Tyre/Road Noise Spectrum Analysis of Ageing Low Noise Pavements

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Summary

Traffic noise is an increasing problem which attracts more and more attention of road authorities, road engineers and planners, municipalities and societies. Various research studies and experiences showed that low noise pavements are an effective and efficient traffic noise mitigation solution. However, low noise pavements' acoustical durability is not perpetual – noise reduction effect decrease over the pavement lifetime due to traffic and climate impacts. Paper presents research study which main objective was to compare acoustical ageing processes of traditional and low noise asphalt mixtures. Research included analysis of measured tyre/road noise levels (CPX) and spectrum changes for different asphalt pavements in the first 2 years of new road operation. Acoustical ageing trends and behaviour for different asphalt mixtures were determined and linked with the impacts of different influencing factors (traffic loads, volumes, texture changes, porosity changes). Paper concludes with initial results and conclusions of a longer-term study when analysing low noise asphalt mixtures' acoustical and structural ageing and gives recommendation for low noise asphalt mixture development, construction and maintenance.

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1. Introduction

Traffic noise is one of the most underestimated environmental problems in the recent decades. In parallel to the increasing urbanisation and mobility processes, traffic noise problem is also rapidly growing and raise challenges for transport infrastructure managers. According to EC calculations [1], annual socio-economic costs of traffic noise are exceeding 40 billion EUR of which 90% is because of road transport generated noise. Exposure to excessive noise levels in medium-long term leads to harmful effects on human health (sleep disturbance, annoyance, cardiovascular, hearing, mental state, central nervous system diseases), negatively affects specific animal species (population and migration) and economies (depreciation of real estate). Taking into account the fact that tyre/road noise is the most dominant vehicle noise source at the medium and high speed range (30-100 km/h) [2] higher attention should be given to mitigate this particular noise source.

Traditional noise mitigation measures such as noise barriers are effective but their construction and maintenance are quite expensive. Additionally, their construction is not always possible due to the technical, legislative or landscape restrictions. As an alternative to noise barriers, low noise pavements successfully are being used more often and widely. However, both noise reduction potential and application areas vary for different low noise pavement solutions. For example, porous asphalt surfaces are the most common low noise pavement solution in Europe (especially in the countries with mild climate), but due to sensitivity to severe climate conditions [3], it is not always feasible to use such pavements in colder climate regions. Therefore, colder climate region countries are more often using modified traditional dense asphalt concrete (AC) and stone mastic asphalt

(SMA) mixtures with an optimized road surface texture and increased porosity.

Acoustical ageing is another issue that has to be assessed when selecting proper low noise pavement solution. Acoustical ageing of low noise pavements is influenced by a number of influencing factors [4]. It should also be noted that acoustical ageing processes are more intensive at colder climate regions where low noise asphalt pavements are affected by large temperature fluctuations, high number of frost and thaw cycles and impact of studded tyres [5].

Research study presented in this paper aims to increase understanding of acoustical ageing processes of low noise asphalt mixtures in colder climate regions. Knowledge on the acoustical ageing behaviour will facilitate low noise asphalt mixture optimisation and design procedures for severe climate regions. This paper presents acoustical ageing analysis which is a part of Lithuanian national research project NOPE that has been started in December 2017 with the main objective to design optimized low noise asphalt mixtures for severe climate regions.

2. Acoustical ageing

Faster acoustic and structural ageing of low noise asphalt mixtures is a major problem that negatively affects the performance of low noise asphalt mixtures and reduces these mixtures competitiveness comparing with traditional asphalt mixtures (from the structural durability point of view) and traditional noise mitigation measures such as noise barriers (from the acoustical durability point of view). Therefore, it is desirable that low noise asphalt pavements should not only have good initial noise reduction but also retain high noise reduction performance for a longer term.

All asphalt mixtures (including traditional and low noise) lose their initial noise reduction properties with time because of continuous traffic and environmental impacts. Acoustic ageing processes mainly can be associated with the clogging (due to the dirt) or densification (continuous compaction from traffic loads) of open pores in the asphalt wearing layer, changes in surface macrotexture.

