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Asphalt wearing course optimization for road traffic noise reduction

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HIGHLIGHTS

- The aim of this study is to optimize AC and SMA mixtures for noise reduction.
- Developed low noise asphalt mixtures for severe climate conditions.
- Simulation of low noise asphalt mixtures resistance to frost-thaw cycles.
- Recommended air void content for low noise asphalt mixtures in cold regions.

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ABSTRACT

Nowadays traffic noise and air pollution are as important as durability parameters, what leads to the need of more comprehensive approach when planning, designing, constructing and maintaining road pavements. Having in mind country differences in traffic volumes, climate conditions and financial capabilities it is not easy to transfer various solutions from country to country. Due to such peculiarities, large research study was initiated in Lithuania seeking to develop efficient and effective low noise pavement solution for specific regional climate conditions. This paper presents research of commonly used asphalt concrete (AC), stone mastic asphalt (SMA), porous asphalt (PA) and a concept of noise reducing asphalt mixtures. As part of this study large scale laboratory testing of acoustical and mechanical performance, durability and resilience to climate were performed. The paper also presents analysis of laboratory testing results which were positive and followed with the pilot implementation of developed asphalt mixtures for further research activities under real traffic and climate conditions.

1. Introduction

Traffic noise as a problematic area for society and quality of living is known for quite a long time. However, in the recent decades noise gained higher attention as it contributes to environmental pollution and generates other environmental problems. Nowadays traffic noise is identified as one of the main environmental problems and an increasing challenge to the national road authorities.

According to the WHO [1] “one in three individuals is annoyed during the daytime and one in five has disturbed sleep at night because of traffic noise”. By WHO data odds of incidence of a disease rise to about 10% when $L_{Aeq,day}$ noise level increases from 55–60 dBA to 65–70 dBA. Especially sleep disturbance at night time leads to human emotional response, annoyance, and psychological stress reactions that increase the risk factor of high blood pressure and cardiovascular diseases [2]. Additionally, negative noise impacts are linked with other health problems (mental state, impaired hearing, central nervous system, autonomous nervous system, learning/understanding/communication performance, work efficiency and other disorders or diseases) [3]. It should be mentioned that some animal species are also negatively affected by noise resulting problems at individual and population levels mostly related with reproduction and migration [4]. From economic point of view, using four major techniques for measuring economic benefits of noise reduction (cost of abatement, cost of illness, contingent valuation method, and hedonic price method) it is possible to do monetary calculations of negative noise impacts on human health, real estate depreciation and other related costs [2].

Observation [5] shows that the percent of highly disturbed people at night time due to road traffic noise rises from 3% at levels of 40 dBA to 6% (50 dBA) and 8% for level of 55 dBA. It was concluded

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that sleep quality, human well-being may be disturbed starting from 40 dBA of outdoor environmental noise night levels. Accordingly, the EC recommended [6] that L_{night} indicator values in noise maps should be lowered to 40 dBA and to 35 dBA for future noise maps.

According to the EC calculations [7] traffic noise is responsible for about 40 billion EUR (mainly caused by the traffic of light and heavy duty vehicles) worth socio-economic costs and is expected to increase 50% by 2050. EC is addressing environmental noise problems by setting common official regulations (i.e. *Directive 2002/49/EC* [8]), building future transport network strategy [9] and preparing other relevant documents. Road infrastructure owners/managers are also raising attention to the increasing traffic noise problem which is named in CEDR Strategic Plan 2014–2017 [10] as an important future road infrastructure challenge.

Vehicle generated noise can be grouped into three sources (propulsion noise, tyre/road noise and aerodynamic noise) which are mostly dependent on the driving speed [11,12]. At lower speeds (up to 40 km/h) propulsion noise is a main contributor to the overall vehicle noise while at the higher speeds (40–100 km/h) tyre and road interaction mechanisms contribute to approximately 90% of emitted acoustics energy and become a dominant component of the vehicle generated noise. At very high speeds, aerodynamic noise starts to be the main vehicle noise source.

Array of possible noise reduction measures can be applied in practice, but their cost-benefit ratio and effectiveness are variable and different. Measures depending on their types and setting (urban, suburban, rural), available place for the noise abatement solution can be engineering measures (earth berms, noise walls and barriers, land-use planning, façade insulation, traffic management measures), or regulative measures.

Construction of noise absorbing barriers along the roads has been the most popular and effective way to reduce negative effects of traffic noise [13]. However, costs of construction/maintenance of the noise barriers are relatively high and in many cases the construction is not even possible or is complicated due to some technical/legislation obstacles, landscape planning issues or social unacceptance. Gibbs et al. [14] have calculated that typically noise barriers cost around 1–2 million US$ per mile. Low noise pavements are being used more widely by the European countries putting low noise pavements as the number one alternative to noise barriers in terms of costs and noise reduction. Low noise pavements are also more acceptable by the society than the noise barriers.

Recent technology advancements in the automotive sector had led to the noise reduction associated with quieter vehicle components, better aerodynamics and tyre improvements. Despite those improvements, in the middle-high speed driving range tyre-road noise generation mechanisms are the dominant noise sources [11,12]. A number of research have been performed worldwide to optimize existing pavements, and construct alternative pavements etc. However, differences (climate conditions, traffic volumes, local resources etc.) between countries sometimes create the big issues that obstruct the transferability of effective low noise pavement solutions.

Situation in Lithuania is similar to described above. There are plenty of unpaved roads in the Lithuania road network and the percentage of road length that needs rehabilitation is dramatically increasing. This implies that strengthening of road construction bearing capacity and pavement condition improvement are on top of the list when it comes to evaluating different road network improvement scenarios. Opposite to that, recently environmental problems are attracting much more attention and induce more sophisticated and holistic thinking which is to find an optimal balance between pavement resilience and environmental friendliness. To solve this arising issue in Lithuania, Road Research Institute of Vilnius Gediminas Technical University has begun a research program for the conventional Lithuanian pavement optimization for tyre-road noise reduction and at the same time ensuring long life performance. This research was initiated by a need of developing or adapting alternative noise mitigation solutions (comparing with noise walls and barriers), to provide recommendations and guidelines of noise reducing pavements that could be efficiently implemented in roads and city streets. It is the first such a research initiative in Lithuania that comprehensively analyses tyre and road interaction concentrating on tyre/road noise generation mechanisms. The research scope includes following activities:

- Analysis of current situation and possible application of low noise pavements in Lithuania.
- Analysis of the feasibilities to transfer well-known effective low noise pavement solutions (e.g. porous asphalt) from other countries.
- Optimization of commonly used AC and SMA asphalt mixtures for noise reduction.
- Perform comparison tests of optimized noise reducing and traditional asphalt mixtures in laboratory in terms of physical and mechanical, acoustical, durability and resilience properties.
- Perform laboratory simulation of Lithuanian specific climate conditions.
- Prepare recommendations for noise reducing asphalt mixtures' design and construction.
- Test mixtures under real traffic and climate conditions.

