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RESEARCH ON THE LONG-TERM ACOUSTIC EFFICIENCY OF ASPHALT MIXTURES USING CRM IN TEST SECTIONS OF SLOVAK ROADS

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Abstract

The article presents the possibilities of utilizing waste from the automotive industry, namely old tires, in constructing pavements. The application of shredded rubber creates conditions for devulcanization, which improves the rheological properties of the binder and ensures its better dissolution in asphalt. The focus is on assessing the condition of the pavement surface, measuring the noise level in the vicinity of the road, and quantifying and evaluating the cost of implementing an asphalt pavement design with a crumb rubber modifier (CRM). A visual inspection was performed after 6 years of pavement life. Based on the inspection outputs, the pavement surface structure was in a favourable condition with no permanent deformations. Verifying the acoustic properties showed a noise reduction compared to the road section with the modified asphalt pavement surface. Currently, the price of rubber-modified asphalt for pavement in Slovakia is on average 10 to 15 % higher than the price of other modified mixes. However, we can conclude that pavements with CRM are economically and especially ecologically more advantageous in the long run.

Keywords:

Waste;
Pavement;
Rubber;
Traffic noise;
Crumb rubber modifier;
Statistical Pass-By method.

1 Introduction

An integral part of improving the quality of life and public health is the sustainable development of Slovakia's integrated transport infrastructure [1]. In the field of road transport, the ever-increasing road traffic load [2], the rapidly changing climatic characteristics of Central Europe [3], [4], as well as the increasing demands on the environmental quality of life of the affected people in the vicinity of the roads, are becoming limiting factors in the design of the mixture and road structures. In the case of bearing layers of the road, it is necessary to ensure an even distribution of the traffic load on the lower layers. Attention is also focused on the protection of the pavement from climatic and weathering influences. In addition, it is necessary to consider the requirements of the surface of the layer, especially surface roughness [5] and unevenness of the abrasive layer [6], drainage properties, durability, and traffic noise and pollution [7]. The arrangement of the roadway in interaction with moving vehicles has a significant share in the noise load arising in the vicinity of the roadway.

Traffic noise is a perpetual form of environmental pollution that adversely affects human health. For this reason, many researchers focus on the continuously evolving low-noise asphalt pavement technologies and the techniques that can be used to evaluate them [8]. Loud traffic noise represents one of the main causes of annoyance for people living close to roads both in urban and non-urban environments, as it is directly linked to sleep disturbances, cardiovascular diseases, hypertension, myocardial infarction, and lower cognitive performance in children [9], [10]. Recently, a holistic perception of economic and environmental aspects of traffic noise has been promoted throughout the entire life cycle of the roads, i.e., in the sustainable preparation, construction, reconstruction, and operation of pavements too. During the operational phase, significant capital costs arise, which are necessary for the road management, maintenance, and repairs of roads to achieve the required levels of noise pollution in their surroundings. In addition to capital costs, social costs are also a part of the operation costs. The social costs are monetizing the negative impacts of road traffic on road users, society, and the environment. The capital and social costs of road operation is part of the economic evaluation of road infrastructure projects [11].

In addition to the porous asphalt surface of pavements, rubber-modified asphalt (RMA) is also becoming increasingly popular recently [12]-[15]. Long-term research activities abroad have made it possible to apply modifications to pavement surface layers utilizing rubber-modified asphalts. Currently, they are the standard technology used to reduce road noise. In the conditions of Slovakia, the first results with the application of asphalt mixtures with rubber-modified binder were published in [16]. This article is a continuation of these results.

2 Utilization of rubber granulation from waste tires

Within the framework of a holistic view of the life cycle of asphalt pavements of roads and traffic areas is from the point of view their sustainability is important that we spend an appropriate (not always the lowest) price on the required quality of the pavement constructions.

