalt mixtures.

	SMA 5 TM	**SMA 8 TM**	**TMOA 5**	**SMA 8 S**	**SMA 11 S**	**AC 11 VS**
Aggregate type	Granite	Granite	Granite	Granite	Granite	Granite
Content by fraction, %:						
Fr. 8/11		6.6			40.3	28.4
Fr. 5/8	9.3	67.5	8.6	51.3	15.9	10.4
Fr. 2/5	61.6	4.7	56.1	18.7	14.1	12.3
Fr. 0/2	16.8	6.6	19.0	13.1	12.2	41.6
Mineral powder	5.6	8.4	11.4	10.3	11.2	1.9
Adhesive additive, %	0.2	0.2	0.2	0.2	0.2	0.2
Stabilisation additive	Cellulose fibre	Cellulose fibre		Cellulose fibre	Cellulose fibre	
Content, %	0.4	0.4		0.4	0.4	
Binder type	PMB 45/80-55	PMB 45/80-55	PMB 45/80-55	PMB 45/80-55	PMB 45/80-55	PMB 45/80-55
Content, %	6.7	6.3	4.9	6.7	6.3	5.5
Air void content, %	7.2	8.3	5.6	2.4	2.0	2.3

3.2. Results

Figure 2 presents the results of measuring particle mass losses after 0, 12, 25, 38 and 50 frost-thaw cycles. Comparing with the traditional asphalt mixtures SMA 8 S, SMA 11 S and AC 11 VS, conceptual noise reducing asphalt mixtures have shown worse results. Particle mass losses increased drastically after first 12 frost-thaw cycles for SMA 8 TM and TMOA 5 mixtures, but later the increase of particle mass losses was more constant. With the SMA 5 TM mixture, situation was a little bit different, at first the increase of particle mass losses was constant, but it was measured large increase after 50 cycles (comparing with the measured value after 38 cycles, it increased by more than 50%).

As it was expected, traditional asphalt mixtures performed well proving the better durability and climate resistance properties than conceptual noise reducing mixtures. It can be stated that for conceptual noise reducing asphalt mixtures higher air void content was one of the main causal factors influencing bigger particle mass losses.

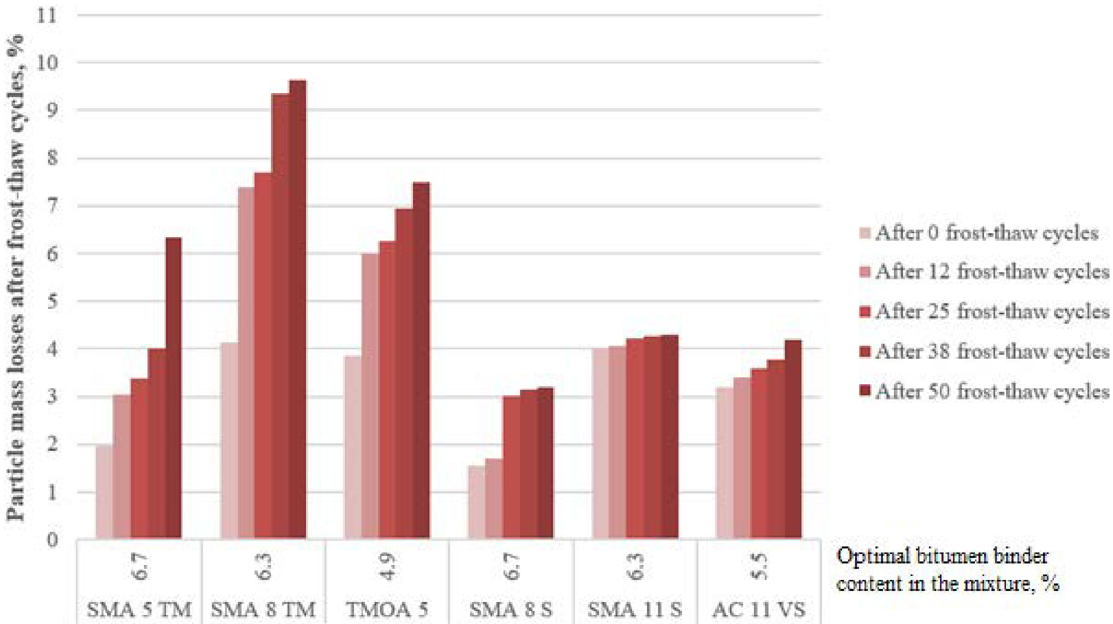

Fig. 2. Results of particle mass losses after 0, 12, 25, 38 and 50 frost-thaw cycles. Number above the name of the pavement, shows the selected optimal binder content for such mixtures.