2. Noise reduction techniques and low noise pavements

Tyre/road interaction noise contributes significantly to the overall traffic noise, especially at a speed range of 40 km/h to 100 km/h where tyre/road noise is the dominant noise source [11]. Tyre/road noise is caused by a large number of various influencing factors related with [15,11,16,17]: surface parameters (aggregate properties, texture, porosity, age and deterioration, stiffness, colour); tyre properties (tyre dimensions, number of tyres, type, tread structure and pattern, rubber hardness, tyre load and pressure); environmental factors (wind, temperature, water on the surface); driving behaviour (type of vehicle, speed, tangential forces and acceleration). All of the above mentioned factors are responsible for different tyre/road noise generation mechanisms that are performing at different frequency ranges [18]. Tyre/road noise mechanisms are classified into vibrational and aerodynamic. Vibrational noise generation mechanisms are associated with rolling tyre tread rubber impacts and deflections with road surface irregularities and adhesion mechanisms at the tyre and surface contact area [19,20]. Noise by vibration mechanism mainly occur at the lower frequency range (below 1000 Hz). Aerodynamic noise mechanisms related with the air circulation (especially air pumping) around the contact patch such as flowing air can be sucked in and trapped in the road surface texture pores or tyre tread grooves. Air pressure causes noise generation and noise amplification mechanisms [21,22]. Noise by aerodynamic mechanism mainly occur at the high frequency range (over 1000 Hz) [23].

Road surface play an important role for traffic noise reduction. In principle, road surface can reduce noise in two ways: reduction of tyre vibrations and acoustical absorption of propagating sound waves above the surface [24].

Porous asphalt (PA) is the most common and popular low noise pavement solution used across the world. Investigation presented by Yu et al. [25] PA pavement shows 1.5 dB to 4 dB reduction of noise level compared with the SMA and dense graded asphalt concrete (DGAC) pavements. However, the shorter lifetime leading to 50% higher life-cycle costs than traditional dense asphalt concrete wearing courses [26] is the main disadvantage when selecting PA as a low noise pavement solution. Short lifetime is related with the increased sensitivity of winter damage as a result of ravelling [27] and other distresses related with water saturation and temperature fluctuations around 0 °C. Another problem of the PA is clogging and intensive winter maintenance that reduces pavement cost-effectiveness. As pointed by Takahashi [28] the Japan experience reveals, that the forecast of noise reduction capabilities of the PA surfaces in comparison with normally used surfaces may drop from 5 dB to 1 dB after 6 years of exploitation which requires expensive and specific cleaning methods. To extend the lifetime and increase noise reduction properties of porous asphalt, double layer porous asphalt layer was developed 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 [24,29].

Some other low noise pavement solutions include thin layers (could also be very thin and ultra-thin) which are characterized by an optimized surface texture and 10–25 mm thickness. Thin layers are mostly constructed from modified SMA mixtures that have 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. Thomsen et al. [30] describes the detected noise reduction in comparison with the DGAC which is 3.7 dB for stone mastic asphalt (SMA) optimized mixture by max size, binder and air void and 4.3 dB for open graded asphalt concrete (OGAC). Another benefit of thin layers is fast and simple implementation as it is used only as a wearing layer.

Different studies, conducted by Sandberg & Ejsmont [11], Bueno et al. [31], Paje, et al. [32] reported noise reduction from 4 to 10 dBA on asphalt rubber pavements comparing with conventional dense asphalt mixtures. Generally, asphalt rubber mixtures contain 18–22% of crumb rubber by weight of binder. Bueno et al. [31] analysed acoustical effects of adding crumb rubber into the binder and found that 12–14% rubber weight by the binder are not significant in determining the acoustic behaviour of the evaluated surfaces, therefore the crumb rubber content and percentage of binder in the mixture should be increased for recognisable noise reduction effects. An alternative to rubber asphalt is the poroelastic road surface (PERS). The PERS characterises a very high content of interconnecting voids so as to facilitate the passage of air and water through it, while at the same time the surface is elastic due to the use of rubber (or other elastic products) as a main aggregate and bound together with a bitumen or polyurethane binder. The design air void content is at least 20% by volume and the design rubber content is at least 20% by weight [33]. Although, both asphalt rubber mixtures and poroelastic surfaces have lower durability and strength parameters, they are more sensitive to abrasion, aging and moisture than traditional asphalt mixtures and require further development.

Besides noise reducing asphalt pavements, there were various innovative solutions developed such as Modieslab [34]. Modieslab consists of prefabricated concrete slabs made from double layer porous concrete and can reduce noise as much as porous asphalt pavement, but at the same time retain durability and strength parameters longer than porous asphalt.

Three noise reduction techniques are known and used in practice when developing and optimizing road pavements for noise reduction [11]: increase of sound absorption, texture optimization and mechanical impedance reduction. For optimizations interdependencies between all requirements the long-term investigations of various pavement surfaces were made [25,28] to examine how low noise performance of these pavements depend on the exploitation time and weather conditions. This knowledge allows to select the most optimal way of designing pavement courses with suitable physical properties. Various models [35] were developed to predict noise on different road surfaces and most of the models highlight the important role of the combined effect of porosity and texture.

According to Hayden [21], Anfosso-Lédée & Dangla [36] increased porosity in the road surface reduces 'air pumping' mechanisms as well as increases absorption of sound waves emitted from the tyre/road contact and propagating over the surface. Absorbed sound waves get into the road surface pores, where dissipate. Asphalt mix designs with air voids content higher than 10% are known to be effective in absorbing tyre-pavement interaction noise [11], but the good absorption properties are seen when mixtures have even higher air void content – pavements with air voids content of 15– 20% can absorb 10–20% of the sound energy [11]. For the mix design it is also important to take into account tortuosity, air flow resistance, shape factor and thickness of pavement surface as these parameters influence sound absorption as well [37]. Ranieri et al. [29] also found out that void content and porosity do not strongly influence the clogging resistance of the mixes as it is more influenced by the initial 'as built' hydraulic conductibility of the mixes. Therefore [38], air void content of porous asphalt mixtures mainly depends on the compaction following temperature. Double layer porous asphalt surfaces with different gradation are good to tune the frequency of maximum absorption and to bring it to lower frequencies than with a single layer [39,40]. However, Descornet [39] highlighted that sound absorption is not the sole factor that describes noise reduction properties or noise reducing pavements and agreed that sound absorption is not even the main factor. Based on the comparisons between of noise spectrum on dense and porous surfaces Descornet [39] found that superficial porosity, preventing air pumping, is the main factor that explains good acoustic performance of thin layers despite the fact they are not absorbing.