One such sustainable solution in the field of civil engineering may be the utilization of reclaimed waste tires in the field of pavements. The number of old tires is constantly increasing, so ways to reuse them are continually being researched. It is estimated that the annual increase in used tires in the European Union countries is 6.5 kg per capita. In Slovakia, the average annual increase in used tires is 3.3 kg per capita.

The rubber compound for tires is 46 % natural or synthetic rubber (elastomer). The remaining 22 % comprises carbon black and 32 % of other materials such as steel wire, textiles, antioxidants, sulphur, and zinc oxide. Based on the mentioned mixture, there is a worldwide effort to recover the rubbers found in tires. As a result, methods for the utilization of waste tires or rubber granulation obtained mainly by mechanical or cryogenic means are being explored.

One of the easiest methods of utilizing waste tires is to incinerate them. Incineration in cement plants produces cement clinker, or incineration to produce thermal energy. However, this method imposes a heavy environmental burden on the country and region concerned. Greater use of rubber granulation is mainly in the rubber industry by mixing it into new rubber compounds.

In the road construction sector, the utilization of recycled material from tires in asphalt mixtures is a particular concern. Mainly their application in the production of modified pavements. The possibilities of its application have been verified in laboratories. It required the preparation of rubber grains of a suitable fraction with a size of up to 0.8 mm. It was also necessary to verify the methods of dissolving the granulate grains in the asphalt binder. The well-known methods are:

- direct dissolution in asphalt,
- dissolution of the granulate with the addition of softeners to accelerate the dissolution process,
- treatment of the rubber granulates by thermal devulcanization followed by treatment with road asphalt.

Laboratory development of asphalts modified with rubber granulation from waste tires was carried out in Slovakia between 2006 and 2008 at Slovnaft. At the same time, operational experiments on the production of rubber-modified asphalt were also carried out. The resulting parameters of the asphalt designated as PMB 45/80-55 according to the Catalogue sheets of asphalts of the Slovak Republic [17] are presented in Table 1.

Table 1: Parameters of rubber-modified asphalt in service test [17].

Properties	Unit	Specification	Class by STN EN 14023 [7]	Achieved properties
Penetration at 25 °C	0.1 mm	STN EN 1426	4	79.0
Softening point	°C	STN EN 1427	7	57.6
Flash point	°C	STN EN ISO 2592	2	318.0
Fraass breaking point	°C	STN EN 12593	8	-20.5
Elastic recovery / 25 °C	%	STN EN 13398	4	76.0
Storage stability – softening point difference	°C	STN EN 13399 STN EN 1427	5	7.8

The addition of rubber granulation in the production of modified asphalt causes devulcanization of the granulate, ensuring better dissolution of the asphalt. The rubber granulation then does not act as a filler or additive. Releasing the hydrocarbon chains of the polymer changes the structure of the asphalt and acts as a modifier. For a complete characterization, rheological measurements would be necessary.

These would make it possible to investigate the material properties based on the relationship between stress, strain, and strain rate.

3 Objectification of noise reduction of asphalt layers

The road surface, especially the texture, and porosity, significantly determines the emissions and distribution of road traffic noise. These characteristics influence the rolling noise generated between the tire and the road (Fig. 1). In addition, porosity can affect the distribution of sound, primarily if the distribution occurs in the vicinity of the road surface.

