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Low-noise and pollutant-reducing asphalt mixtures

Helena Miera-Dominguez[a], Irune Indacoechea-Vega[a]*, Pedro Lastra-González[a], Ronald van Loon[b], Gijsjan van Blokland[c], Daniel Castro-Fresno[a]

[a]*GITECO research group, Universidad de Cantabria, Av. Los Castros 44, 39005 Santander, Spain*
[b]*M+P Consulting Engineers, Visserstraat 50, Aalsmeer 1431GJ, The Netherlands*
[c]*Cooperating with M+P Consulting Engineers, Visserstraat 50, Aalsmeer 1431GJ, The Netherlands*

Abstract

Transport is the main cause of noise and air pollution in cities, as well as the main source of non-exhaust pollutants, like tire and road wear particles. To reduce these pollutants, an integrated solution is being developed for both urban and peri-urban roads. Two road surfaces with improved functional properties are being designed based on the different technical requirements that are needed in each case due to the different types of vehicles, speeds and runoff collection management. The main objective in the design of the new mixtures is to optimize noise reduction without compromising their rolling resistance and good mechanical performance. Additionally, the use of photocatalytic materials in the asphalt mixtures and their ability to collect and store microplastics within their pore network are also evaluated.

Keywords: Asphalt mixtures; noise absorption; microplastics; photocatalytic

1. Introduction

As one of the biggest sources of noise and pollutant emissions in cities, road transportation is a major environmental health problem in Europe. According to the European Environmental Agency (EEA), more than 12.000 and 550.220 yearly premature deaths are related to noise and air pollution long-term exposure respectively, due to the increase in health problems such as sleep disturbance, stress and cardiovascular and respiratory diseases, among others.

* Corresponding author. Tel.: +34-942-201-756.
E-mail address: indacoecheai@unican.es

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To address these worrying issues, targets have been proposed by the European Commission (EC) through different directives and programmes. Thus, the EU's 7th Environment Action Programme set the objective to significantly decrease noise pollution by adapting EU noise policy and implementing measures to reduce noise at source. Concerning air pollution and based on the Green Deal target of becoming the world's first net-zero emissions continent by 2050, a proposal for reaching zero emissions from new cars by 2035 was launched by the EC in July 2021.

With the end of combustion internal engines, both noise and pollutant emissions will be reduced, especially the latter due to the zero exhaust emissions generated by electric vehicles. However, non-exhaust emissions (NEE) also generated by cars have been found to exceed the exhaust emissions as far as particulate matter is concerned. Thus, tires, brakes and road surfaces jointly produced 5.8 g of NEE per vehicle and kilometre, a figure 1289 times higher than that related to exhaust emissions (GreenCarsCongress 2020). This harmful particle matter from NEE is a growing environmental problem since it significantly contributes to the flow of microplastics into the ocean, being estimated that 5% to 30% of the microplastics ended up in the ocean are related to tire and road wear (Jan Kole et al. 2017; Sommer et al. 2018). Regarding noise, although the rise in electric vehicles will favour to some extent the noise levels, the major traffic noise source is not related to the car's engine but to the tire/road interface what will remain a challenge.

Facing these pressing issues and to help EC targets, the Noise and Emissions MOnitoring and Radical Mitigation (NEMO) project seeks to reduce emissions and noise from road transport through two different approaches. The first one comprises an autonomous remote sensing system to identify noisy and polluting vehicles so this information can be made available to tolling or access systems. As for the second approach, mitigation solutions are being investigated to reduce both noise and pollutants from the source. The mitigation part of NEMO project is being coordinated by GITECO with the participation of M+P company and Université Gustave-Eiffel (UGE). In it, specific low-noise road surfaces are proposed for urban and peri-urban roads based on the different technical requirements that are needed in each case due to the different types of vehicles, speeds and runoff collection management. In this sense, for peri-urban roads, the main priority is the mitigation of microplastics coming from tires and road wear since due to the lack of water collection and treatment systems in these zones, these contaminants are uncontrolled, so the possibility of using porous asphalt mixtures for microplastics buffering is explored. In addition, another target will be to obtain lower rolling resistance that will not only supress CO2 but also related exhaust-emissions in both types of roads.

2. Materials and methods

2.1. Low-noise asphalt mixtures

To maximize noise reduction, the technical requirements that the road surface needs to accomplish depends on the fleet composition and traffic conditions. Because of this, in this work, specific formulas for urban and peri-urban areas are defined. The materials used are a commercial polymer-modified bitumen (PMB 45/80-65), ophite in the coarse fraction, and limestone in the fine and filler fractions.

Additionally, a synthetic fibre and hydrated lime were used to improve the cohesion of the peri-urban mixture. The fibre selected was aramid pulp (Pulp) from Teijin company which has small branches and fibrillary surfaces that offers large friction properties and can easily adhere to the binder.

After selecting the materials, the design of the asphalt mixtures was carried out based on previous researches on tire/road interaction models to optimize texture spectrum, surface flow resistance and porous structure for different fleet compositions and traffic conditions (Blokland 2010; GmbH 2001; Kropp 2006; Ministry of Transport 2008). These models take the dynamic process in the contact area between tire and road into account. From this the excitation forces on the tire structure are found that are eventually coupled to tire noise radiation through a statistical model. Added to this is the model that predicts the effect of a partly noise absorbing road surface on the horn amplification between tire and road geometry. By extending the tire/road interaction modelling applied for the acoustic design, the mechanical loss in the rolling tire can also be calculated. Therefore, through a design optimization process, the optimal combination of high noise reduction and low rolling resistance can be defined. Apart from minimizing noise and rolling resistance, the new formulations have to ensure a good mechanical performance according to EN standards. Finally, an Accelerated Pavement Test (APT) will be conducted on the pavement fatigue carrousel of UGE to assess the two asphalt mixtures long-term performance.