Sound absorption measurements by impedance tube with standing wave method provided with the results showing that SMA 8 TM and TMOA 5 mixtures have higher absorption properties than traditional mixtures (Fig. 3). The highest absorption was measured at low frequency range (300–630 Hz) with the maximum absorption coefficient 0.26 for SMA 8 TM and 0.2 for TMOA 5 mixture. Better absorption can be related with the larger air void content in the mixture.

SMA 5 TM didn't show any difference from traditional asphalt mixture.

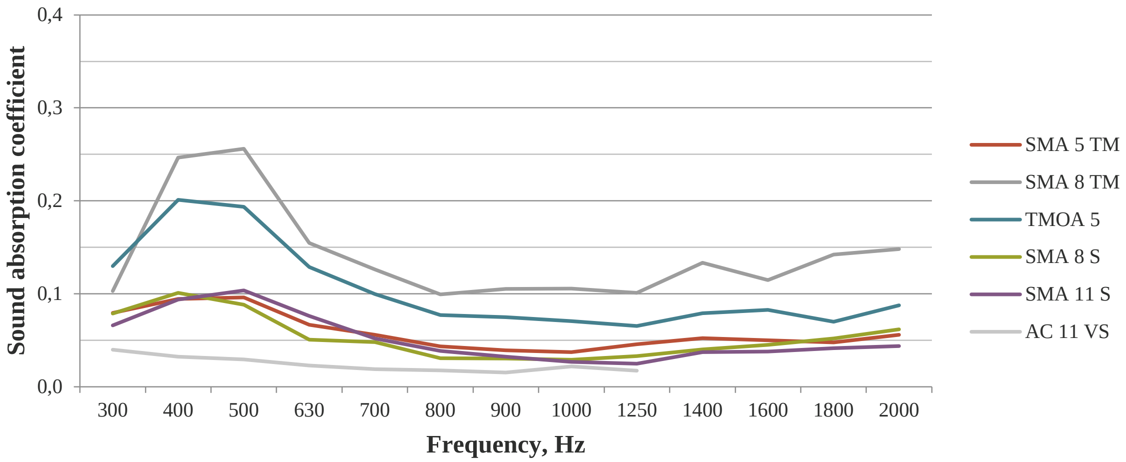

Fig. 3. Sound absorption coefficient for different asphalt mixtures.

3.3. Next steps

Laboratory testing provided positive and promising results for research continuation by constructing first test sections. Based on the research results and recommendations for asphalt wearing layer construction of noise reducing asphalt mixtures Test Road of Noise Reducing Asphalt Pavements were constructed in the highway A2 Vilnius-Panevėžys. Short test sections of 175 m length were built.

Periodic noise level, durability, and surface texture measurements are planned in the Test Road of Noise Reducing Asphalt Pavements. Acoustocal properties will be measured using three methods: Statistical Pass By (SPB), Close-ProXimity (CPX) and acoustical absorption using impedance tube in the laboratory. Various road surface texture parameters will be measured as well: mean texture depth (MTD), mean profile depth (MPD), root mean square (RMS), skewness, IRI, skid resistance.

There will also be performed periodical testing of physical and mechanical properties in laboratory after drilling core samples in the test sections.

Further research will be continued with focus orientation on improving durability conditions for noise reducing SMA 5 TM, SMA 8 TM and TMOA 5 mixtures.

4. Conclusions and recommendations

Outcomes of the performed research – three developed noise reducing asphalt mixtures SMA 5 TM, SMA 8 TM, TMOA 5 bearing in mind peculiarity of Lithuanian climate conditions. Mixtures were tested using conventional and innovative testing methods, which were first time used for asphalt mixtures testing in Lithuania.

According to the research results, seen tendencies and accomplished comparison tests with traditional mixtures, it can be expected that developed noise reducing asphalt mixtures will reduce traffic noise from 2 to 4 decibels comparing with traditional SMA and AC mixtures.

Based on the research results, first test sections were constructed to be further tested and analyzed under real traffic and climate conditions in the context of noise reduction, durability and climate resilience. If the mixtures' perform sufficient under real traffic and climate conditions, they will be further recommended for wide implementation in Lithuanian road network.

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