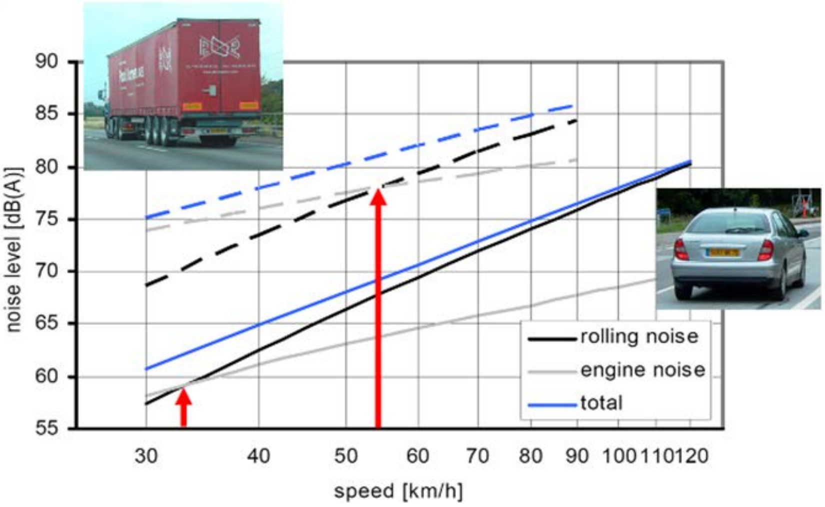

Fig. 1: Noise sources: rolling noise, engine noise, and total noise from road traffic at the constant speed [18].

Powertrain noise is usually generated at a greater height above the road surface than rolling noise. It may also be affected during propagation by the porosity of the road surface. The mentioned facts lead to differences in noise levels at the same traffic flow intensity and composition (up to 15 dB according to EN ISO 11819-1). It can have a significant impact on the environmental quality of the road environment. Consequently, property values and rental levels are also affected. For credible prediction of traffic noise reduction through low-noise asphalt pavement developed by Technical Committee ISO/TC 43 two basic procedures for assessing the effect of pavement surface on traffic noise are developed:

- Part 1: Statistical Pass-By method,
- Part 2: Close-proximity method,
- Part 3: Reference tires (from 2017 specify two types of reference tires using the CPX (Close proximity) method specified in ISO 11819-2).

The Statistical Pass-by (SPB) method was implemented in Slovak technical standards by STN EN ISO 11819-1 [19]. ISO 11819-2:2017 [20] specifies the CPX method for the assessment of different pavement surfaces concerning their impact on road traffic noise. It is assuming a predominant tire/carriageway noise constituent.

The Department of Highway and Environmental Engineering of the Faculty of Civil Engineering of the University of Žilina (KCEI SvF UNIZA) has been measuring the impact of road surfaces on traffic noise according to STN EN ISO 11819-1 since 2007. The standard is primarily intended for comparing the noise performance of different road surfaces. It provides road transport and environmental authorities with an instrument for establishing standard procedures or restrictions. They relate to the application of road pavement surfacing complying with specific noise criteria. However, it does not set assessment criteria. To obtain the overall level of influence of the road surface on traffic noise for a representative mix of vehicles (Table 2.), we need to calculate a statistical pass-by index according to relation (1):

$$SPBI = 10 \cdot log\left[W_1 \cdot 10^{\frac{L_1}{10}} + W_{2a} \cdot \left(\frac{v_1}{v_{2a}}\right) \cdot 10^{\frac{L_{2a}}{10}} + W_{2b} \cdot \left(\frac{v_1}{v_{2a}}\right) \cdot 10^{\frac{L_{2b}}{10}}\right] \quad (1)$$

where:
SPBI - Statistical Pass-By Index for a standardized mix of light and heavy vehicles,
L_1, L_{2a}, L_{2b} - vehicle sound pressure levels for vehicle category 1, 2a, 2b,
W_1, W_{2a}, W_{2b} - weighting factors corresponding to the expected proportions of vehicle categories in the traffic flow,
v_1, v_{2a}, v_{2b} - the reference speeds for each vehicle category according to Table 2.

Table 2: Categories and required number of vehicles passes according to STN EN ISO 11819-1 with typical examples of vehicles on MS 2 - 14.09.2017 [20].

