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Low-noise road mixtures for electric vehicles

Filippo G. Praticò, Gianfranco Pellicano and Rosario Fedele

(DIIES Department, University Mediterranea of Reggio Calabria, Italy)

filippo.pratico@unirc.it; gia.pellicano@gmail.com; rosario.fedele@unirc.it

Presenting author: Rosario Fedele

Integrating the *Iberian Encounter of Acoustics*
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List of contents (1/1)

- Problems statement (related to traffic noise increase and electric vehicles diffusion);
- Main objectives of the study (studying two low-noise road pavement mixtures);
- Tasks presentation and description (in-lab sample creation and testing);
- Results and discussions (performance of the two mixtures above);
- Conclusions (achievements and future work).

Problems statement (1/1)

Based on the literature review and previous studies:

- The road pavements of the future should be designed to take into account the variation of the traffic noise due to Internal Combustion Engine Vehicles (ICEVs) traffic decrease and electric vehicles (EVs) diffusion;
- By comparing acoustic annoyance of light ICEVs-EVs: (i) EVs are usually quieter than ICEVs at low speeds (<70 km/h); (ii) EVs are noisier than ICEVs at high speeds (>90 km/h);
- Traffic noise at high frequency can be attenuated by reducing the dynamic stiffness (or mechanical impedance) of road pavements;
- Researchers are working on: (i) characterizing and minimizing the noise produced by (both ICEVs and Evs) vehicle engines and tyres; (ii) developing new solutions, e.g. low-noise road surfaces (e.g., LIFE project “E-VIA”: LIFE18 ENV/IT/000201);
- An Open Asphalt Concrete (AC), with Nominal Maximum Aggregate Size (NMAS) of 6 mm, was selected as the reference mixture in the LIFE Project “E-VIA”.

https://life-evia.eu/

Main objective and Tasks presentation (1/1)

- Main objective:

Presenting the performance (particularly acoustic and mechanical) of two AC6 mixtures that were designed to reduce the problems related to traffic noise mentioned above. In particular, an AC6* (without treated crumb rubber, TCR), and an AC6** (with TCR) were designed and tested.

- Tasks presentation:

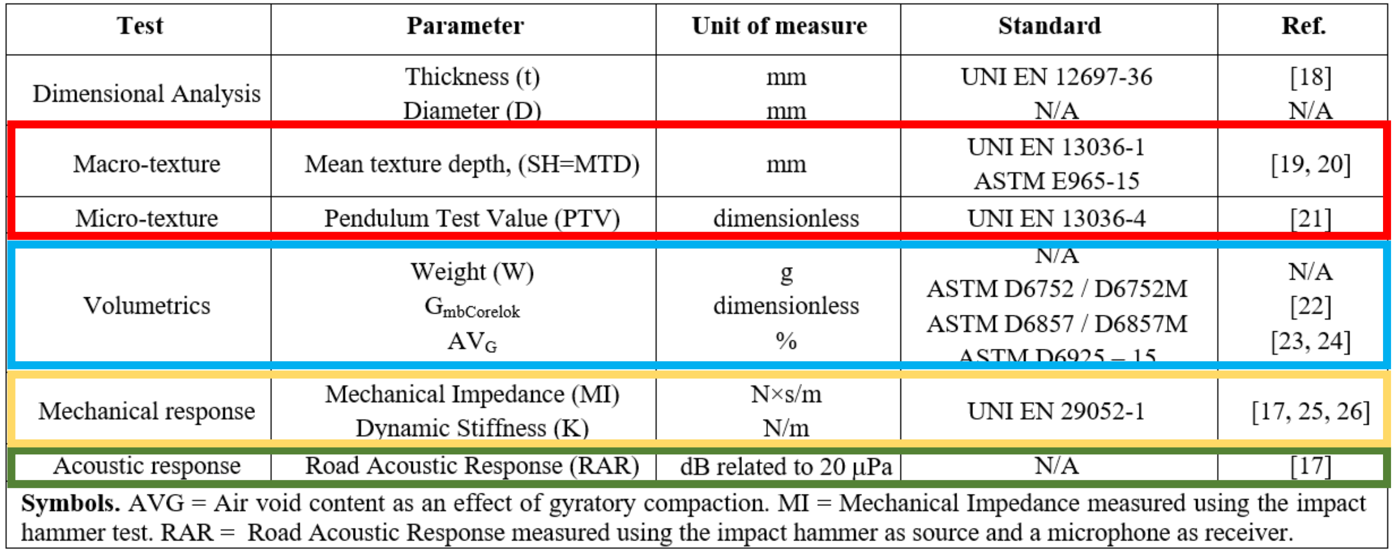
The following tasks were carried out to achieve the aforementioned objectives:

- Task 1) Design of the experimental investigation.
- Task 2) Design/creation of mixtures/samples with and without TCR.
- Task 3) Testing of samples with and without TCR.
- Task 4) Analysis of the results.

Task 1) Design of the experimental investigation (1/1)

- Two types of mixtures: AC6* without TCR, and AC6** with TCR.
- Three samples for each mixture, varying the percentage of bitumen.
- Mix design method: Superpave gyratory mix design method.
- Properties investigated: surface (texture), volumetric, mechanical, and acoustic ones.
- Tests (see Table 1).

Table 1 – Tests to carry out.



Test	Parameter	Unit of measure	Standard	Ref.
Dimensional Analysis	Thickness (t) Diameter (D)	mm mm	UNI EN 12697-36 N/A	[18] N/A
Macro-texture	Mean texture depth, (SH=MTD)	mm	UNI EN 13036-1 ASTM E965-15	[19, 20]
Micro-texture	Pendulum Test Value (PTV)	dimensionless	UNI EN 13036-4	[21]
Volumetrics	Weight (W) $G_{mbCorelok}$ AV_G	g dimensionless %	N/A ASTM D6752 / D6752M ASTM D6857 / D6857M ASTM D6925 – 15	N/A [22] [23, 24]
Mechanical response	Mechanical Impedance (MI) Dynamic Stiffness (K)	N×s/m N/m	UNI EN 29052-1	[17, 25, 26]
Acoustic response	Road Acoustic Response (RAR)	dB related to 20 µPa	N/A	[17]

Symbols. AVG = Air void content as an effect of gyratory compaction. MI = Mechanical Impedance measured using the impact hammer test. RAR = Road Acoustic Response measured using the impact hammer as source and a microphone as receiver.

Task 2) Design/creation of mixtures/samples with and without TCR (1/1)

- Based on the Superpave mix design method, the optimum %B was 5%. Hence, three percentages of bitumen per mix type were considered (about 3%, 5%, and 7%).
- The gyratory compactor revolution number was maintained constant (i.e., 210).
- The TCR was added applying the dry process. TCR seems to negatively affect the compaction level of the samples (cf. G_{mb_DIM}). Hence, %TCR = 2.

Table 2 – Samples' compaction and features.

Type of mixture	Sample ID	Bitumen by mix weight [%]	TCR by mix weight [%]	Gyratory compactor revolution number	Sample dimensions (thickness × diameter) [mm × mm]	Sample weight [g]	G_{mb_DIM} [-]
AC6*	AC6o_3%B_0%TCR_21	3.2	0.0	210	117.4 × 97.5	2066.09	2.36
AC6*	AC6o_5%B_0%TCR_22	5.2	0.0	210	117.2 × 97.5	2109.57	2.41
AC6*	AC6o_7%B_0%TCR_23	7.2	0.0	210	119.6 × 97.5	2154.78	2.41
AC6**	AC6o_3%B_2%TCR_24	3.0	2.0	210	123.7 × 97.5	2105.22	2.28
AC6**	AC6o_5%B_2%TCR_25	5.0	2.0	210	107.0 × 97.5	2151.30	2.39
AC6**	AC6o_7%B_2%TCR_26	7.0	2.0	210	123.9 × 97.5	2198.26	2.36

Symbols. AC6 = Asphalt Concrete with Nominal Maximum Aggregate Size of 6 mm. 3%B = Percentage of bitumen of 3% (w/w by the total weight of the mixture). 0%TCR = Percentage of TCR of 0%. $G_{mb\ DIM}$ = Bulk Specific Gravity calculated considering the characteristics of the sample (dimensions and weight).

