PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Use of waste and marginal materials for silent roads

Lily POULIKAKOS[1], Sahand ATHARI[1,2],Peter MIKHAILENKO[1], Zhengyin PIAO[1,2], Muhammad Rafiq Khan KAKAR[1], Moises BUENO[1], Reto PIEREN[1], Kurt HEUTSCHI[1]

[1] Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland

[2] ETHZ, Swiss Federal Institute of Technology, Switzerland

ABSTRACT

Inhabitants of the urban environment are exposed to high levels of traffic noise and increase in amounts of waste. One way to mitigate their exposure to noise is to take advantage of the existing public spaces between buildings and transform the available surfaces of pavements into elements that foster comfort and health for urban residents.

This work aims to develop low noise pavements by using certain waste materials. Semi-dense asphalt (SDA) mixtures (Air Voids = 12-16%) is used in this study due to their acoustic properties. Part of the aggregate matrix incorporates crumb rubber (CR). The various mixtures produced are compacted into 100mm dimeter specimens and subjected to texture measurements by 3D laser profilometry, porosity measurements and sound absorption measurements by the impedance tube method (EN 10534-2). The SDA mixtures showed a higher surface macrotexture amplitude, MPD. They also showed a more negative surface profile R_{sk}, indicating better noise properties based on the shape. This study gives us an understanding on how waste materials impact the texture and acoustic properties of roads and ultimately, to what degree they can be incorporated in low-noise asphalt mixtures.

Keywords: Semi Dense Asphalt; Low Noise Pavements, Crumb Rubber

1. INTRODUCTION

Greater demands on the road transport infrastructure as a result of economic growth have manifested themselves in an increase in the number of vehicles worldwide. This increase is inherently accompanied by increase in congestion, noise, energy use and gaseous and particle emissions as well as an increase in the infrastructure overuse. A recent report by the World Health Organization (WHO) indicates that in the EU and Norway, traffic noise is the second biggest environmental problem affecting health after air pollution (1).

A review by the authors has demonstrated how a considerable amount of waste produced in the urban and peri-urban environment can be recycled in asphalt roads. It was shown that various waste materials such as glass, asphalt, concrete, wood, tires, plastics etc. have technically a potential for re-use in asphalt roads. The available quantities of the European target waste materials that would otherwise be incinerated or disposed of in landfills were considered. It was shown that there is high potential in Europe for recycling in road construction, in particular, under the hypothetical scenario where 33% of new roads would be made of the target waste materials (excluding reclaimed asphalt pavement RAP which is already recycled), it is estimated that 16% of the available waste quantities could be recycled in roads. Four hypothetical roads were analyzed showing a considerable savings in costs, CO2 and energy in comparison to conventional asphalt mixtures using all virgin components (2). However although technically viable, only those waste materials should be considered that their use in the roads are also environmentally superior to alternative uses in other applications. A viable example is the amount of crumb rubber from old tires that is expected to continue to increase and be available in the near future, and the best use of this material may indeed be road construction. Figure 1 shows effects related to vehicle and surroundings during driving, such as noise, rolling resistance, and tire wear, plotted against texture wavelength. It can be seen from this illustration that lower macrotexture have positive effects on road noise and the opposite effect on rolling resistance that is a safety consideration. Introduction of rubber in mixtures, including ground tires, can also contribute towards reduction of traffic noise by 2.5 to 4 dB (3). Development of low noise pavements specifically for the urban environment considering the frequencies and loading of such pavements is lacking. In Switzerland the semi dense mixtures (SDA) have shown promising results (4). These are special type of gap graded mixtures with high porosity up to 18%.