Vehicle category	Typical example of vehicles		Min. number of passes	Reference ground speed with driving speed			Weights coefficients W_i		
				low	medium	high	low	medium	high
1) Cars	2 axles, 4 wheels, passenger cars		100	50			0.900		
					80			0.800	
						110			0.700
2a) dual-axle heavy vehicles	2 axles, light trucks, BUS		30 (2a+2b = 80)	50			0.075		
					70			0.100	
						85			0.075
2b) multi-axle heavy vehicles	heavy goods vehicles, more than 2 axles		30 (2a+2b = 80)	50			0.025		
					70			0.100	
						85			0.225

STN EN ISO 11819-1 specifies that vehicle sound pressure levels L_{eq}^{Ti} measured at T_i [°C] should be corrected to a reference temperature of 20 °C. According to relation (2), a calculation is performed, which was also used in the SPENS –Sustainable Pavement for European New Member States.

$$L_{eq}^{T-20°C} = L_{eq}^{T_i} - 0{,}04 \cdot (20 - T_i) \quad (2)$$

Figs. 2 to 4 present examples of the evaluation of the correlation dependencies of the maximum noise levels on the logarithm of the speed of vehicles of categories 1, 2a, and 2b. From them, the values of sound pressure levels L_1, L_{2a}, and L_{2b} for the measurements performed at MS1 and MS2 on 14 September 2017 are determined.

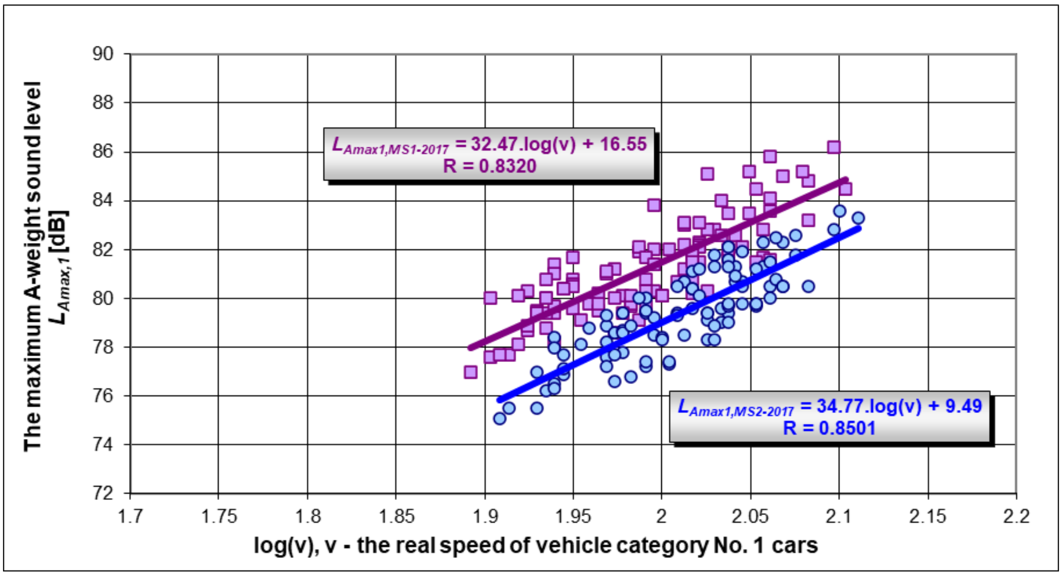

Fig. 2: Regression lines of the dependence of the maximum sound pressure levels on the decadic logarithm of the speed for vehicle category No. 1 cars.