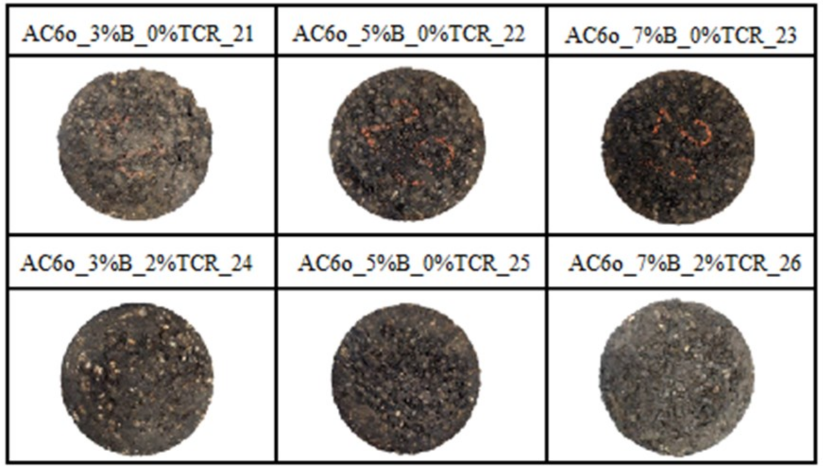


Figure 1 – Upper surfaces of samples.

Task 3) Testing of samples with and without TCR (1/1)

- Six samples (with or without TCR) were tested using the devices in Figure 2.
- The method and the system used to measure both mechanical and acoustic responses were developed by the authors of the paper.

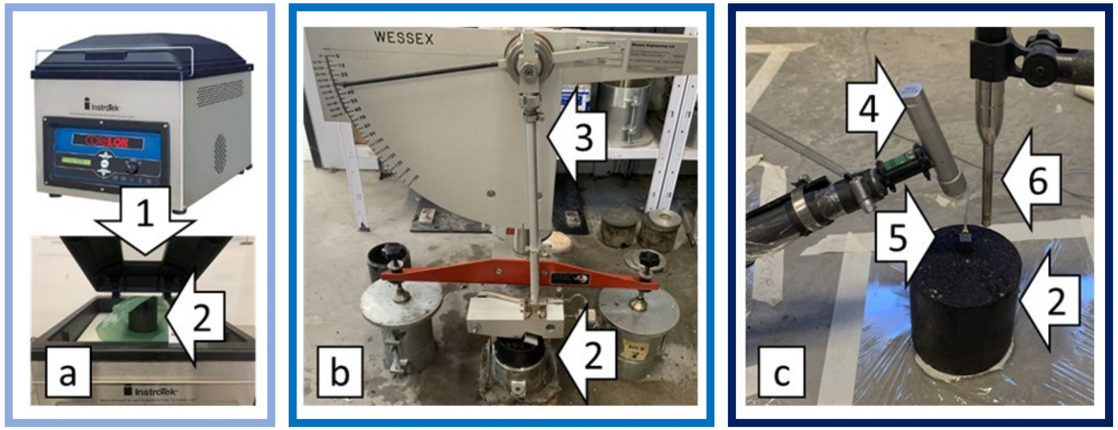


Figure 2 – Main devices.

Notes. 1: Corelok machine. 2: Samples. 3: Pendulum tester. 4: Impact hammer. 5: Accelerometer. 6: Microphone.

