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ACOUSTIC PERFORMANCE AND DURABILITY OF LOW-NOISE STONE MATRIX ASPHALT (SMA8 LA) WEARING COURSE

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Abstract

This paper presents the results of field and laboratory investigations aimed at improving the acoustic and mechanical performance of low-noise Stone Matrix Asphalt (SMA8 LA) pavements. Statistical Pass-By (SPB) measurements conducted under the INREH research project on four SMA11 and two SMA8 LA surfaces demonstrated that SMA8 LA reduces tire-pavement noise by 2.5–3.1 dB compared to SMA11 across a speed range of 60–110 km/h. Building on this field evidence, laboratory investigations were performed on SMA8 LA mixtures modified with rubber granulate (RG), incorporated via the dry process at 10%, 20%, and 30% by volume as a partial replacement of the 1/4 mm aggregate fraction. Four binder types were investigated: unmodified 50/70 penetration-grade bitumen (reference), S-5 (5 wt.% SBS – Styrene-Butadiene-Styrene copolymer), RP-10 (10 wt.% rubber powder), and a composite S-2+RP-10 (2 wt.% SBS + 10 wt.% rubber powder). Sound absorption coefficient measurements using the impedance tube method showed that increasing RG content progressively improved acoustic performance, with the most favorable results recorded for mixtures containing 20–30% RG with the RP-10 binder. Hysteresis loop analysis further confirmed that RG incorporation markedly enhances mechanical durability, with the RP-10 binder at 30% RG yielding a 1210% increase in energy dissipation relative to the reference mixture. The combined use of RP-10 binder and RG at 20–30% by volume is identified as the most promising configuration for further development of SMA8 LA mixtures, warranting validation on experimental road sections.

Keywords: low-noise asphalt pavements, rubber granulate, sound absorption, sustainable infrastructure

1 Introduction

The development of durable and environmentally friendly asphalt pavements has become a fundamental part of sustainable road infrastructure, driven by the need to mitigate traffic noise, reduce reliance on virgin materials, and extend pavement service life. At medium and high traffic speeds, tire-pavement interaction noise is the dominant component of road traffic noise [1, 2]. Research into noise-reducing pavement surfaces is being conducted in numerous countries [3]. Known solutions include porous asphalt (PA), thin asphalt layers of the Béton Bitumineux Très Mince type (BBTM), and Stone Matrix Asphalt mixtures with reduced noise emission (SMA LA). However, it has been demonstrated that the acoustic durability and service life of porous asphalt pavements are inferior compared to SMA LA surfaces [4]. Furthermore, it is considered that the addition of rubber powder (RP) for binder modification and rubber granulate (RG) may improve the acoustic properties of mixtures employing such solutions, while simultaneously making use of end-of-life tires.

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Recycled RG from end-of-life tires is a key modifier in this context, providing noise reduction and enhanced damping while supporting circular economy principles by reducing virgin aggregate consumption. The primary mechanism of acoustic efficiency in these structures is the dissipation of sound energy within the interconnected pore network, where acoustic energy is converted to heat through viscous friction at the pore walls. The incorporation of rubber particles further enhances this process by enabling poroelastic deformation of the pore walls, which increases energy dissipation across a broader frequency range. Research by Apaza et al. [5] demonstrated that RG shifts peak absorption toward lower frequencies and widens the effective absorption bandwidth, while field studies confirm that SMA mixtures containing crumb rubber maintain acoustic stability over 24 months when porosity is maintained at 10–12% [6]. Consequently, incorporating RG via the dry process is a viable strategy for improving the acoustic performance of SMA8 LA mixtures.

Research at the Bialystok University of Technology is currently focused on improving asphalt technologies by simultaneously reducing tire/road noise and lowering production temperatures. While the challenge of reducing the production temperature of SMA8 LA mixtures using zeolitic additives was previously presented at the CETRA conference [7], this paper details how the acoustic properties of this mixture can be further improved through binder modification and the addition of rubber granulate. The objective of this study is to evaluate the combined effect of binder modification and rubber granulate content on the acoustic performance of SMA8 LA mixtures, in order to identify the most promising configurations for validation on experimental road sections.

2 Field noise testing of SMA LA road surfaces

Within the framework of the INREH project (Innovative methods for reducing road noise and principles for their application, grant RID-II No. RID2/0015/2022), a comprehensive analysis was conducted on the tire/road noise measurements of passing passenger cars and multi-axle heavy vehicles using the Statistical Pass- By (SPB) method to evaluate maximum sound level results. These investigations were performed on test sections representing various technologies, including five asphalt surfaces (AC11, SMA11, SMA8, SMA8 LA, and BBTM8) and cement concrete surfaces textured using the exposed aggregate technique (EAC8), jute fabric (CC-BuD), cross brushing (CC-BrD), and grooving and grinding (G&G) [8].