Porous asphalt pavements are the most common low noise pavement solution that can achieve noise level reduction by 4-6 dBA comparing to traditional SMA and AC pavements [6]. Contrary to high noise reduction potential, porous asphalt mixtures acoustically and structurally deteriorate much faster resulting in nearly 50% higher life-cycle costs than traditional dense asphalt concrete wearing courses [7]. Dutch experience show that acoustic ageing of porous asphalt mixtures is 0.2-0.4 dBA per year [8] while other research study in Japan determined acoustic ageing from 5 to 1 dBA after 6 years of exploitation [9]. Different acoustical ageing in Netherlands and in Japan can be explained by the difference in climate conditions. QUESTIM project analysed the influence of climatic zones on ageing and it was found that specific road surface types results in a stronger acoustic ageing process due to more frequent freeze/thaw cycles [5]. Acoustical ageing of porous asphalt mixtures mainly could be associated with clogging [10] and ravelling [11] effects. Clogging occurs much faster for the traffic volumes and speeds are not high enough. To slow down clogging process, double layer porous asphalt pavement could be used where the upper layer consists of smaller maximum aggregate size to protect surface texture from clogging while the bottom layer is constructed using larger size of maximum aggregate to ensure good acoustical absorption [12]. Ravelling is the most common porous pavement distress and is mostly related with the binder performance at low temperatures [11]. Additionally, acoustic ageing might be strongly influenced by the use of studded tyres – Norwegian experience shows that noise level on a newly laid pavement increased 2-4 dB after the first winter with exposure to studded tires [13].

Acoustic ageing of dense asphalt pavements mainly can be explained by the structural changes and wear of road surface texture. Texture evolution is mainly a function of traffic load (especially of the number of heavy vehicles) leading to a disaggregation of the filler component in the surface texture. HOSANNA project [14] results showed that CPX measurements performed on different dense asphalt surfaces on highways driving 80 km/h had acoustical regression of 0.5 dBA/year on right traffic lane comparing with 0.3 dBA/year on the left traffic lane, meaning that the acoustic ageing is slower on the less trafficked traffic lanes. Other research studies show that acoustic ageing is a non-linear process [4,15] – typically noise levels increase for the first 1–2 years of exploitation, then stabilize until the end of the lifetime or significant pavement distress occurs. Increase is mostly by 1-2 dBA and generally occurs at frequencies typical of air-displacement mechanisms [4].

Semi-porous asphalt mixtures suffer different acoustical ageing. Belgian research [16] on the acoustical ageing of thin asphalt layers revealed a linear relationship of the acoustic ageing effect on the noise reduction: noise increase of 0.02–0.14 dBA per month (based on SPB measurements) and 0.05–0.2 dBA per month (based on CPX measurements). Strong relationship between the acoustic ageing and ravelling was found for thin asphalt layers, which can be explained by the composition of the mixtures (aggregate grading and bitumen content) and the higher void content.

Acoustic ageing is a continuous process caused by the impacts of traffic, environment related phenomenon, regular and winter maintenance actions. The speed of acoustic ageing process also depends on the asphalt mixtures itself (wearing course mix design, air void content and porosity, aggregate quality and grading, binder and binder modification, laying conditions and pavement degradation [4].

Before a visual pavement wear and significant pavement distresses (polishing of aggregate, ravelling, cracks, potholes, bitumen bleeding) occur, the following processes might influence the acoustic ageing [17]:

- Additional continuous pavement compaction because of traffic loads.
- Aggregate pressed further down in mortar and the openness of the surface structure is reduced.
- Change in the orientation of the aggregate because of traffic load.
- Clogging where the open structure with communicating pores in the upper part of a porous pavement layer is more or less clogged.
- The average driving speed might have an influence on the clogging process as the high speed and traffic volumes are causing self-cleaning effect.
- Ordinary pavement maintenance and cleaning.
- Winter maintenance procedures (snow and ice removal, salting, plowing).
- Impact of studded tyres and snow chains.
- Weather conditions (rain water, sun, snow, freeze-thaw, oxidation, etc.).
- Ultraviolet radiation from the sun.

