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Asphalt wearing course optimization for road traffic noise reduction

Audrius Vaitkus [a,*], Tadas Andriejauskas [a], Viktoras Vorobjovas [a], Aleksandras Jagniatinskis [b], Boris Fiks [b], Ewa Zofka [c]

[a] Road Research Institute, Vilnius Gediminas Technical University, Vilnius, Lithuania
[b] Laboratory of Acoustics, Scientific Institute of Thermal Insulation, Vilnius Gediminas Technical University, Lithuania
[c] Road and Bridge Research Institute, Poland

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

* Corresponding author.
E-mail address: audrius.vaitkus@vgtu.lt (A. Vaitkus).

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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