In this paper, particular attention is focused on the SMA8 LA surface. These mixtures, characterized by an air void content of 9–12% and a high coarse aggregate content of approximately 80%, create an open negative texture that reduces noise at the tire-pavement contact, offering a durable intermediate solution between traditional dense SMA and fully porous PA mixtures. A comparative analysis of tyre-pavement noise was conducted using the Statistical Pass-By (SPB) method on four SMA11 and two SMA8 LA surfaces, constructed on expressways (S8, S51) and national roads (DK36, DK62), as illustrated in figure 1. Each line represents a regression fit for one road section; the legend color corresponds to the road number indicated in table 1.

The relationships between the maximum sound level LA_{max} and the logarithm of vehicle speed are presented in table 1. Table 2 provides the LA_{max} values and the differences between the mean sound levels determined for a statistical passenger car passing on SMA11 and SMA8 LA surfaces.

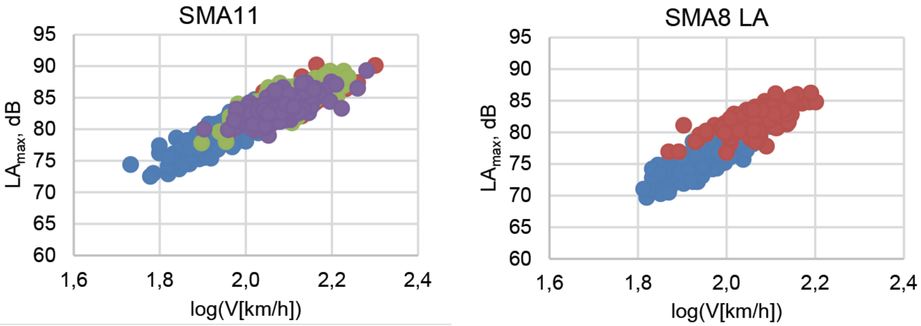

Figure 1 Comparison of LA_{max} values for SMA11 and SMA8 LA surfaces as a function of vehicle speed (passenger car), left diagram: SMA11 surfaces (S8 road – two sections shown in different colors, S51 road, DK62 road); right diagram: SMA8 LA surfaces (S51 road, DK36 road)

Table 1 Relationships between maximum sound level LA_{max} and the logarithm of vehicle speed for SMA11 and SMA8 LA surfaces

No.	Road No.	Surface type	Relationship between maximum sound level and logarithm of speed	LA_{max} (V). dB	
				80 km/h	110 km/h
1	S8	SMA11	$LA_{max} = 24.6 \cdot \log V + 32.7$; $R^2 = 0.65$	79.5	83.0
2	S8		$LA_{max} = 26.0 \cdot \log V + 29.8$; $R^2 = 0.71$	79.4	83.0
3	S51		$LA_{max} = 20.8 \cdot \log V + 40.3$; $R^2 = 0.62$	79.8	82.7
4	DK62		$LA_{max} = 30.5 \cdot \log V + 20.0$; $R^2 = 0.85$	78.1	82.3
5	S51	SMA8 LA	$LA_{max} = 23.8 \cdot \log V + 33.0$; $R^2 = 0.77$	78.3	81.6
6	DK36		$LA_{max} = 32.1 \cdot \log V + 13.3$; $R^2 = 0.83$	74.4	78.8

Table 2 LA_{max} values (dB) for SMA11 and SMA8 LA surfaces at selected vehicle speeds; values in parentheses indicate noise reduction relative to SMA11

Surface type	LA_{max} (V). dB					
	60 km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h
SMA11	76.0 (0.0)	77.8 (0.0)	79.2 (0.0)	80.5(0.0)	81.7 (0.0)	82.8(0.0)
SMA8 LA	72.9 (3.1)	74.8 (3.0)	76.4 (2.8)	77.8 (2.7)	79.1 (2.6)	80.3 (2.5)

SMA8 LA surfaces were found to reduce LAmax by approximately 2.5-3.1 dB compared to SMA11 across the speed range of 60-110 km/h, confirming their acoustic advantage under real traffic conditions. However, further improvement of SMA8 LA acoustic performance remains desirable, particularly through optimization of mixture composition.

3 Laboratory investigation of SMA8 LA asphalt mixtures

3.1 Materials

The study utilized a conventional 50/70 paving bitumen modified with SBS copolymer and recycled rubber powder with a fraction of 0/0.8 mm. The modified binders were prepared as follows: S-5 contains 5 wt.% SBS, S-10 contains 10 wt.% SBS, RP-10 contains 10 wt.% rubber powder, RP-20 contains 20 wt.% rubber powder, and the composite S-2+RP-10 contains 2 wt.% SBS combined with 10 wt.% rubber powder. Although five modified binders were initially prepared (S-5, S-10, RP-10, RP-20, and S-2+RP- 10), the S-10 and RP-20 variants were excluded based on a z-score standardization procedure. These binders required excessive mixing temperatures of 195°C and 217°C, which would increase production costs and accelerate binder ageing. A detailed description of this selection procedure is provided in [9]. The remaining binders (50/70, S-5, RP-10, and S-2+RP-10) were used to produce stone matrix asphalt SMA8 LA mixtures. To further optimize the acoustic performance of SMA8 LA, recycled rubber granulate (RG, fraction 1/4 mm) was incorporated via the dry process at 10%, 20%, and 30% by volume as a partial replacement for the 1/4 mm aggregate fraction.