Acoustical ageing can be also clearly seen from the measured noise level spectra. Variation in noise spectrum due to different ageing processes were determined by [18] and showed in Figure 1.

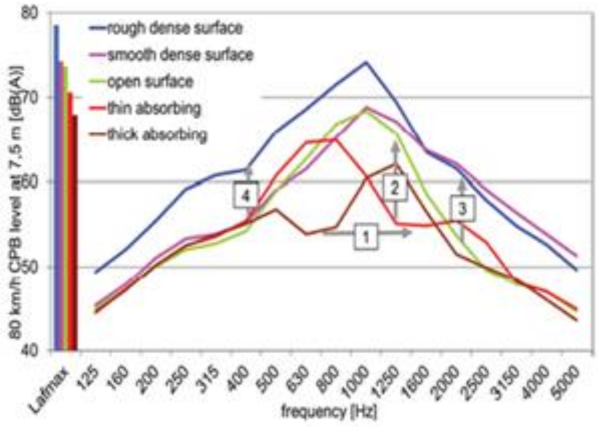

Figure 1 Spectral distribution of the different aging processes: (1) filling up of the lower layer, (2) further filling, (3) clogging of top-layer, (4) stone loss [18]

Analyzed literature gave an overview of the main acoustic ageing influencing factors and different process for different surface types. Knowledge on the acoustic ageing (either linear or non-linear regression curves) is important for mixtures application (conditions, locations, lifetime, etc.) and further development directions. Regional and country variables need to be included in the mixtures construction procedures. Further analysis aims to evaluate regional peculiarities in terms of acoustical ageing.

3. Experimental testing

3.1. Test Road of Low Noise Pavements

Measurements of acoustical properties were carried out in the Test Road of Low Noise Pavements which was constructed in September 2015 as a follow-up of successful national research project “Laboratory development of Low Noise Asphalt Mixtures for Lithuanian climate conditions” results” [3]. Test Road was constructed on one of the main Lithuanian dual-carriageway highways A2 Vilnius-Panevėžys, where an average annual daily traffic (AADT) varies from 7000 to 10000 vehicles per day. Speed limit is 110 km/h. Test Road is 1.5 km in length and consists of 9 short sections where asphalt wearing course was constructed of different asphalt mixtures, including include 3 optimized thin low noise asphalt mixtures (TMOA 5, SMA 5 TM, SMA 8 TM) developed by Road Research Institute of Vilnius Gediminas Technical University (VGTU RRI) for Lithuanian and regional 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) [3]. Further analysis of acoustical ageing of low noise asphalt mixtures includes only sections, that were constructed of low noise asphalt mixtures SMA 5 TM, SMA 8 TM, TMOA 5 and PA 8.

3.2. Testing method

Noise level and spectrum measurements were performed using Close proximity method (CPX) (ISO 11819-2). Used CPX measurement equipment consists of a closed CPX trailer (to isolate microphones from unwanted outside sound sources, wind or traffic influence) towed by a light vehicle (Fig. 2). CPX measurement trailer includes two measurement tyres, that measure tyre/road noise in both wheel tracks simultaneously.

CPX noise level measurements were performed periodically – 8 times over the two years' period (1 month after Test Road construction each autumn before winter season, twice in each spring (when average daily temperature is higher than 5 ^{O}C and when average daily temperature is 10-15 ^{O}C).

CPX noise level measurements were performed at two driving speeds – 50 km/h and 80 km/h. Standard Reference Test Tyres (SRTT), that represent passenger vehicles generated tyre/road noise, were used.

Parallel to the CPX measurements, driving speed, road section length, GPS coordinates, air and road surface temperature are measured too.