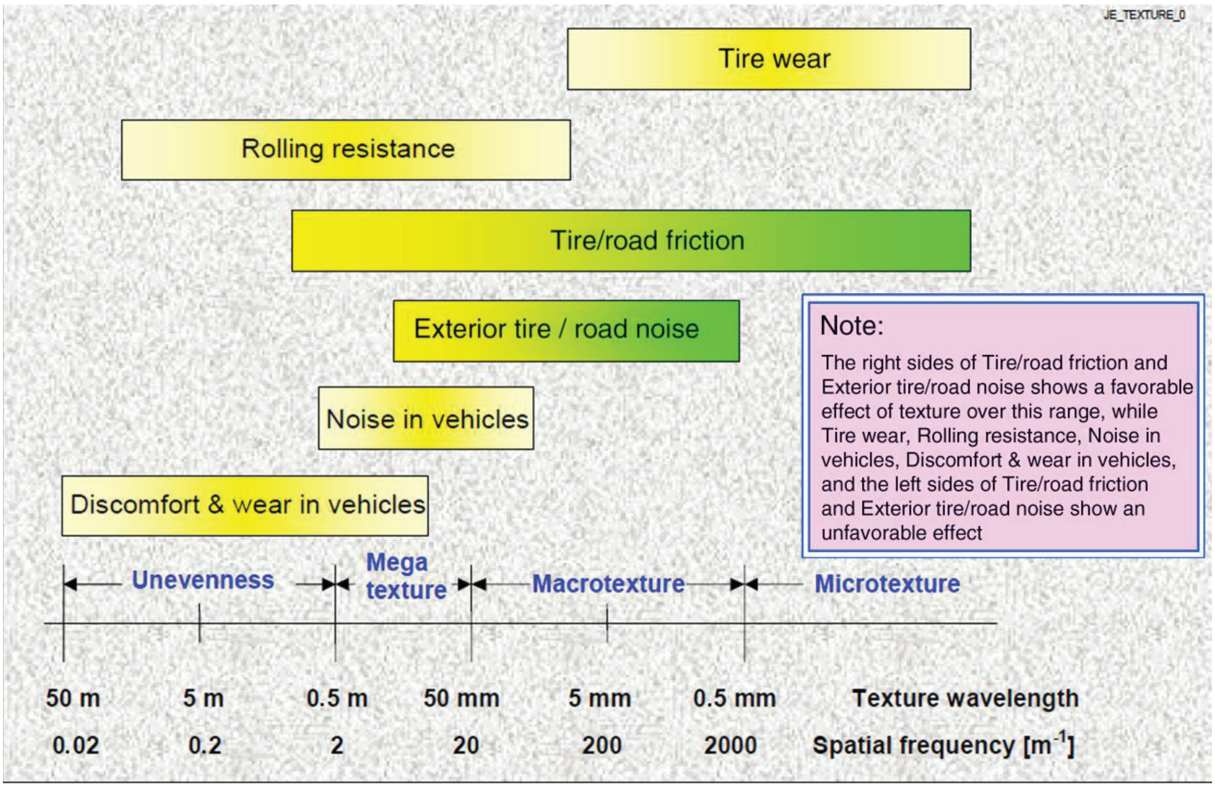

Figure 1 Illustration of texture wavelengths, anticipated effects showing that noise is affected by macrotexture (4)

One potential urban waste material that has been shown to have low noise properties is crumb rubber (CR) from used tires (3). This project aims to investigate the low noise properties of CR modified asphalt concrete as potential low noise pavement.

2. MATERIALS

Two semi dense asphalt concrete mixtures with maximum aggregate size of 4 and expected porosity of 14% to 18% (SDA4-16) were produced in the lab. The gradation of both is shown in Figure 2. According to the standard, conventional polymer modified bitumen was used to prepare the reference mixture (SDA4-PmB). For the experimental one, crumb rubber produced by mechanical grinding with size <800µm was used as additive in a mixture with non-modified bitumen. The overall void content (connected and not connected) determined for Marshall cylindrical samples (100mm dimeter; ca 60mm height) of the two mixtures was 13.2 and 13.8 for SDA 4-CR and SDA4-Pmb respectively.