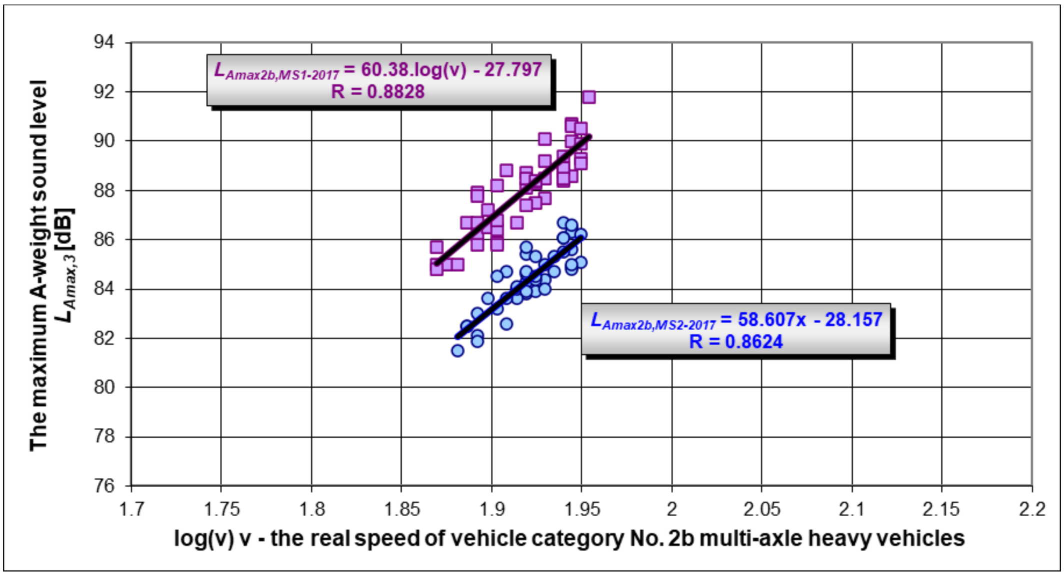

Fig. 3: Regression lines of the dependence of maximum sound pressure levels on the decadic logarithm of speed for vehicle category No. 2a dual-axle heavy vehicles.

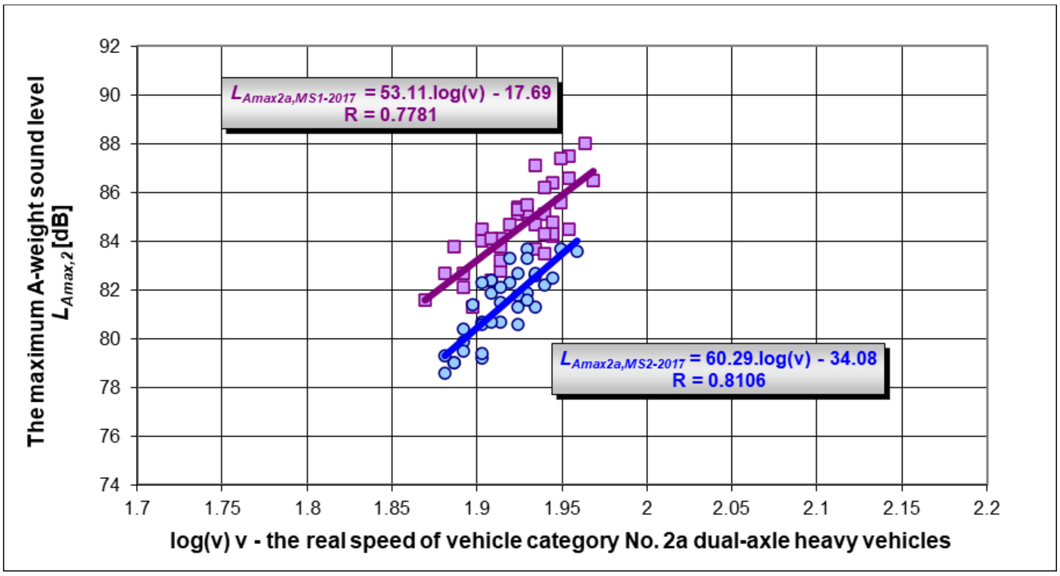

Fig. 4: Regression lines of the dependence of maximum sound pressure levels on the decadic logarithm of speed for vehicle category No. 2b multi-axle heavy vehicles.

Table 3. presents the evaluated quantities of interest required to determine the SBPI values for measurement stations MS1 and MS2. The measurements were carried out on 04.11.2011 and 14.09.2017.

Table 3: Evaluated quantities and SPBI indexes for measurements performed on MS1 and MS2 on 04.11.2011 and 14.09.2017.