Figure 2 CPX measurement equipment

4. Results and interpretation

Comprehensive analysis of acoustical ageing was performed for 3 sections of the Test Road. These sections were constructed using porous asphalt (PA8) and thin low noise asphalt layers (SMA8TM and SMA5TM).

Spectral composition of CPX results for SRTT tyres on PA8 pavement showed considerable increase of sound levels at higher frequencies (800-3150 Hz). Increase at lower frequencies was moderate. Similar tendencies were identified for both 50 and 80 km/h driving speeds (Fig. 3-4). Sound level increase could be associated with the decrease of porosity due to clogging and traffic compaction.

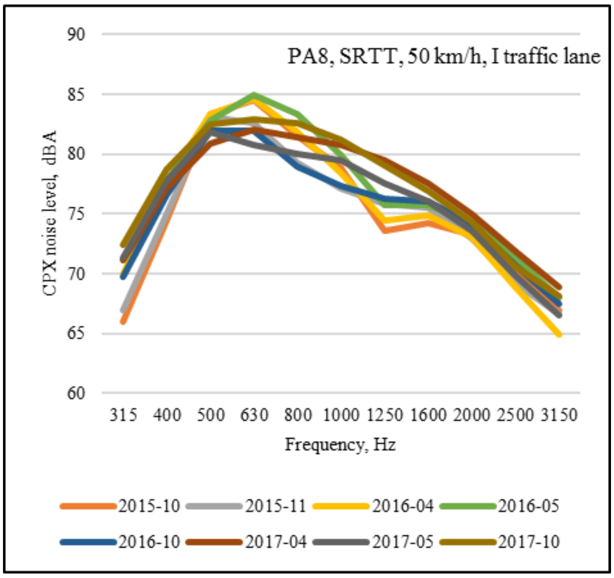

Figure 3 Spectral composition of CPX results for SRTT tyres at 50 km/h driving speed on PA8 pavement of the first traffic lane

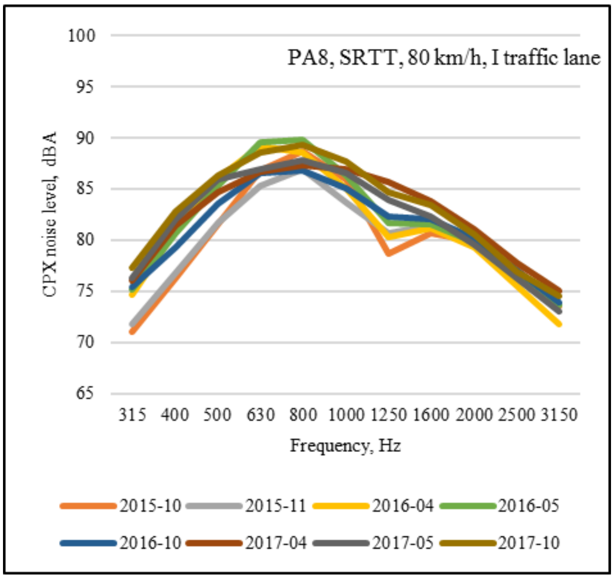

Figure 4 Spectral composition of CPX results for SRTT tyres at 80 km/h driving speed on PA8 pavement of the first traffic lane

Larger sound level increase was determined for the first traffic lane (Fig. 5-6). This can be linked with the initial considerable differences in air void content and degree of compaction that occurred because of unequal construction of different traffic lanes. That was verified after the construction by drilling cores and doing laboratory tests which showed that air void content and degree of compaction was lower in the second traffic lane. In addition to this, first traffic lane was more trafficked by heavy duty vehicles than the second traffic lane and that resulted in more intense traffic related compaction over the time.