Legend: Test → Parameter

a → $G_{mb\_Corelok}$

b → PTV

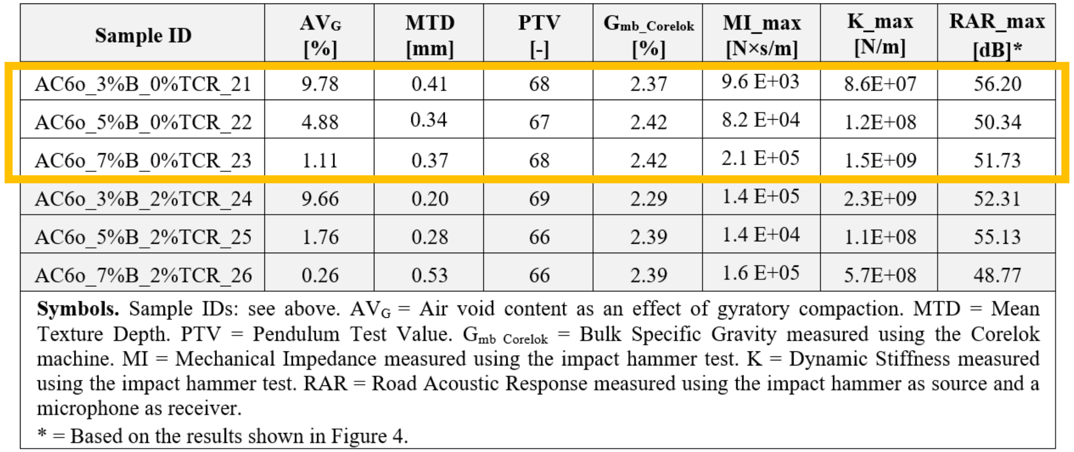
c → K = Force/Displacement;
MI = Force/Velocity;
RAR = Acoustic response to an impact hammer hit.

Task 4) Analysis of the results (1/5)

Effect of the percentage of asphalt binder increase (%B= 3, 5, 7; $\%B_{optimum}$=5%), in samples without Treated Crumb Rubber (%TCR=0):

- AV_G decreases (from about 10% to about 1%).
- $G_{mb\_Corelok}$ increases (2%);
- MTD (macro-texture) has a minimum at the optimum %B;
- Negligible effects are observed in terms of micro-texture for skid resistance (PTV = 67-68);
- Maximum values of mechanical response (Max MI & Max K) sharply increase;
- Maximum values of acoustic response (Max RAR) has a minimum at the optimum %B.

Table 3 – Samples' main properties.



Sample ID	**AV_G [%]**	**MTD [mm]**	**PTV [-]**	**$G_{mb\_Corelok}$ [%]**	**MI_max [N×s/m]**	**K_max [N/m]**	**RAR_max [dB]***
AC6o_3%B_0%TCR_21	9.78	0.41	68	2.37	9.6 E+03	8.6E+07	56.20
AC6o_5%B_0%TCR_22	4.88	0.34	67	2.42	8.2 E+04	1.2E+08	50.34
AC6o_7%B_0%TCR_23	1.11	0.37	68	2.42	2.1 E+05	1.5E+09	51.73
AC6o_3%B_2%TCR_24	9.66	0.20	69	2.29	1.4 E+05	2.3E+09	52.31
AC6o_5%B_2%TCR_25	1.76	0.28	66	2.39	1.4 E+04	1.1E+08	55.13
AC6o_7%B_2%TCR_26	0.26	0.53	66	2.39	1.6 E+05	5.7E+08	48.77

Symbols. Sample IDs: see above. AV_G = Air void content as an effect of gyratory compaction. MTD = Mean Texture Depth. PTV = Pendulum Test Value. $G_{mb\ Corelok}$ = Bulk Specific Gravity measured using the Corelok machine. MI = Mechanical Impedance measured using the impact hammer test. K = Dynamic Stiffness measured using the impact hammer test. RAR = Road Acoustic Response measured using the impact hammer as source and a microphone as receiver.

* = Based on the results shown in Figure 4.

Task 4) Analysis of the results (2/5)

Effect of percentage of asphalt binder increase (%B= 3, 5, 7; $\%B_{optimum}$=5%), in samples with Treated Crumb Rubber (%TCR=2):

- AV_G decreases (from about 10% to about 0.3%).
- $G_{mb\_Corelok}$ increases (4%);
- MTD (macro-texture) increases (from 0.20 to 0.53);
- PTV (micro-texture) decreases (from 69 to 66);
- Maximum values of mechanical response (Max MI & Max K) has a minimum at the optimum %B;
- Maximum values of acoustic response (Max RAR) has a maximum at the optimum %B.
- **Effects related to bitumen drain-down (i.e., bitumen drains off the aggregates during sample compaction) and bitumen-TCR interaction (i.e., higher %Bs better melt the given amount of TCR, while lower %Bs do not completely melt the same %TCR) may explain the trends listed above.**