Date of measurement	**Measuring station**	**Reference and average driving speeds [km.h^{-1}]**					**SPBI [dB] converted to *T*=20ºC**		
		Value to be evaluated		**1**	**2a**	**2b**	**SPBI$_{MS1}$**	**SPBI$_{MS2}$**	**SPBI$_{MS1}$ - SPBI$_{MS2}$**
14.09.2017	**MS1** SMA 0 11	v_{ref}	**[km.h^{-1}]**	**110**	**85**	**85**	86.0 dB		**3.3 dB**
		v_{sk}	[km.h^{-1}]	98.8	84.4	82.7			
		L_i	[dB]	82.8	84.8	88.7			
	MS2 SMA 0 11; PMB	v_{sk}	[km.h^{-1}]	103.0	82.3	84.2		82.7 dB	
		L_i	[dB]	80.4	82.2	85.0			
04.11.2011	**MS1** SMA 0 11	v_{sk}	[km.h^{-1}]	82.8	84.0	88.3	85.1 dB		**3.2 dB**
		L_i	[dB]	102.0	83.1	82.9			
	MS2 SMA 0 11; PMB	v_{sk}	[km.h^{-1}]	79.4	81.2	85.2		81.9 dB	
		L_i	[dB]	79.4	81.2	85.2			

4 Results of reduction of traffic noise induced by CMR application in Slovak pavements

The article was based on the results of long-term cooperation between the Research Institute of Engineering Constructions - Roads (VUIS-CESTY) Bratislava and the Faculty of Civil Engineering of the University of Žilina in Žilina. In the framework of the cooperation carried out at the beginning of the second decade of the 20th century [22], [23] the following facts were objectified. By analysing the measured noise levels during the years 2010 to 2012 induced by the passing of vehicles with known driving speeds and the SPBI values evaluated from them, the following facts can be concluded:

- SMA 11; PmB (CRM) on the test section on the R1 expressway at the Zvolen – Kovacova level crossing reported SPBI values 3.2 dB lower concerning SMA 11 for the category of roads with high driving speed,
- AC 11 O; PmB (CRM) on the test section on road II/510 in the section crossing with road I/62 (Sladkovicovo – Velke Ulany) reported SPBI values of 3.0 dB concerning AC 11 O for the category of roads with low driving speed,
- AC 11 O; PmB (CRM) on the experimental section Voderady – Samsumg reported a SPBI value of 2.3 dB lower concerning standard AC 11 O, for the category of roads with medium driving speed,
- AC 11 O; PmB (CRM) on the test road section II/548 Stos – Smolnik concerning AC 11 O behind the in question showed an SPBI value of 2.7 dB lower for the category of roads with low driving speed.

For all 3 categories of roads with low, medium, and high reference driving speeds, a decrease in SPBI in the range of 2.3 to 3.2 dB was objectified, caused using CRM technology of devulcanization of rubber from waste tires of road vehicles. In this article, the long-term acoustic efficiency of the asphalt mixture SMA PmB (CRM) was demonstrated, which even after the passage of 1.2 million heavy trucks induced noise immissions 3 dB lower than SMA PmB.