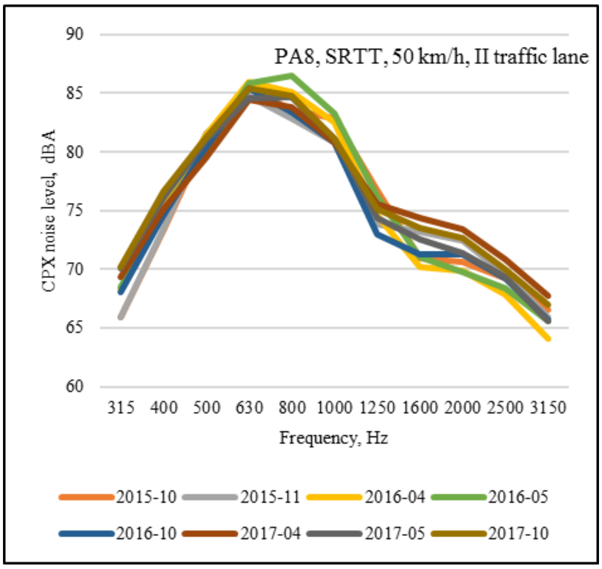

Figure 5 Spectral composition of CPX results for SRTT tyres at 50 km/h driving speed on PA8 pavement of the second traffic lane

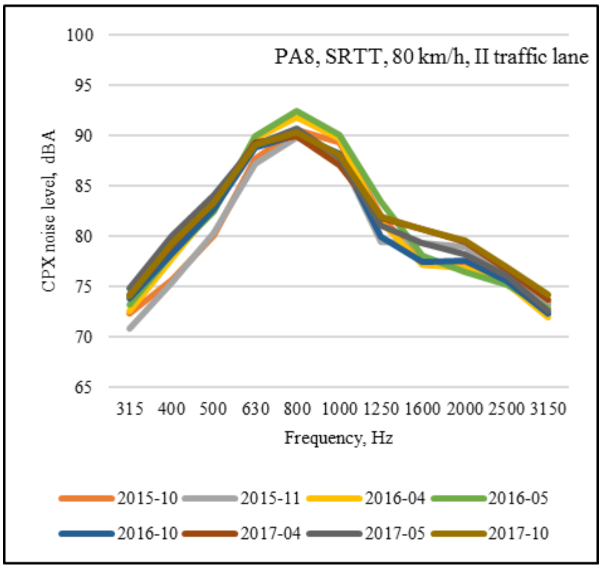

Figure 5 Spectral composition of CPX results for SRTT tyres at 80 km/h driving speed on PA8 pavement of the second traffic lane

Spectral composition analysis of the SMA8TM pavement, which has optimized texture and increased air void content for heavy vehicle noise reduction, also showed large differences between the traffic lanes (Fig. 7-10) what can be also linked with the large initial differences in air void content and degree of compaction.

If acoustical ageing of PA8 pavement was mostly noticeable at higher frequencies, then for SMA8TM pavement, sound level increase was determined at the whole frequency range (Fig. 7-8). This can be explained by the surface texture changes (for the lower frequencies) and clogging/densification processes (for the higher frequencies).

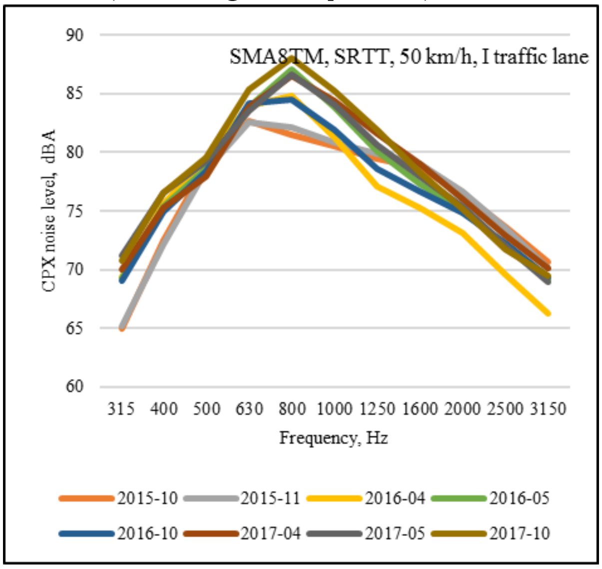

Figure 7 Spectral composition of CPX results for SRTT tyres at 50 km/h driving speed on SMA8TM pavement of the first traffic lane