Texture optimization of road surface is based on the reduction of vibrational mechanisms which generate noise. 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 as well as to define relevant geometric descriptors in order to assess the relationships between road surface texture and other parameters. Texture optimization is performed mostly at macrotexture scale [11] by selecting aggregate type, size and mineralogy parameters. According to [41] gradation size, maximum aggregate size and air voids are the main influential factors affecting surface texture. First correlations between tyre/road noise and road surface texture were established by Sandberg & Descornet [42] and later by Sandberg & Ejsmont [11], on a large variety of dense road surfaces [43]. Sandberg & Descornet [42], Sandberg & Ejsmont [11] and Dare et al. [18] investigated that 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). Izevbekai & Voller [44] investigated texture spikiness and effect on tyre/road noise generation. It was discovered that texture direction refers to the dominant direction of texturing of the surface either from the process of texturing or from the ultimate appearance of the texture [44]. Main principles of texture optimization for AC and SMA pavements [11,39,45] according to their impact on tyre/road noise reduction potential can be sorted to:

- Use of small size maximum aggregate 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.
- Macrotexture optimisation:

  - o High amplitudes in the 1–8 mm wavelength range and low amplitudes in the 10–50 mm wavelength range for light vehicles.
  - o High amplitudes in the 0.5–12 mm wavelength range and low amplitudes in the 16–50 mm wavelength range for heavy duty vehicles.
  - o 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.
- Air void content about 5–6% to ensure reduction of air pumping. This could be achieved using low sand and filler content in the asphalt mixture.
- Cubic shape, uniform and with sharp edges aggregate to ensure even and smooth surface.

Most important factors when selecting a pavement surface are its performance and life cycle costs. Therefore, the research and development of noise reducing asphalt mixtures for specific regional climate conditions were focused on asphalt mixtures design that have sufficient durability and at the same time have long-term acoustical benefit.

3. Laboratory development of noise reducing asphalt mixtures

Corresponding to environmental noise problem and specific situation in national road network, a large scale research programme was initiated in Lithuania. It was started with the laboratory development of low noise asphalt mixtures for specific regional climate conditions with the intention to test developed low noise asphalt mixtures under real traffic and climate conditions by constructing test section on operating road.

3.1. Design of noise reducing asphalt mixtures

Having in mind specific region climatic conditions characterized as severe winter conditions for road infrastructure (60–80 frost-thaw cycles annually [46]), and long-term research works on evaluation of the influence of asphalt composition materials on performance of pavements [47,48] in Lithuania, the use of traditional and popular in other European countries noise reducing pavements (porous asphalt, rubber asphalt) is questionable wherever they could be suitable for Lithuanian climate conditions. For this reason, it was decided to develop specific noise reducing asphalt mixtures for specific regional climate conditions. The main objective of the research was to assess and compare conceptual noise reducing asphalt mixtures with traditional noise reducing and conventional asphalt mixtures in terms of noise reduction characteristics, durability, mechanical strength and climate resistance.

As a basis for noise reduction asphalt mixtures, most common conventional asphalt concrete (AC) and stone mastic asphalt (SMA) mixtures were selected for optimization. With reference to foreign noise reducing thin asphalt layer experience, especially German low noise asphalt mixtures (SMA 0/5 LA, SMA 0/8 LA and LOA 5 D), two types of Lithuanian noise reducing stone mastic asphalt mixtures SMA 5 TM, SMA 8 TM with the maximum aggregate size respectively 5 mm (for light vehicles' noise reduction) and 8 mm (for heavy duty vehicles' noise reduction) and one noise reducing asphalt concrete mixture TMOA 5 with the maximum aggregate size of 5 mm were designed [49]. The mixtures were designed using local materials used for high volume roads in Lithuania. To adequately evaluate noise reduction and durability properties, these asphalt mixtures were compared with the ones commonly used in Lithuania including, SMA 8 S, SMA 11 S, AC 8 VS, AC 11 VS, AC 8 PAS-H, porous asphalt – PA 8 and special patented low noise product from EU road construction company. Gradation curves for all the mixtures (except special product as it is patented name) are shown in Fig. 1 (AC type mixtures) and Fig. 2 (SMA and PA type mixtures).

Furthermore, before the asphalt mixture were designed, additional laboratory tests on bitumen binder's properties were performed testing 20 samples of bitumen binder PMB 45/80–55 penetration (average penetration 50.3 dmm, st. dev. 2.7 dmm), softening point (average softening point is 56.9 °C, st. dev. 2.7 °C) and elastic recovery (average elastic recovery 92.3%, st. dev. 1.6%). For all asphalt mixtures granite aggregates were used witch met the requirements of standard *EN 13043* and technical normative documents.

Asphalt mixtures for this research were designed, produced and tested at Vilnius Gediminas Technical University (VGTU), Faculty of Environmental Engineering, Road Research Institute (RRI).

3.2. Laboratory testing

3.2.1. First stage

Our research was executed in three stages. At the first stage asphalt mixtures with 3 different binder contents for each type of asphalt mixture were prepared. Then asphalt specimens from each mixture were formed according to standard EN 12697-30 (by 2 × 50 blows). The following mechanical and physical properties of asphalt mixtures were determined:

- air void content (according to the standard EN 12697-8);
- Marshal stability and flow (according to the standard EN 12697-34);
- water sensitivity (indirect tensile strength ratio) (according to the standard EN 12697-12);
- indirect tensile strength (according to the standard EN 12697-23).

After determination of mechanical and physical properties of asphalt mixtures, according to the results, optimal and close to optimal binder contents for each asphalt mixture were identified. Further research was performed with 2 binder contents for each asphalt mixture.

Ranking of bitumen binder content according to the lab tests is shown on Table 1. Air void content was chosen as the main criteria for ranking. According to literature analysis and Lithuanian normative documents' requirements it was decided that asphalt mixtures air void content should be: SMA 5 TM from 7% to 9%, SMA 8 TM from 8% to 10%, TMOA 5 from 5% to 6%, PA 8 from 24% to 28%, SMA 8 S and SMA 11 S from 2% to 3%, AC 8 VS and AC 11 VS from 2% to 4% and AC 8 PAS-H from 3.5% to 5.5% (see Fig. 5).

3.2.2. Second stage

The Second stage of this analysis covered research of the noise related properties of asphalt mixtures including:

- surface mean texture depth (according to the standard *EN 13036-1)*;
- sound absorption coefficient (according to the standard *EN 10534-1)*.

It should be noted that only samples of asphalt mixtures with optimal and close to optimal binder contents were tested during this stage. Measurements of sound absorption were performed in the Laboratory of Acoustics of Scientific Institute of Thermal Insulation of Vilnius Gediminas technical university.