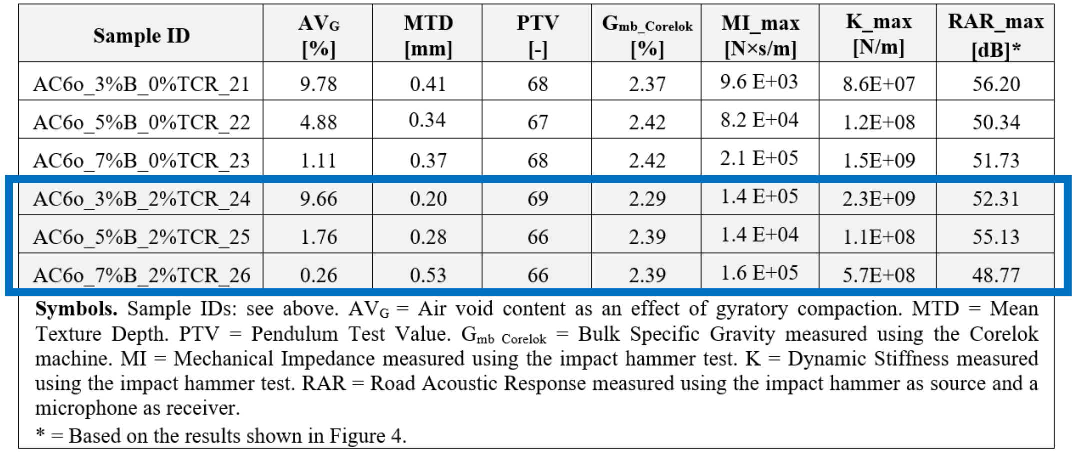


Table 3 – Samples' main properties.

Sample ID	AV_G [%]	MTD [mm]	PTV [-]	$G_{mb\_Corelok}$ [%]	MI_max [N×s/m]	K_max [N/m]	RAR_max [dB]*
AC6o_3%B_0%TCR_21	9.78	0.41	68	2.37	9.6 E+03	8.6E+07	56.20
AC6o_5%B_0%TCR_22	4.88	0.34	67	2.42	8.2 E+04	1.2E+08	50.34
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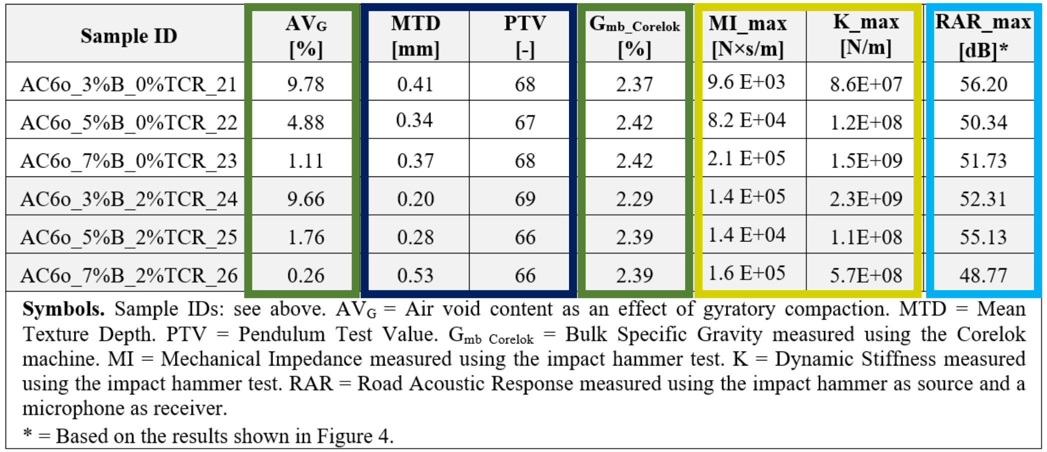
Task 4) Analysis of the results (3/5)

Effect of presence of Treated Crumb Rubber (%TCR= 0 and 2) in samples with percentage of asphalt binder (%B) = 3, 5, 7 (%$B_{optimum}$=5%):

- Volumetric properties (AV_G and $G_{mb\_Corelok}$) undergo a reduction (e.g., AV_G form 9.78% to 9.66%), which is more evident when TCR is used;
- Micro- and macro-texture trends may be explained by the magnitude of drain-down effects combined with partial or total TCR melting;
- If TCR is not used and %B increases, the maximum of the samples stiffness increases (rapid acceleration decrease), while if TCR is used and %B increases, the sample stiffness decreases (slow acceleration decrease);
- Acoustic properties can be improved (Max RAR reduction of about 4 dB) using proper %Bs, which may be different from the optimal %B given by the superpave mix design method (e.g., 3% and 7%, instead of 5%).