In the conditions of Slovakia, the first credible results objectification long-term reduction of traffic noise through rubber-modified binder (CRM - Crumb Rubber Modified) were found during cooperation Dr. h. c., Ing. Zdenek Lovecek, CSc. with Faculty of Civil Engineering UNIZA. The pavement with an abrasive layer from Stone Mastix Asphalt with Polymer modified asphalt (SMA 11, PMB) asphalt mixture has been realized in 2008 on the R1 expressway from the Zvolen interchange in the direction of Banska Bystrica (test section on road R1). Within the subject section of the expressway, a verification (trial) section was built located in the right lane, including reinforced shoulders, which has an abrasion layer built using asphalt modified with treated rubber granules from used tires. The section was subjected to a second visual inspection and verification of noise reduction objectified by measurements in 2017 using the SPB methodology according to STN EN ISO 11819-1. After six years of pavement life cycle operation, a visual inspection was carried out on the MS1 experimental section from the aspect of pavement surface condition assessment. The average traffic intensity in both directions was 23,000 vehicles per 24 hours. The asphalt applied in the wearing course was a modified rubber granulate asphalt from waste tires – SMA O 11, PMB 45/80-55 (Fig. 5.). Following on detailed visual inspection in 2017 and analysis of its outputs, can be constant, that pavement of the experimental road section of the R1 Zvolen no significant permanent deformations. As already mentioned, in the monitored profile of the section of the R1 expressway up to the period of noise levels measurement in 2017 in both directions, the total number of passing vehicles was recorded in the level of 12 million. Considering the 20% share of trucks in the traffic flow, this represents 1.2 million heavy lorries in one traffic direction, and despite this, a visual assessment revealed a very good quality of the road surface of the test section of interest.

Fig. 5: Views of SMA O 11 using CRM asphalt.

The Statistical Pass-By method from 1997 was used to verify the long-term acoustic efficiency of the test road section using CRM, which was implemented in the Slovak system of standards in 2002 through STN EN ISO 11819-1 [19]. The measurements carried out on 14.09.2017 revealed the following. The pavement abrasive layer MS1 – SMA 11; PMB demonstrated SPBI values lower by 3.1 dB to MS2 – SMA 11 for the high-speed road category. The reduction in equivalent noise levels for the MS1 experimental section was ΔL_{Aeq} = 3 dB after rounding to the nearest whole dB. We can conclude that the experimental section with rubber-modified asphalt still demonstrates dB lower noise levels after six years than the section using conventional modified asphalt SMA 11. The following examples can be given to provide a better idea:

- in terms of changes in traffic volumes, all currently applied SR road traffic noise prediction methodologies consider a 3 dB increase in equivalent noise levels for a doubling of traffic volume. A reduction of ΔL_{Aeq} = 3 dB represents a halving of traffic intensity,
- in the case of road traffic noise, a theoretical decrease in the noise level of 3 dB is considered for doubling the distance to the receiver. A decrease of ΔL_{Aeq} = 3 dB represents an increase in the distance of the road from the receiver.

5 Conclusions

In comparison with road traffic noise-reducing devices (noise barriers, cladding, covers,...) low noise pavements have a great potential to significantly reduce the noise load of their surrounding roads with low construction costs. From a physical point of view, low-noise asphalt pavement reduces traffic noise in two basic ways, through high porosity mixtures, or by using noise-absorbing materials in the wearing course, most often CRM. The article presents the objectified results of noise reduction research through the CRM application in 4 experimental sections of roads in Slovakia. As part of the VUIS-CESTY and UNIZA research collaboration, an average SPBI reduction of 2.8 dB due to the use of CRM was found. On the R1 test section in 2017, after passing 1.2 million heavy trucks, the same 3 dB reduction as in 2011 was detected.

The findings presented in the article, representing the first measurements of this type of low-noise pavements in Slovakia, are convergent with the latest works of foreign authors. Porous asphalt absorbs the rolling noise mainly through large air voids [24] up to a value of 3–3.5 dB [8] compared with standard asphalt mixtures used in the wearing course layer of non-rigid and semi-rigid roads [8]. Low-noise asphalt road cover built using CRM reduces rolling noise energy through rubber damping, which reduces the equivalent noise levels by up to 3 dB [25]. In article [26] it is stated that the asphalt wearing course layer containing CRM proved to reduce the resulting equivalent noise level in the range from 2 to 3 dB(A) at different speeds of the passing vehicles.

The price of rubber-modified asphalts for the abrasive layer in Slovakia is on average 10-15 % higher than for other modified asphalts. The authors believe that the found results give a realistic basis in the conditions of Slovakia to significantly reduce the noise load around roads and crossroads [27], without the use of exceptionally costly equipment to reduce road traffic noise.

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