Volumetric patch method for the mean texture depth (MTD) determination in laboratory was selected as this method could

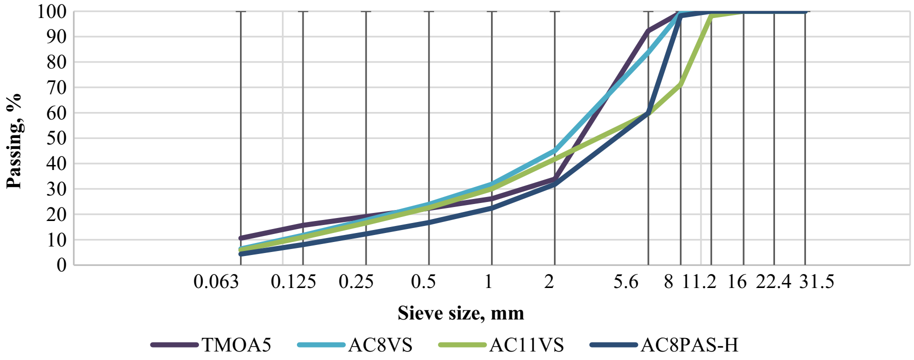

Fig. 1. Aggregate gradations of TMOA 5, AC 8 VS, AC 11 VS, AC 8 PAS-H mixtures.

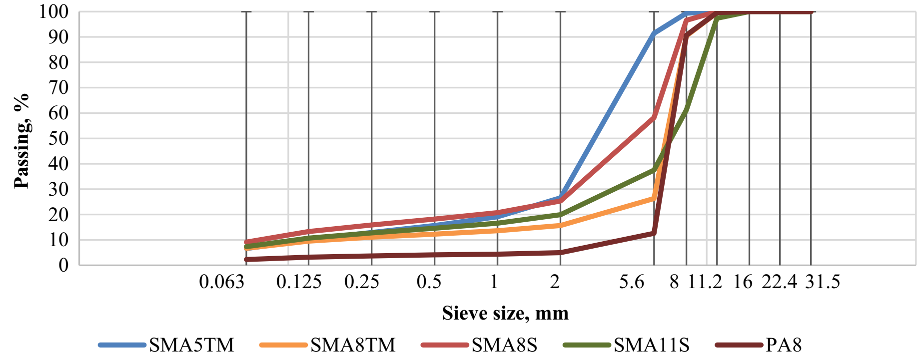

Fig. 2. Aggregate gradations of SMA 5 TM, SMA 8 TM, SMA 8 S, SMA 11 S, PA 8 mixtures.

evaluate basic asphalt sample surface texture properties and give rough estimation of surface texture impact on tyre-road noise generation mechanisms.

The Standing Wave Tube method allows to make a quick and easy, yet precise measurements of the normally incident sound absorption coefficients. The sound absorption coefficient of a material is by definition the ratio of the sound power entering the surface of the test object to the incident sound power. The absorption coefficient is a function of frequency and measurements over the frequency range of interest required. Impedance tube with moving microphone (according a standing wave ratio method presented in *ISO 10534-1*) using the gated sine wave gave an opportunity to measure the incidental and reflected sound wave amplitudes, along with the phase shift between waves.

The tube has a sample holder from one end and from other end is screwed to the loudspeaker cabinet. The microphone probe for sound pressure in the tube sampling is led through a hold in the loudspeaker, and is connected with the actual microphone, which lies in elastic mountings within the microphone carriage, well insulated from airborne noise and impact sound or vibrations. The impedance tube requires only small, carefully erected samples of the tested materials without any differences concerning applicable sound measuring technique. For presented investigations designed apparatus use moving microphone in the impedance tube with an interior diameter of 8.5 cm and 90 cm length. It allows to carry out measurements in the frequency range from 100 Hz to 2500 Hz. Metrological characteristics of used impedance tube apparatus were checked and shown possibility to determinate normal incidence sound absorption coefficients values from 0.02 till 1.00. Common view of tested samples with holder and piston disk before mounting in the tube is shown on Fig. 3.

3.2.3. Third stage

During the third stage of this analysis, laboratory tests of asphalt mixtures' durability and climate resistance properties were performed including:

- indirect tensile strength (according to the standard *EN 12697-23)* after the frost-thaw cycles;
- while particle mass losses (according to the standard *EN 12697-17)* after the frost-thaw cycles testing samples using the Los Angeles machine (according to the standard *EN 1097-2*).

In this stage, only samples of asphalt mixtures with optimal binder content were tested. Fig. 4 showing the SMA 8 TM, SMA 5 TM, TMOA 5 and PA 8 test samples after the particle mass loss testing in the Los Angeles machine.

Indirect tensile strength and particle mass loss laboratory tests were performed before the frost-thaw cycles and after 12, 25, 38 and 50 frost-thaw cycles. One cycle – prepared asphalt samples (cylindrical Marshall samples, made by 50 blows per side) were sunk into +20 ± 5 °C temperature water bath 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 h; hereafter the samples were taken out from the freezer and thawed for 2 h in the room temperature water bath. The described frosting-thawing process was repeated 50 times to simulate 50 frost-thaw cycles.

Table 1
Optimal and close to optimal binder contents for asphalt mixtures.

Asphalt mixture	Bitumen binder type	Bitumen binder content,%	Ranking of bitumen binder content according to the lab tests
SMA 5 TM	PMB 45/80–55	6.4	–
		6.7	Optimal binder content
		7.0	Close to optimal binder content
SMA 8 TM	PMB 45/80–55	6.0	–
		6.3	Optimal binder content
		6.6	Close to optimal binder content
TMOA 5	PMB 45/80–55	4.6	–
		4.9	Optimal binder content
		5.2	Close to optimal binder content
PA 8	PMB 45/80–55	6.2	Close to optimal binder content
		6.5	Optimal binder content
		6.8	–
SMA 8 S	PMB 45/80–55	6.7	Optimal binder content
		7.0	Close to optimal binder content
		7.3	–
SMA 11 S	PMB 45/80–55	6.3	Optimal binder content
		6.6	Close to optimal binder content
		6.9	–
AC 8 VS	PMB 45/80–55	5.7	Close to optimal binder content
		6.0	Optimal binder content
		6.3	–
AC 11 VS	PMB 45/80–55	5.5	Optimal binder content
		5.8	Close to optimal binder content
		6.1	–
AC 8 PAS-H	PMB 45/80–55	5.5	Close to optimal binder content
		5.7	Optimal binder content
		6.0	–
Special product[a]	n.a.	n.a. (I var.)	Optimal binder content
		n.a. (II var.)	Close to optimal binder content
		n.a. (III var.)	–

[a] Data about bitumen binder content not available, because it is a patented product.