3.2 Sound absorption testing

The sound absorption coefficient (α) characterizes the acoustic effectiveness of a pavement material, ranging from 0 (complete reflection) to 1 (complete absorption). When pores are open and interconnected, acoustic energy is dissipated through viscous friction at pore walls; when pores are closed, sound waves are reflected into the environment [8]. Measurements were performed using the Spectronics ACUPAVE System configured as an impedance tube in accordance with ISO 10534-2. The system was adapted for laboratory use at Bialystok University of Technology by attaching a dedicated specimen holder designed on the principle of a Kundt's tube, allowing precise positioning of cylindrical specimens at the zero reference position corresponding to in situ measurement conditions.

Rectangular plates (300 x 400 x 40 mm) were compacted using a plate compactor in accordance with EN 12697-33. Five cylindrical cores of 99 mm diameter were extracted from each plate and tested individually at normal incidence in one-third- octave bands at eight frequencies: 315, 400, 500, 630, 800, 1000, 1250, and 1600 Hz. Mean α values with standard deviations were calculated for each mixture type and binder combination. Figure 2 presents the mean sound absorption coefficient (α) values determined via impedance tube measurements for SMA8 LA mixtures with increasing RG content and four binder types. The sound absorption coefficient ranges from 0 (complete reflection) to 1 (complete absorption), with higher values indicating better acoustic performance.

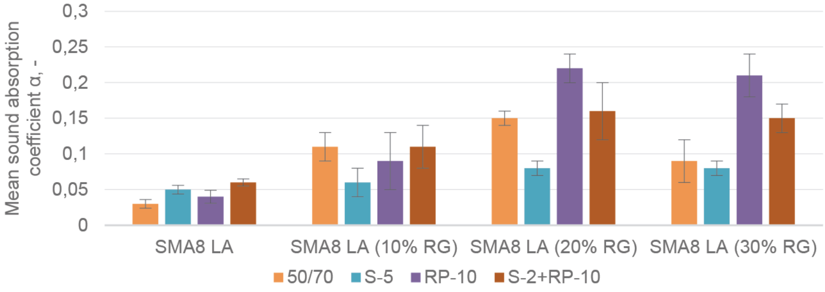

Figure 2 Sound absorption coefficient (α) of tested asphalt mixtures as a function of mixture type and binder

Sound absorption coefficients, measured via the impedance tube method, varied according to the internal structure of the investigated mixtures. As illustrated in figure 2, the reference SMA8 LA mixture without RG exhibited very low sound absorption values, indicating a predominantly closed pore structure. The modification of SMA8 LA with RG via the dry process led to a measurable and progressive improvement in acoustic performance. The best results were recorded for mixtures containing 20% and 30% RG combined with the RP-10 binder, where the sound absorption coefficient reached its highest levels.

Specifically, the RP-10 binder consistently yielded the highest sound absorption across the higher RG concentrations, reaching a peak α value of approximately 0.22 at 20% RG. At higher RG content levels (20–30%), the influence of binder type on sound absorption was found to be less pronounced compared to the effect of RG content, although RP-10 consistently yielded the highest absorption values across all RG levels, suggesting that binder selection remains a relevant factor in mixture optimisation. These findings suggest a poroelastic behavior in which the presence of rubber particles allows the pore walls to deform slightly, further dissipating sound energy through viscous friction and internal damping. The SMA8 LA mixture with 30% RG and RP-10 binder proved to be an effective configuration for urban low- noise applications, corroborating research regarding the optimization of urban road surfaces.

The experimental data obtained through the impedance tube method indicates that the acoustic properties of SMA8 LA can be significantly enhanced by adjusting its internal structure. The impedance tube results further indicate that additional acoustic improvement is achievable through the optimization of the mixture composition, particularly via the incorporation of rubber granulate at 20–30% by volume combined with RP-10 binder modification. However, the optimal configuration of RP-10 binder combined with 20–30% RG by volume warrants validation on experimental road sections to confirm its effectiveness under real traffic conditions.