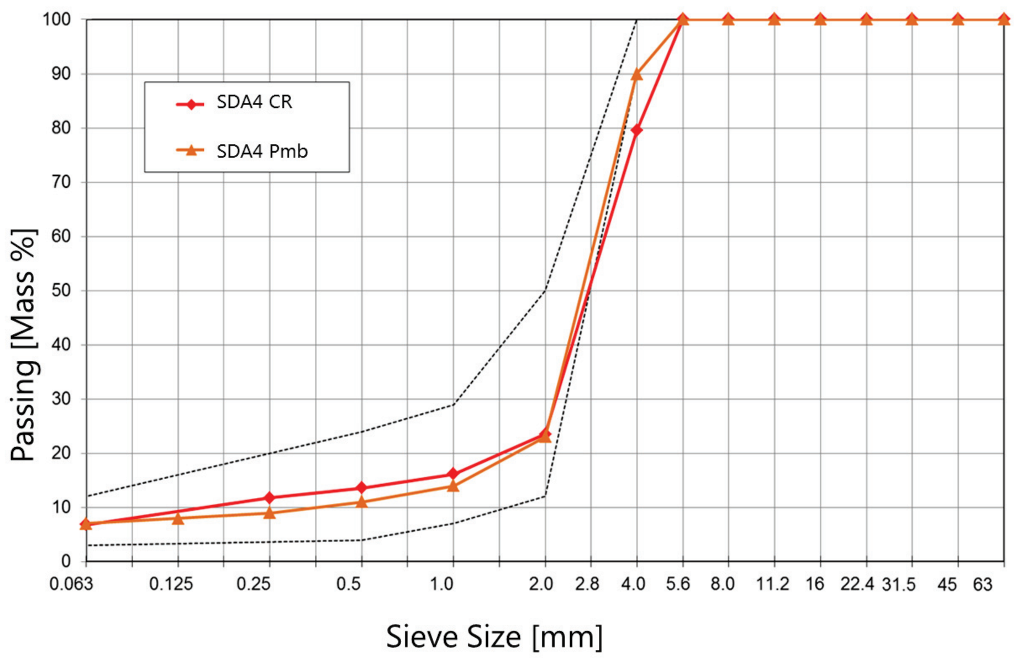

Figure 2 Aggregate size distribution of SDA-4 with polymer modified bitumen and with straight run bitumen 50/70 and 1% CR

3. METHODS

3.1 Mixture and Sample Production

All mixtures were produced in the laboratory using polymer modified bitumen and straight run bitumen with 50/70 penetration grade with crumb rubber modification. 1% crumb rubber was added using the dry process to the mixture. In the dry process CR is added to the hot aggregates before the addition of bitumen. After the mixing process, the mixtures were conditioned for 120 minutes at 160°C. This conditioning time is important for the crumb rubber to interact with the bitumen. The samples were compacted using the Marshall hammer with 50 blows per side.

3.2 Mechanical Tests

The tensile strength of the specimen was determined using the indirect tensile test according to the European standard (EN 12697-23). In this test, the load is applied to a cylindrical specimen (100mm dimeter, 60mm height) loaded diametrically until failure. The experiments were performed at room temperature ca 23°C.

3.3 Surface Texture

The surface texture of the asphalt mixture samples was measure by an Ames Engineering 9400HD 3D laser scanner. The tests were conduction on one Marshall sample of each type: dense asphalt with about 5% pores, semi-dense asphalt (SDA 4 Pmb), and semi-dense asphalt with 1% crumb rubber (SDA 4 CR); both with about 13% pores. The test was conducted by placing the sample horizontally under the device and conducting two 50x50 mm area scans in two random directions. The resolutions were 0.005 mm vertically, 0.00635 mm along the length of the scan and 0.02469 mm for the width. 2000 scan lines were conducted for each area scan, for a total of 4000 scan lines for each sample.