4. Interpretation of the results

As indicated in paragraphs above, standard mechanical and physical properties tests were performed during the first research stage of this study. Asphalt mixture air void content for each mixture with 3 different binder content were measured (Fig. 5). Among the selected mixtures with optimal binder content, highest air void content was determined for PA 8–24.94%. From the SMA mixtures category, newly developed SMA 5 TM and SMA 8 TM mixtures had the highest air void content, respectively 7.15% and 8.26% in comparison with traditional SMA mixtures. From AC mixtures category, newly developed TMOA 5 mixture and special low noise product had the highest air void content, respectively 5.59% and 5.92%. Results confirmed that modified SMA and AC mixtures gradation curves with the objective to optimize mixtures for noise reduction, resulted increase of air void content.

Flow by Marshall (Fig. 6) was determined highest for traditional SMA 11 S mixture – 4.63 mm and AC 11 VS, while the lowest for PA 8 mixture – 2.15 mm. Developed low noise mixtures SMA 5 TM (2.50 mm), SMA 8 TM (3.30 mm) and TMOA 5 (2.65 mm) showed similar properties to traditional mixtures SMA 8 S (3.13 mm), AC 8 VS (3.88 mm) and AC 8 PAS-H (3.13 mm).

Stability by Marshall and Indirect tensile strength results (Figs. 7 and 8), present the tendency of air void content negative correlation with the mechanical properties. Largely increased air void content in SMA 8 TM mixture, resulted in worsening of mechanical properties comparing with traditional SMA 8 S and SMA 11 S mixtures. Other low noise asphalt mixtures developed, SMA 5 TM and

Fig. 3. Common view of 2 tested samples, sample holder, piston disk and open end of impedance tube.

Fig. 4. Low noise asphalt mixtures SMA 8 TM (top left), SMA 5 TM (top right), TMOA 5 (bottom left) and PA 8 (bottom right) samples after particle mass loss testing with Los Angeles machine.

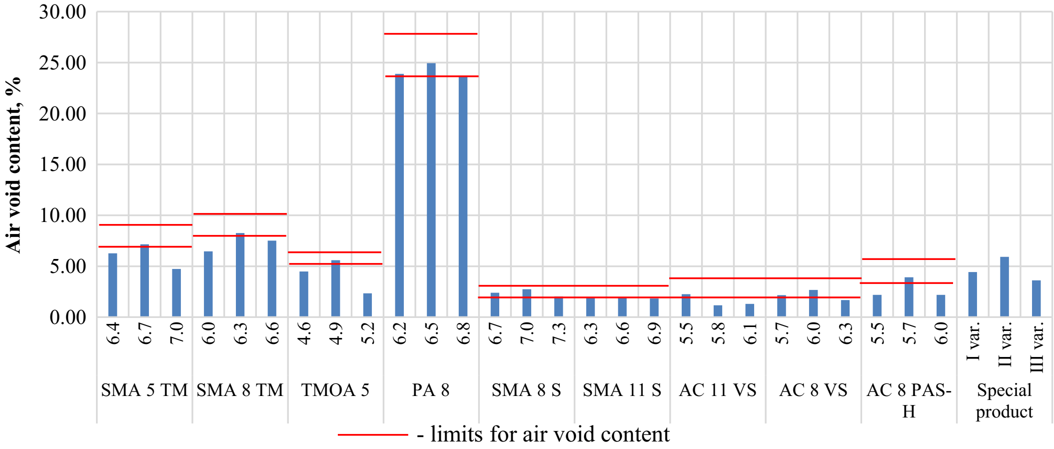

Fig. 5. Air void content testing results for each asphalt mixture with 3 different binder contents.

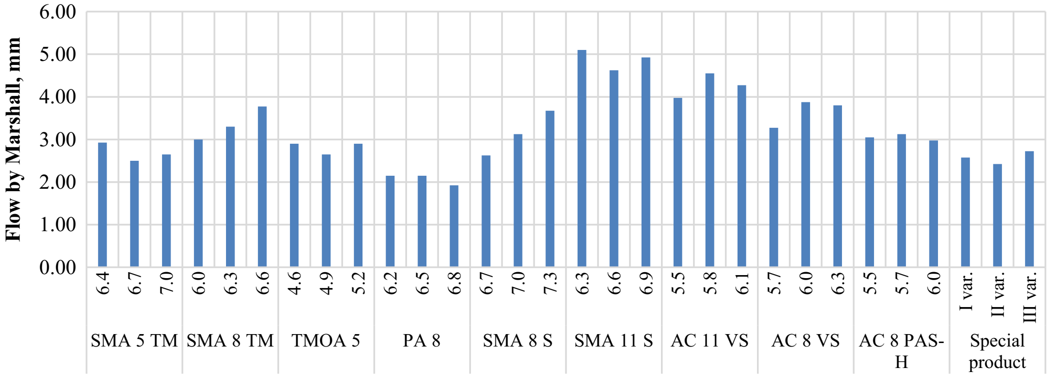

Fig. 6. Flow by Marshall testing results for each asphalt mixture with 3 different binder contents.

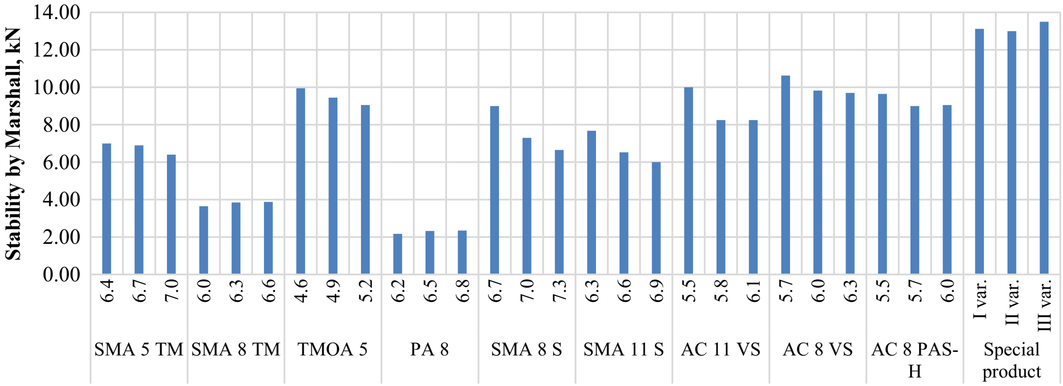

Fig. 7. Stability by Marshall testing results for each asphalt mixture with 3 different binder contents.