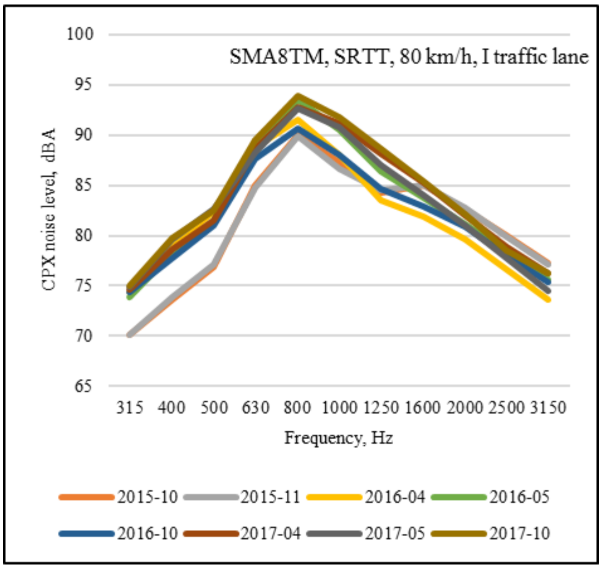

Figure 8 Spectral composition of CPX results for SRTT tyres at 80 km/h driving speed on SMA8TM pavement of the first traffic lane

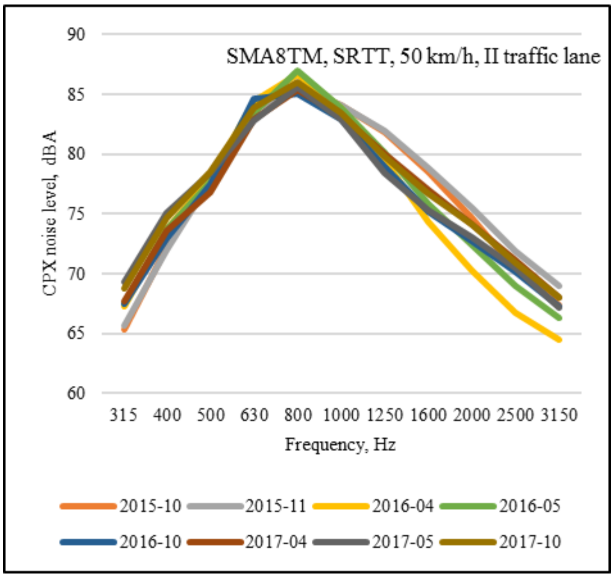

Figure 9 Spectral composition of CPX results for SRTT tyres at 50 km/h driving speed on SMA8TM pavement of the second traffic lane

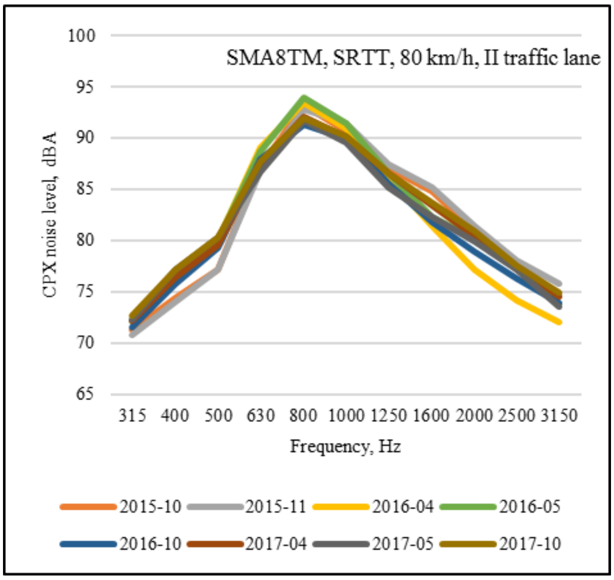

Figure 10 Spectral composition of CPX results for SRTT tyres at 80 km/h driving speed on SMA8TM pavement of the second traffic lane