3.4 Acoustic Absorption

Three specimens from three types of mixtures were tested in the impedance tube based on ISO EN 10534-2 (7). This procedure measures the normal incidence sound absorption coefficient using the transfer function method. In these tests one sample of each mixture type was used: SDA4-Pmb SDA4-CR. Furthermore, a dense asphalt specimen with less than 5% air void content was evaluated as control specimen to analyze the effect of the porosity on the sound absorption. The testing was conducted on the same samples as the surface texture. Figure 3 shows these specimens. Each sample was tested three times with about 120 degrees of rotation. The produced plots are the average of these three measurements for each sample. Figure 4 shows the test rig using the B&K two-microphone impedance measurement tube type 4206.

Figure 3 Specimens used for acoustic tests a)Dense asphalt, b)SDA4 Pmb, c)SDA4 CR

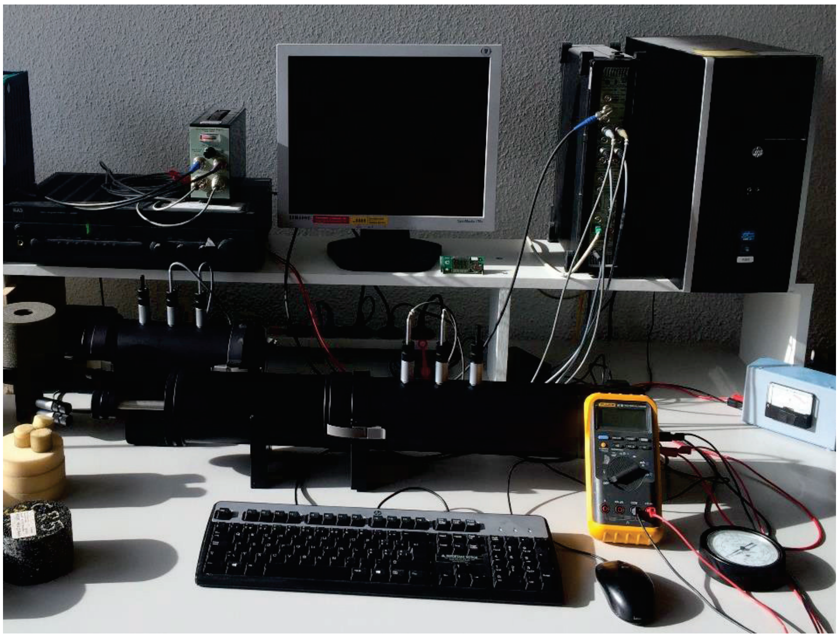

Figure 4 Acoustic test setup showing the impedance tube and data acquisition devices

Initially, the SDA4 Pmb and SDA4 CR specimens were 99mm in diameter, therefore an air gap existed between the specimen and the inner wall of the impedance tube (which is 100mm). The results obtained in this condition contained an artefact at about 200 Hz to 300 Hz. The tests were repeated with the same specimens but this time sealed and fixed using masking tape around the perimeter of the cylindrical specimens. In this condition, the artefacts were not present in the measurement results. The difference between the results in these two conditions emphasizes the importance of fitting the specimens correctly in the impedance tube to avoid artefacts.

4. RESULTS

4.1 Mechanical Tests

Figure 5 shows the results of three repetitions for the indirect tensile test on the CR modified mixture and the conventional mixture with Polymer modified binder. As shown in Figure 5, the CR modified mixtures could withstand slightly higher loads in comparison to the polymer modified mixtures.

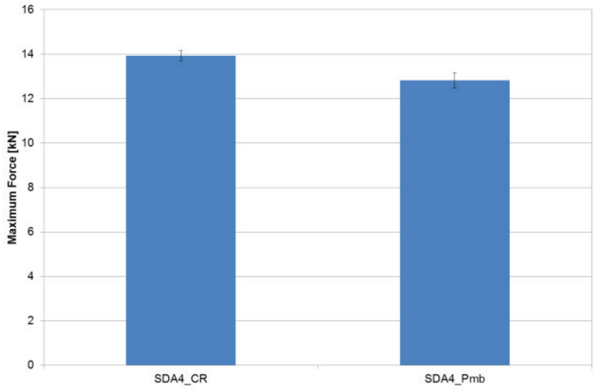

Figure 5 Maximum force to mechanical failure as a result of the indirect tensile tests