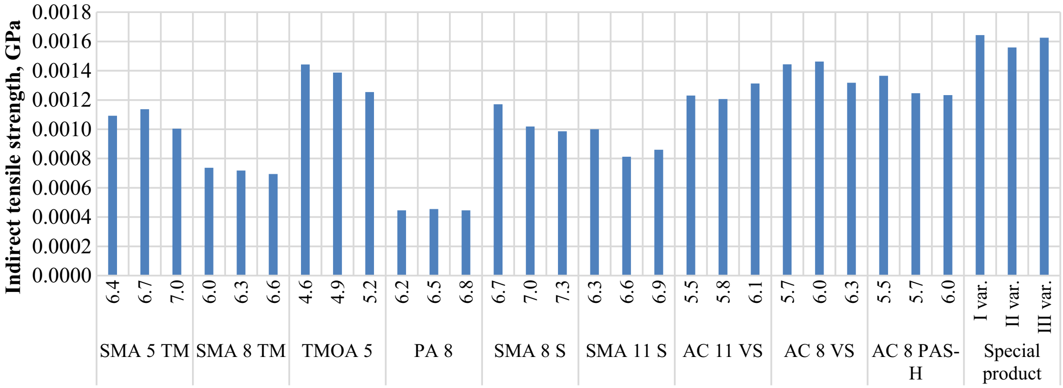

Fig. 8. Indirect tensile strength testing results for each asphalt mixture with 3 different binder contents.

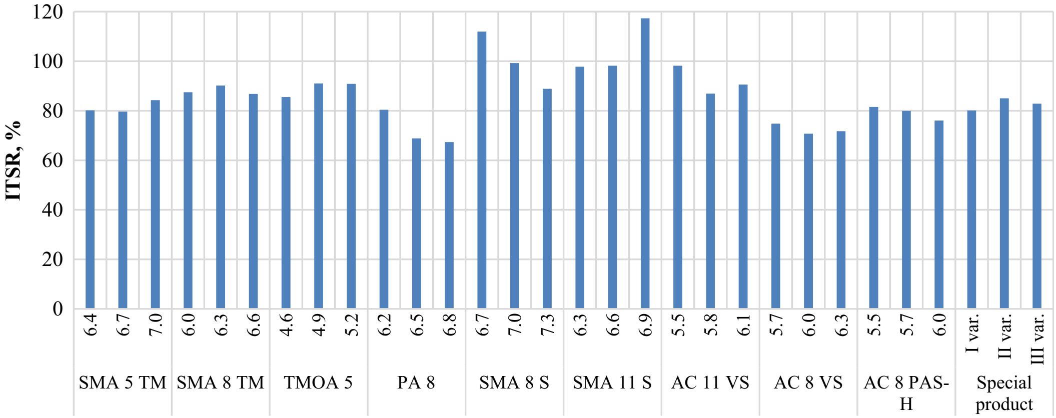

Fig. 9. ITSR testing results for each asphalt mixture with 3 different binder contents.

TMOA 5 experienced better results, more towards the traditional AC and SMA mixtures.

Indirect tensile strength ratio (ITSR) testing results (Fig. 9) revealed that in-house developed low noise asphalt mixtures, SMA 5 TM, SMA 8 TM and TMOA 5 have the closest properties to traditional mixtures of AC 11 VS, AC 8 VS, AC 8 PAS-H and special product, but lower than SMA 8 S and SMA 11 S.

Summarizing all the results after conducting mechanical and physical properties of asphalt mixtures testing, it can be stated, that developed low noise asphalt mixtures have slightly worse properties, but still sufficient for exploitation, comparing with traditional asphalt mixtures. Worse properties can be mainly linked with the high air void content in the mixture. That is the primary reason why such mixtures have much better properties comparing with the porous asphalt PA 8. On the other hand, mechanical characteristics of SMA 5 TM asphalt mixture are closest to traditional asphalt mixtures.

For the noise reduction properties analysis, firstly sound absorption measurement were carried out and showed that higher porosity directly correlates with the sound absorption. For the asphalt mixtures with the optimal binder content highest sound absorption (Fig. 10) were determined for PA 8 mixture – in the 700–1200 Hz frequency range sound absorption coefficient is higher than 0.4 and in the 800–950 Hz frequency range it is higher

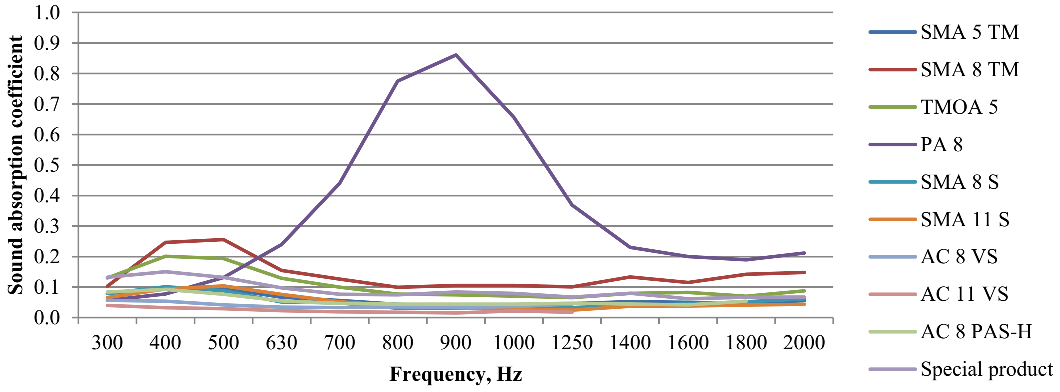

Fig. 10. Sound absorption coefficient for each asphalt mixture with optimal binder content.

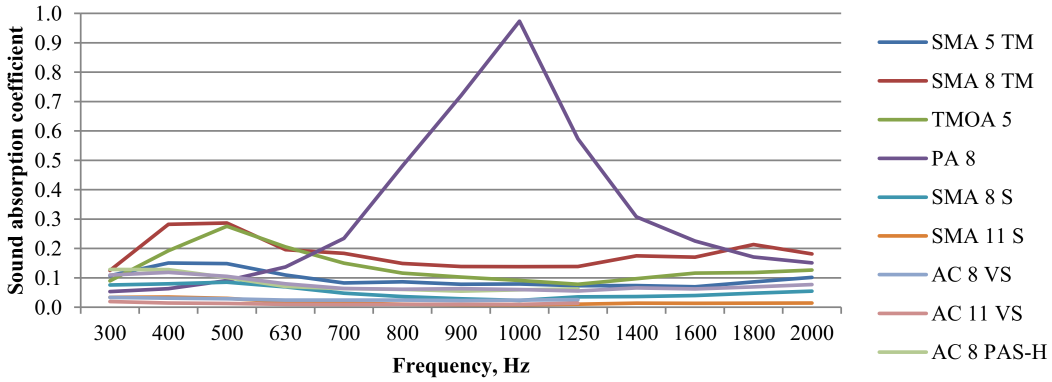

Fig. 11. Sound absorption coefficient for each asphalt mixture with close to optimal binder content.