3.3 Hysteresis loop analysis

Rubber granulate modifies not only the acoustic but also the mechanical behavior of SMA8 LA mixtures. Vibration damping was assessed via the area of the hysteresis loop in uniaxial cyclic compression tests conducted in accordance with EN 12697-25. Marshall-compacted cylindrical specimens (101.6 mm diameter, 60 mm height) were subjected to pulsating loads of 850 kPa at temperatures of 15°C, 25°C, and 35°C, with a pulse and relaxation time of 500 ms. The dissipated energy S was calculated as the difference between the work done during loading and the work recovered during unloading, directly reflecting the material's ability to dissipate vibrational energy. The testing methodology and full results are reported in [9]. Figure 3 presents selected hysteresis loops recorded for the RP-10 binder at 35°C for SMA8 LA mixtures with varying RG content (0%, 10%, 20%, and 30% RG).

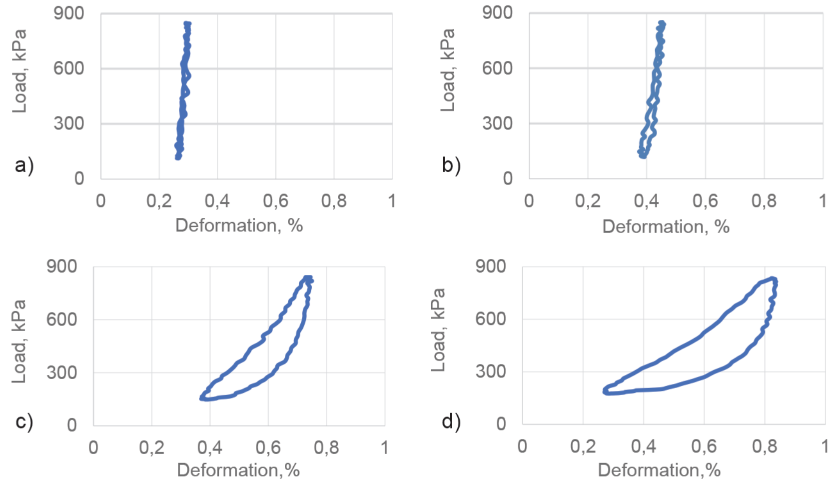

Figure 3 Hysteresis loop area at 850 kPa and 35°C for RP-10 binder across SMA8 LA mixtures with increasing RG content: a) 0% RG, b) 10% RG, c) 20% RG, d) 30% RG

Incorporation of RG via the dry process markedly and progressively increased the hysteresis loop area across all binder types and test temperatures. The most pronounced effect was recorded at 30% RG: at 35°C and 850 kPa, the RP-10 binder yielded a 1210% increase in energy dissipation relative to the reference SMA8 LA mixture (91.25 vs. 6.97 kPa). Among the binder types, RP-10 consistently produced the highest energy dissipation values, attributable to its spreading effect on the aggregate skeleton, while S-5 proved essential for maintaining structural integrity at 30% RG content. Full numerical results are reported in [9]. These results confirm that the incorporation of RG combined with modified binders, particularly RP-10 and S-5, significantly enhances the mechanical durability of SMA8 LA mixtures by improving their capacity to dissipate vibrational energy under repeated traffic loading, thereby contributing to longer pavement service life [10]. The increased elasticity of the wearing course resulting from RG incorporation reduces the dynamic contact force at the tire–pavement interface, thereby attenuating the excitation mechanism responsible for tire-pavement noise generation.

4 Conclusion

The results of field noise measurements and laboratory investigations conducted on SMA8 LA mixtures with rubber granulate incorporated via the dry process led to the following conclusions:

- SPB field measurements conducted under the INREH project confirmed that SMA8 LA surfaces reduce the maximum tire-pavement noise level by 2.5–3.1 dB compared to SMA11 across the speed range of 60–110 km/h, demonstrating their acoustic advantage under real traffic conditions.
- The reference SMA8 LA mixture without RG exhibited low sound absorption coefficient, indicating a predominantly closed pore structure. Incorporation of RG via the dry process progressively improved acoustic performance with increasing RG content, with the most favorable α values recorded for mixtures containing 20–30% RG.
- While RP-10 binder consistently yielded the highest sound absorption coefficient across all RG content levels, the effect of binder type was less pronounced at higher RG concentrations (20–30%) compared to the effect of RG content. These findings indicate that binder selection, while important for optimizing acoustic performance, plays a supporting role at high RG dosages.
- Hysteresis loop analysis confirmed that incorporation of RG via the dry process markedly enhances the mechanical durability of SMA8 LA mixtures. At 35°C and 850 kPa, the addition of 30% RG with the RP-10 binder resulted in a 1,210% increase in energy dissipation relative to the reference mixture, while S-5 proved essential for maintaining structural integrity at high RG content levels.
- The combined use of RP-10 binder and RG at 20–30% by volume is identified as the most promising direction for further development of SMA8 LA mixtures, offering simultaneous improvement of acoustic performance and mechanical durability.

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