4.2 Surface Texture

Based on the 3D laser scans, a number of texture parameters were calculated as shown in Table 1. These parameters were calculated on the Macrotexture as defined in ISO 13473-1 (8), where only the texture wavelengths between 0.5-50 mm were considered. The pavement macrotexture has been shown to be critical to pavement noise (4). Mean Profile Depth (MPD) is a measure of the depth of the profile deviation from the mean. R_{sk} is the skewness value of the depths, which is an indication of whether there is a "positive" and "negative" surface texture. R_{ku}, the kurtosis parameter indicates the presence of disproportionately high peaks or deep valleys (9). Finally the length and area ratios indicate the length of the profile versus the horizontal axis, which is a simple indication of roughness.

Table 1 Macrotexture Parameters for Asphalt Mixture Samples

Mixture	Air Voids %	MPD mm	R_{sk} mm	R_{ku} mm	Length Ratio	Area Ratio
Dense	5	0.461	-0.224	0.188	1.016	1.031
Std Dev		*0.132*	*0.577*	*1.204*	*0.008*	*0.000*
SDA 4 PmB	13	0.615	-0.586	0.420	1.036	1.070
Std Dev		*0.145*	*0.483*	*1.178*	*0.015*	*0.000*
SDA 4 CR	13	0.519	-0.311	0.324	1.023	1.047
Std Dev		*0.146*	*0.606*	*0.883*	*0.011*	*0.000*

The texture result show higher amplitude of macrotexture for the SDA mixtures in terms of MPD, as found with previous studies with more pervious asphalts (9,10). This can primarily be attributed to the higher content of voids for SDA causing an increased quantity of cavities at the surface. This increase in macrotexture or generally higher roughness is also visible from the higher length and area ratios for the SDA mixtures. The lower amplitude in the SDA 4 sample with CR is not clear, and could be attributed to the variation sample to sample, so more robust testing is needed, although some studies have also found a lower MPD with CR (11).

The R_{sk} results showed negative skewness for all of the samples, with the SDA samples more negatively skewed. This negative skewness indicates the presence of deep valleys in the samples (12), and this type of surface profile has been shown to cause less vibration and therefore less noise during service (13). The R_{ku} kurtosis values were less than 3 for all of the samples, indicating a more bumpy as opposed to spikey surface. This is an indication of better resistance to wear (12). In this parameter, the dense asphalt has a lower value, which indicates better wearing properties.

The standard deviations for the MPD, R_{sk} and R_{ku} values are quite high due to having been derived from a series of small segments from 0.5-50mm. The length and area ratios have very little variability due to having been derived from the whole length segments or areas.

4.3 Acoustic absorption

Figure 6 shows the values of absorption coefficient for the sealed and non-sealed conditions on a vertical axis from 0 to 0.2. The horizontal axis shows the frequency spectrum from 63 Hz to 2000 Hz. As mentioned before, the artefacts at 200 Hz to 300 Hz seem to have been occurred due to the air gap around the sample and passage of acoustic energy to the back of the specimen.

The SDA4_CR sample has slightly higher absorption coefficients than SDA4_Pmb. This difference reaches 0.015 at its maximum which considering the uncertainty in the measurements are nearly identical.