Thin low noise asphalt mixture SMA5TM which was designed with the optimized surface texture and increased air void content for light vehicle noise reduction acoustically deteriorates in a different manner comparing with PA8 and SMA8TM mixtures. Spectral composition analysis showed that highest sound level increase for SMA5TM pavements were determined at low frequencies (up to 1000 Hz) (Fig. 11-14). This acoustic ageing tendency can be explained mainly by the surface texture changes and its impact on vibrational noise generation mechanisms.

It should be also noted that differences between the traffic lanes are reverse comparing with PA8 and SMA8TM sections.

Initially, first traffic lane had higher degree of compaction what resulted in more consistent increase of sound levels on the first traffic lane, even if this lane is more trafficked. From the sound level curves, it is visible that increase of sound levels is much larger at higher driving speeds.

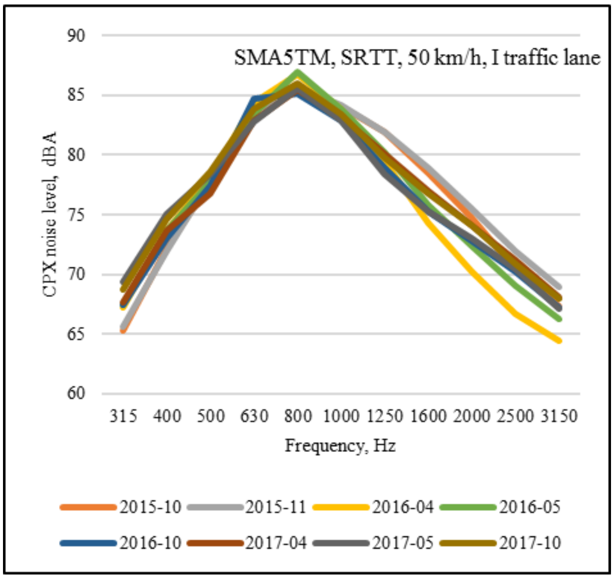

Figure 11 Spectral composition of CPX results for SRTT tyres at 50 km/h driving speed on SMA5TM pavement of the first traffic lane

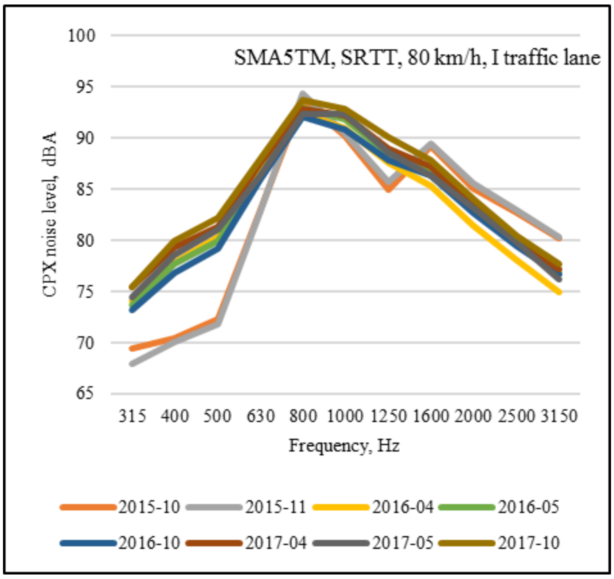

Figure 12 Spectral composition of CPX results for SRTT tyres at 50 km/h driving speed on SMA5TM pavement of the first traffic lane