Table 3 – Samples' main properties.



Sample ID	**AV_G [%]**	**MTD [mm]**	**PTV [-]**	**$G_{mb\_Corelok}$ [%]**	**MI_max [N×s/m]**	**K_max [N/m]**	**RAR_max [dB]***
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Task 4) Analysis of the results (4/5)

Best linear correlations

- Pearson coefficients related to all the parameters investigated (Table 3) show strong linear correlations (Pearson coefficients: ±0.7 - ±0.8) between:
  - Max MI – Max K →mechanical impedance & dynamic stiffness (obvious);
  - Max MI –Max RAR →mechanical impedance & acoustic response;
  - PTV – Max K → micro-texture & dynamic stiffness.

- Pearson coefficients related to all RAR, K, and MI results (@0-3.2 kHz) show strong linear correlations (Pearson coefficients: ±0.7 - ±0.8) between:
  - RAR (@400-1600 Hz) - K or MI (@0-1600 Hz) → acoustic response @medium-high frequencies & mechanical response @low-to-medium-high frequencies.

Task 4) Analysis of the results (5/5)

Mechanical response of the samples

Acoustic response of the samples

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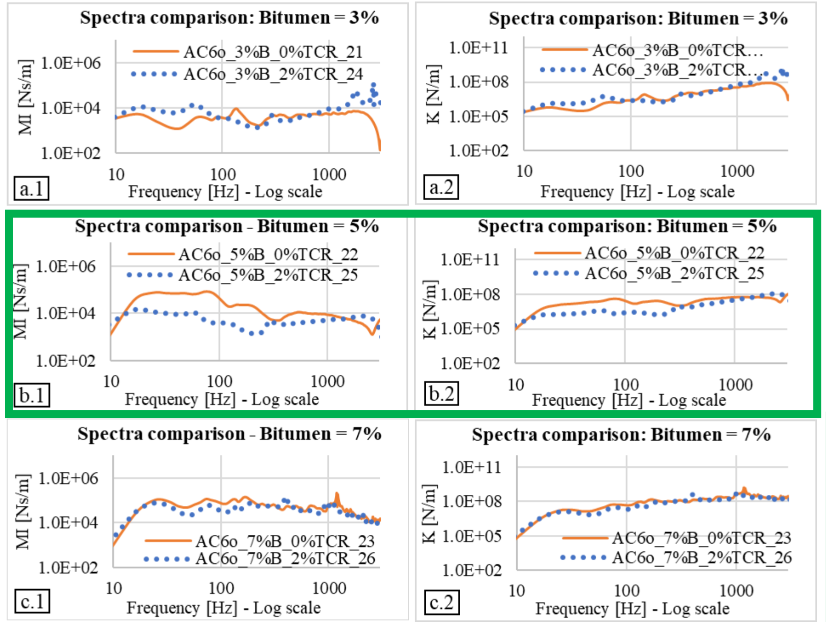