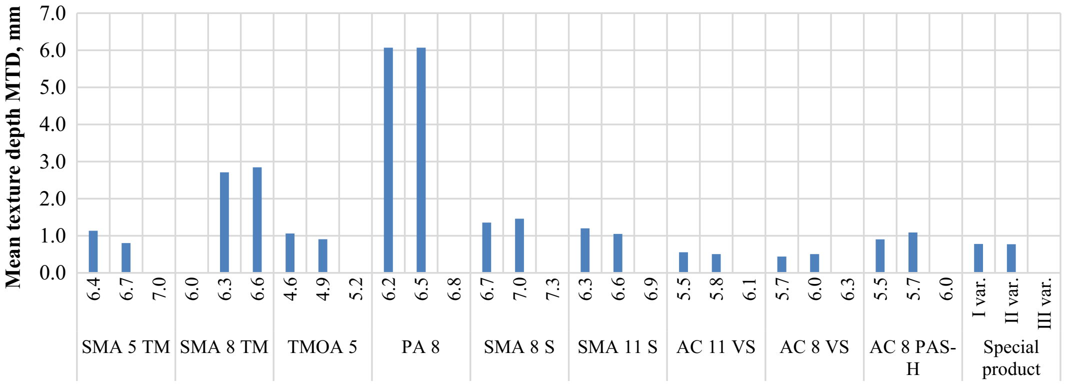

Fig. 12. Mean texture depth (MTD) results for each asphalt mixture with 2 different binder contents.

than 0.8. SMA 8 TM. Additionally, TMOA 5 mixtures showed good results at low frequency range (350–550 Hz), sound absorption was 0.2–0.25 and higher than all the other mixtures. Except PA 8 mixture, SMA 8 TM mixture showed higher sound absorption in the overall tested frequency range (300–2000 Hz) than all of the mixtures – sound absorption coefficient is between 0.1 and 0.25. For the asphalt mixtures with the close to optimal binder content the results were similar (Fig. 11). It was determined that for low noise asphalt mixtures such as SMA 5 TM, SMA 8 TM and TMOA 5 sound absorption was higher by 0.05 in all frequency range. Sound absorption of PA 8 asphalt mixture was determined very high (over 0.8) at frequencies 900–1250 Hz. However, the sound absorption at low frequency and very high frequency ranges were determined lower by 0.05.

Another relevant parameter to assess noise reduction characteristics and potential of developed low noise asphalt mixtures is surface texture. Mean texture depth was measured for asphalt mixtures of optimal and close to optimal bitumen binder. MTD, as it was expected, ranked the highest for the mixtures (with optimal binder content) with the higher air void content: PA 8 – 6.07 mm, SMA 8 TM – 2.71 mm (Fig. 12). When comparing MTD between optimal and close to optimal binder contents, there was no large difference identified. Some evidences of correlation between MTD and sound absorption values were also found. Unfortunately, the correlation was not precisely calculated as the MTD measurement method (volumetric patch method) has some restrictions and limitations regarding the pavements with higher porosities.

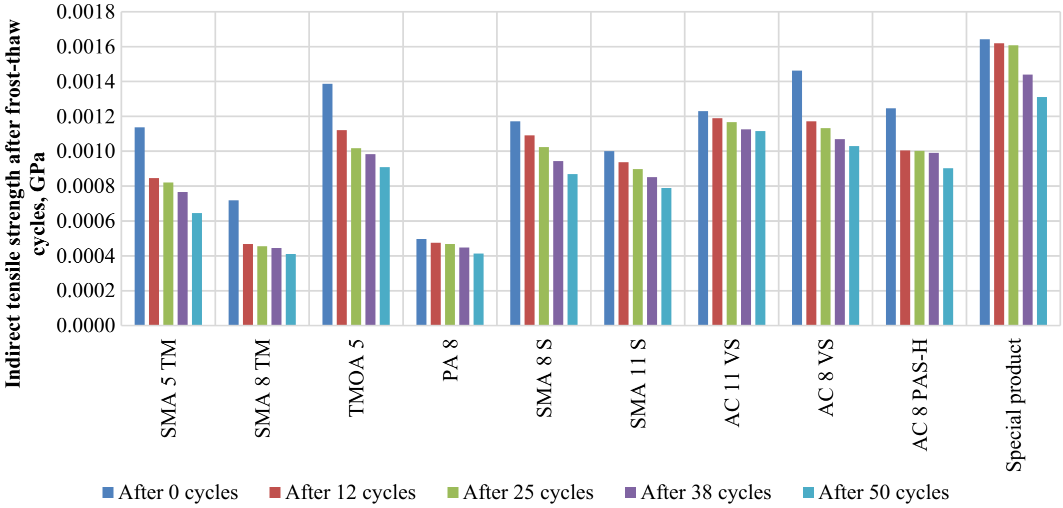

Fig. 13. Testing results of indirect tensile strength after frost-thaw cycles for each asphalt mixture with optimal binder content.

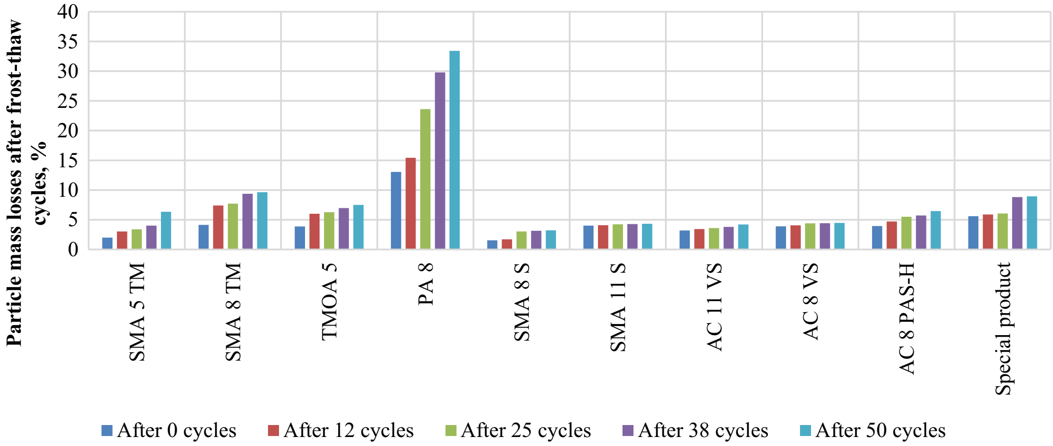

Fig. 14. Testing results of particle mass loss after frost-thaw cycles for each asphalt mixture with optimal binder content.