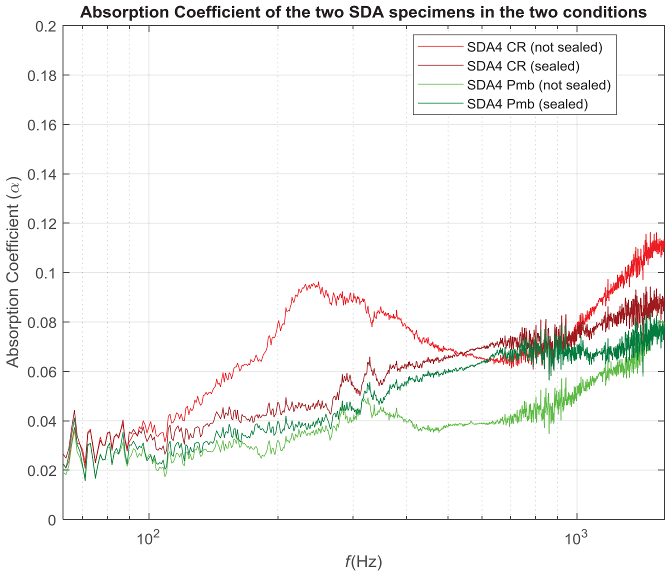

Figure 6 Absorption coefficient of two SDA specimens in two conditions

Figure 7 shows the results of the impedance tube test for the two specimens for both sealed and non-sealed conditions together with the results for the dense asphalt. The absorption coefficient for a 75mm-thick foam sample is also included to give a reference for an effective porous absorber material.

As it can be observed, regardless of the medium air void contents, the range of absorption coefficients of these asphalt samples is considerably small along the frequency spectrum, i.e. always below 0.1.

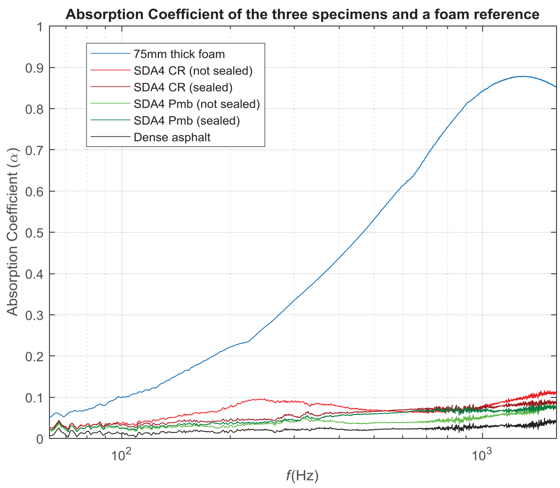

Figure 7 Absorption coefficient of the three asphalt samples in comparison to a highly absorbent foam sample

Figure 7 shows the difference between the absorption coefficient of the three specimens SDA4_CR, SDA4_Pmb and dense asphalt for the correctly sealed condition.

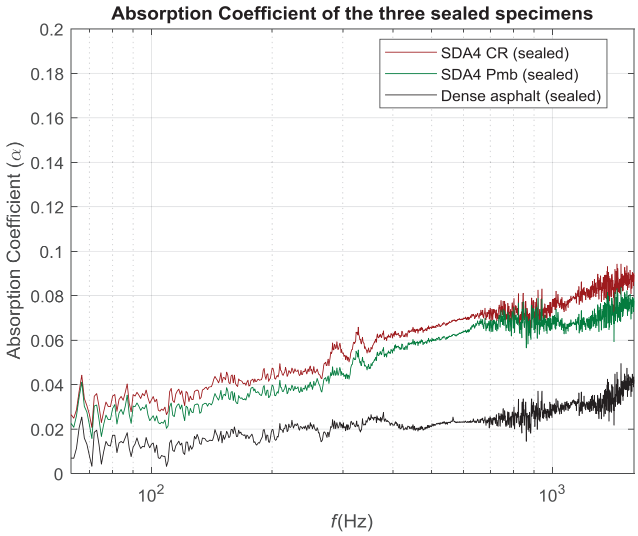

Figure 8 Absorption coefficient of SDA4_CR; SDA4_Pmb and dense asphalt

As illustrated on Figure 8, the absorption coefficient of both semi-dense asphalts is only slightly higher than dense asphalt. As a quantitative example, the ratio of the absorption coefficient of SDA_CR to that of dense asphalt changes from a minimum of 1.7 to a maximum of 8.1. This means that SDA_CR is at least 1.7 time more absorbing than dense asphalt. However these preliminary measurements show that SDA4 is not an effective absorber and its low noise properties are due to other characteristics.