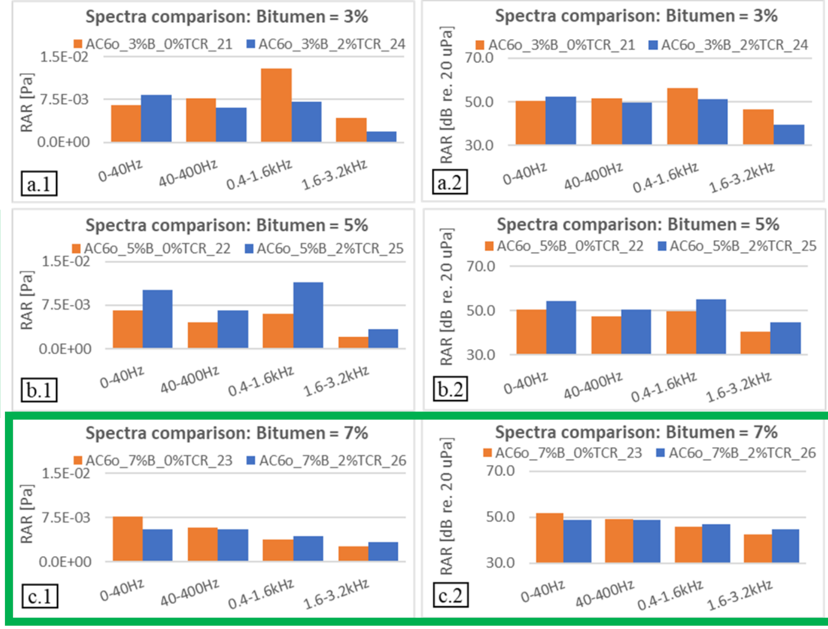

Figure 4 – Road Acoustic Response (RAR) spectra.

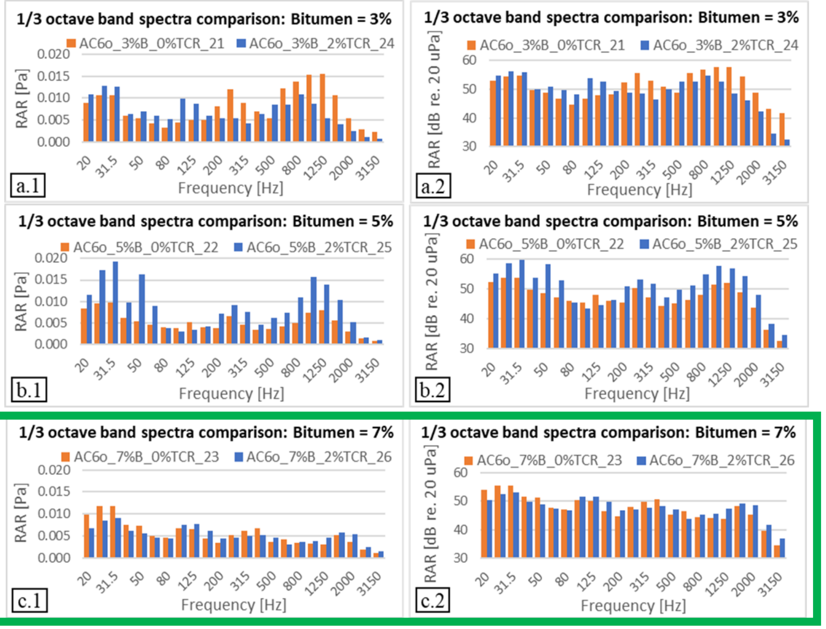

Figure 5 – Road Acoustic Response (RAR) 1/3 octave band spectra.

MI [Ns/m]

K [N/m]

RAR [Pa] Octave bands

RAR [dB] Octave bands

RAR [Pa] 1/3 Octave bands

RAR [dB] 1/3 Octave bands

Conclusions (1/1)

- During the LIFE project "E-VIA", a low-noise Asphalt Concrete (AC) mixture was developed to obtain roads that can be able to reduce traffic noise increase and mitigate the noise due to Electric Vehicles (Evs).
- Two AC mixtures, which contain aggregates with Nominal Maximum Aggregate Size (NMAS) equal to 6 mm, were studied considering three bitumen percentages (that are 3, 5, and 7%) and the addition of 2% of Treated Crumb Rubber (TCR).
- Results suggest that:
  - Volumetric properties (AV_G and $G_{mb\_Corelok}$);
  - Micro- and macro-texture (PTV and MTD);
  - Mechanic properties (K and MI);
  - Acoustic properties (RAR);

  can be positively/negatively affected by: (1) the interaction between bitumen and TCR, and (2) the occurrence of drain-down effects combined with partial or total TCR melting. In general, the TCR allows to reduce the stiffness and the "noise" because it seems to influence the accelerations of the samples after the hammering.
- Good linear correlations (Pearson coefficients) were observed between: (i) Mechanical impedance & Acoustic response; and (ii) Micro-texture & Dynamic stiffness.
- Future works will include: (i) Mixtures improvement; (ii) RAR goodness evaluation; and (iii) Mechanical-Acoustic properties correlation in deep study.

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