Results from durability testing after frost-thaw cycles are shown in Fig. 13. It was observed that indirect tensile strength for low noise asphalt mixtures SMA 5 TM, SMA 8 TM and TMOA 5 reduced drastically after the first 12 frost-thaw cycles – respectively by 25%, 35% and 20%. After the next cycles, the reduction was consistent – overall reduction of indirect tensile strength after each cycle was respectively 0.65%, 0.34% and 0.50%. Furthermore, it was observed that SMA 8 TM indirect tensile strength after the 12, 25, 38 and 50 was very similar to PA 8 mixture. SMA 5 TM mixture showed similar properties to traditional SMA mixtures and TMOA 5 similar to traditional AC mixtures which means that durability of these low noise asphalt mixtures is sufficiently enough.

Biggest particle mass losses (Fig. 14) were determined again for PA 8 asphalt mixture 13.04% before the frost-thaw cycles and 33.42% after 50 frost-thaw cycles. It was assumed that PA 8 mixture is very sensitive to cold climate conditions. Low noise asphalt mixtures SMA 5 TM, SAM 8 TM and TMOA 5 showed better resistance to frost-thaw cycles. It was determined that low noise asphalt mixtures have similar properties to traditional mixtures.

5. Conclusions

Best practice of noise reducing pavements consider noise absorption as a primary requirement (e.g. wide application of porous asphalt), still pavement surface roughness and texture should be considered as important as porosity. Change in pavement porosity due to clogging is very much dependent on exploitation characteristics (e.g. traffic composition and flow). The low noise pavements with optimized surface texture should be considered as a number one alternative for roads and streets in residential areas and areas with low traffic. In case of roads with high traffic volumes, both texture optimisation and noise absorption should be combined.

Large scale experimental research with AC and SMA asphalt mixtures modified with the specific focus on surface texture optimization for noise reduction revealed benefit of usage of cubic shape and smaller size aggregate, special gradation and selection of optimal binder content. That allowed to design low noise asphalt mixtures with the two combined noise reduction mechanisms: reduction of tyre vibrations due to smoother and negative texture; reduced air pumping and increased noise absorption due to increased porosity.

The basic properties such as air voids, flow and stability by Marshall, indirect tensile strength and indirect tensile strength ratio, of asphalt mixtures were evaluated for identification of optimal and close to optimal binder contents. It was determined that:

1) The highest flow by Marshall has traditional asphalt SMA 11 S (5.1 mm) and AC 11 VS (4.9 mm) mixtures, while the lowest – PA (2.1 mm). Developed low noise asphalt mixtures showed similar properties to traditional asphalt mixtures.

2) The highest stability by Marshall and indirect tensile strength has traditional asphalt concrete AC 8 VS (9.8 kN and 0.00146 GPa), AC 11 VS (10.0 kN and 0.00124 GPa) and low noise asphalt concrete TMOA 5 (9.6 kN and 0.00139 GPa) mixtures, while the lowest – PA 8 (2.2 kN and 0.00046 GPa) and low noise asphalt concrete SMA 8 TM (3.8 kN and 0.00072 GPa). Largely increased air void content in SMA 8 TM mixture, resulted worsening in mechanical properties comparing with traditional SMA 8 S and SMA 11 S mixtures. Other developed low noise asphalt mixtures SMA 5 TM and TMOA 5 showed better results, closer towards the traditional AC and SMA mixtures.
3) Developed low noise asphalt mixtures SMA 5 TM (80%), SMA 8 TM (90%) and TMOA 5 (90%) mixtures have the closest indirect tensile strength ratio to traditional mixtures AC 11 VS (90%), AC 8 VS (70%), AC 8 PAS-H (80%) and special product (80%), but lower than SMA 8 S (110%) and SMA 11 S (97%).

Further tests including sound absorption measurement, mean texture depth measurement and durability in terms of climate resistance, were performed for asphalt mixtures with optimal binder content.

Experimental research showed potential of optimized asphalt mixtures to reduce noise levels approximately by 3–5 dBA. The highest sound absorption were determined for PA 8 mixture – in the 700–1200 Hz frequency range sound absorption coefficient is higher than 0.4 and in the 800–950 Hz frequency range it is higher than 0.8. SMA 8 TM and TMOA 5 mixtures showed good results at low frequency range (350–550 Hz), sound absorption was 0.2–0.25 and higher than all the other mixtures. Except PA 8 mixture, SMA 8 TM mixture showed higher sound absorption in the overall tested frequency range (300–2000 Hz) than all of the mixtures with sound absorption coefficient between 0.1 and 0.25.

Another relevant test for determination of noise reducing characteristic was MTD measurements. It was found that the highest MTD have asphalt mixtures with higher air void content: PA 8 – 6.07 mm, SMA 8 TM – 2.71 mm and lowest – asphalt concrete AC 8 VS (0.51 mm) and AC 11 VS (0.56 mm) mixtures, and developed low noise asphalt SMA 5 TM and TMOA 5 mixtures – respectively 0.80 mm and 0.91 mm.

Besides achieved positive and promising results in terms of noise reduction, optimized asphalt mixtures also showed adequate durability and resilience to climate properties, what is highly important in severe regional climatic conditions. It was observed that SMA 8 TM indirect tensile strength after the 12, 25, 38 and 50 was very similar to PA 8 mixture. SMA 5 TM mixture showed similar properties to traditional SMA mixtures and TMOA 5 similar to traditional AC mixtures which indicates that durability of these low noise asphalt mixtures are sufficiently enough. Variation of particle mass loss after 50 frost-thaw cycles distributed from 3.21% (SMA 8 S) to 33.42% (PA 8) depended on asphalt mix type. SMA 5 TM showed almost the same stability as traditional AC and SMA mixtures. SMA 8 TM and TMOA 5 mixtures showed about twice larger particle mass loss than SMA 5 TM mixture after 12, 25, 38 and 50 frost-thaw cycles.

In the regions, where large number of annual freeze-thaw cycles occur (at least 50), low noise pavement solutions with optimized surface texture and with air void content in the range of 5–8 % are recommended to be used. Higher air void content, results in significant reduction in durability. On the other hand, more sophisticated pavement cross-section should be designed and more effective winter maintenance practices should be exercised.

Besides laboratory research the test road with noise reducing wearing layers were constructed in autumn 2015 on highway A2 Vilnius-Panevėžys. Correlation between noise absorption, overall noise levels and texture parameters (also including mechanical and physical properties) will be researched under the real traffic and maintenance conditions. Further research will bring more precise recommendations and cost-effectiveness assessment for the use of SMA 5 TM, SMA 8 TM and TMOA 5 asphalt mixtures.

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