5. SUMMARY AND CONCLUSIONS

The mechanical and acoustic performance of semi dense asphalt with and without crumb rubber waste from tires were tested and compared. The results show that crumb rubber modification does not compromise the mechanical performance of the mixture in terms of strength.

The surface texture properties indicate higher macrotexture and overall texture of SDA mixtures relative to the dense asphalt. The SDA CR sample had a lower profile than the SDA PmB sample, but more testing is needed to find if this is a trend. The samples also showed a negative skewness, indicating better shape properties for noise. All of the samples tested showed a bumpy (as opposed to spikey) profile, indicating better resistance to wear, although the dense asphalt had the best result with this parameter.

The acoustic absorption tests show that the absorption coefficient of SDA is considerably higher than the dense asphalt, however both materials are not effective absorbers.

The semi-dense asphalt with crumb rubber has similar absorption coefficients compared to the one without crumb rubber. On that basis, sound absorption does not seem to be the dominant noise reduction mechanism when incorporating crumb rubber in the asphalt mixture.

It is probable that other mechanisms of tyre-pavement noise generation such as air pumping and tyre vibrations can contribute more to the acoustic effectiveness of asphalt mixtures with crumb rubber. Measuring other properties of asphalt mixtures such as mechanical impedance, surface texture and porosity can help obtaining better expressions for the difference in the acoustic performance of the mixtures. The future work will be focused on measuring these properties and predicting noise reduction using more parameters than the absorption coefficient.

ACKNOWLEDGEMENTS

This research project is funded by a grant from the Swiss National Science Foundation grant number 205121_178991/1.

REFERENCES

1. World Health Organization press release and report available at

http://www.euro.who.int/__data/assets/pdf_file/0008/136466/Burden_of_disease.pdf
2. Poulikakos LD, Papadaskalopoulou C, Hofko B, Gschösser F, Cannone Falchetto A, Bueno M, et al. Harvesting the unexplored potential of European waste materials for road construction. Resources, Conservation and Recycling. 2017;116:32-44.
3. Paje SE, Luong J, Vazquez VF, Bueno M, Miro R. Road pavement rehabilitation using a binder with a high content of crumb rubber: Influence on noise reduction. Construction and Building Materials. 2013;47:789-98.
4. Sandberg, U., and Ejsmont, J. A. (2002). Tyre/road noise reference book, INFORMEX, Kisa, Sweden
5. Bafu report low noise pavements (2017)
6. EN 12697-23 Bituminous mixtures - Test methods for hot mix asphalt – Part 23: Determination of the indirect tensile strength of bituminous specimens
7. ISO EN 10534-2; Acoustics — Determination of sound absorption coefficient and impedance in impedance tubes — Part 2
8. ISO EN 13473-1; Characterization of pavement texture by use of surface profiles — Part 1: Determination of Mean Profile Depth
9. Remisova E, Decky M, Kovac M. The influence of the asphalt mixture composition on the pavement surface texture and noise emissions production. 14th SGEM GeoConference Energy Clean Technol. 2014;2:583–590.
10. McDaniel R, Shah A, Dare T, Bernhard R. Hot mix asphalt surface characteristics related to ride, texture, friction, noise and durability. Institute for Safe, Quiet, and Durable Highways North Central Superpave Center Purdue University; 2014. Report No.: 2014–07.
11. Vázquez VF, Paje SE. Study of the road surface properties that control the acoustic performance of a rubberised asphalt mixture. Appl Acoust. 2016 Jan;102:33–9.
12. Menezes PL, Nosonovsky M, Ingole SP, Kailas SV, Lovell MR. Tribology for Scientists and Engineers: From Basics to Advanced Concepts. Springer Science & Business Media; 2013. 940 p.
13. Angst C, Bürgisser P, Beckenbauer T. IMPACT: Investigation Machine for Pavement ACoustic durability; Testing the durability of low noise road. In: Proceedings of 6th Eurasphalt & Eurobitume Congress. Czech Technical University in Prague; 2016.