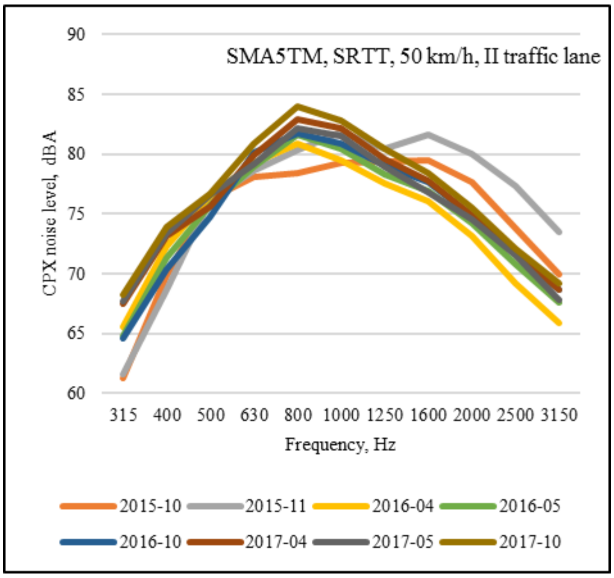

Figure 13 Spectral composition of CPX results for SRTT tyres at 50 km/h driving speed on SMA5TM pavement of the second traffic lane

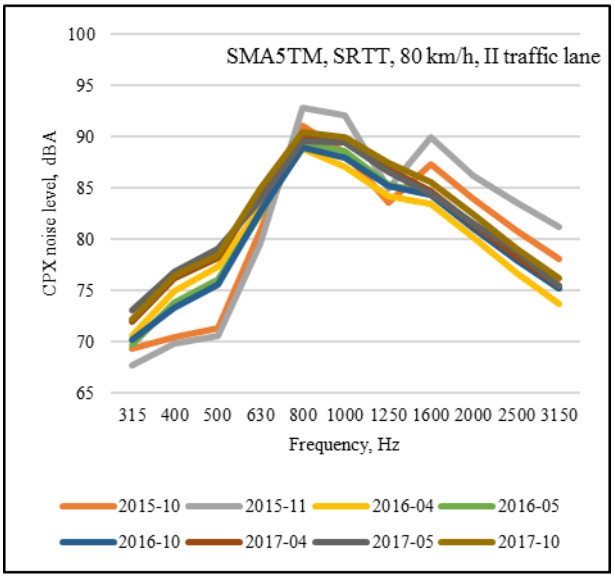

Figure 14 Spectral composition of CPX results for SRTT tyres at 80 km/h driving speed on SMA5TM pavement of the second traffic lane

5. Conclusions

Region and climate based knowledge on acoustic ageing of different low noise asphalt mixtures and influencing factors are necessary for proper low noise asphalt mixture design and application.

Largest sound level increase at higher frequencies (800-3150 Hz) was determined for porous asphalt pavements. This can be linked with the partly clogged pores in the pavement.

Low noise asphalt pavement construction quality has as significant impact on acoustic ageing process. Differences between noise levels and spectral composition between the traffic lanes can be associated only with the construction quality and consistency. Air void and degree of compaction differences between the traffic lanes resulted in different acoustic ageing. Therefore, it is recommended to set strict requirements for low noise asphalt mixtures construction.

Higher traffic volumes and higher percentage of heavy duty vehicles on the first traffic lane, resulted faster acoustical ageing due to surface texture densification.

Large sound level increase at lower frequencies after the first winter was determined for all of the analysed pavements and could be linked with the surface texture variation because of the winter road maintenance actions and probably clogging of the surface texture pores. It is recommended to apply different winter maintenance strategies and actions for low noise asphalt mixtures (not using abrasive materials; use pre-wetting of liquid snow melting/de-icing materials instead of salting).

Potential damaging impact of vehicles with studded tyres on low noise asphalt mixture texture was identified. Analysis showed that SMA5TM mixture, which has smallest maximum aggregate size, is the more sensitive to the impact of the studded tyres resulting in increase of sound levels at lower frequencies.

Further analysis and explanation of acoustic ageing trends will be continued by comparing noise spectral composition with measured surface texture spectral composition.

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