The experimental work plans followed for the design of the urban and peri-urban mixtures are presented in Fig. 1. For the urban mixture, different formulations varying the particle size distribution, maximum aggregate size, void and bitumen contents were tested. The starting formula was a dense mixture (AC) with a higher than usual voids content and with a conventional 50/70 penetration grade bitumen. However, due to the high plastic deformations, PMB was finally selected due to its better mechanical performance. On the other hand, for the peri-urban mixtures, different variants of two-layer Porous Asphalt mixtures (2L-PA) have been tested, modifying both the top, due to its direct interaction with the tire, and bottom layer, due to the effect that the void content and thickness of this layer has on the acoustic absorption.

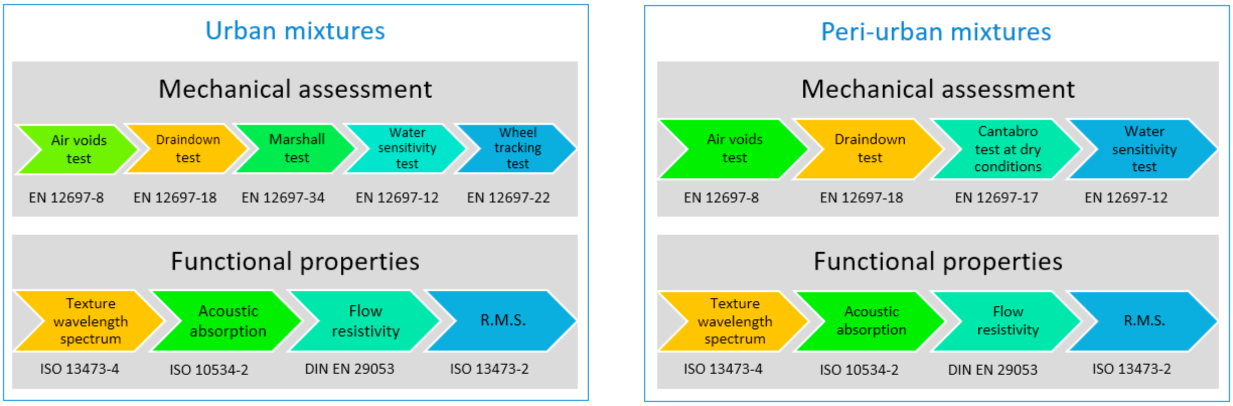

Fig. 1. Experimental work plan for urban and peri-urban mixtures

The target values for the functional properties according to the tire/road interaction models are shown in Table 1 and Fig. 2. The texture and the air voids play a key role in the functional performance of the mixture, and their impact is opposite depending on the analysed property, so it is required to find a balance in order to achieve the requirements concerning noise emissions and rolling resistance, ensuring the friction level and the mechanical performance. It is important to manage the conflict targets between noise emissions (it improves with low macro texture and porous structure), rolling resistance (low macro texture), and friction (it requires high micro and macro texture). The design of both mixtures, urban and peri-urban, was carried out according to EN12697 standards. Different tests (Fig. 1) were conducted to assess the mechanical performance, such as void content test and water sensitivity test.

Table 1. Functional properties requirements

	Urban	Peri-urban
Texture wavelength spectrum	Fig. 2 (left)	Fig. 2 (right)
Texture level (mm r.m.s.)	≤ 0,6	≤ 0,7
Flow resistivity (Pa s/m)	< 8000	< 4000
Acoustic absorption	-	Frequency of max. absorption between 800 and 1000 Hz Height of peak ≥ 60% Width at 30% absorption ≥ 40% of peak frequency

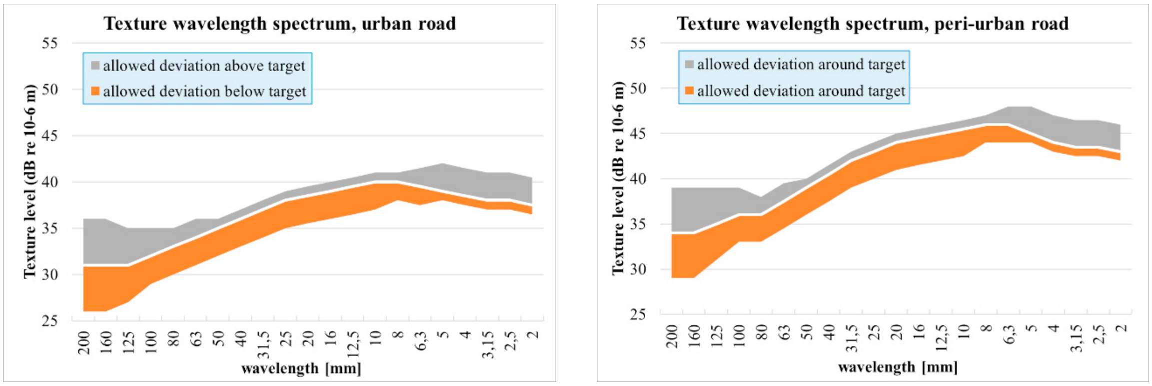

Fig. 2. Targeted texture wavelength spectrum. Urban road (left); Peri-urban road (right)

To achieve these targets, for urban mixtures, the focus of interest was on the variation of the maximum aggregate size that allowed smoothing the texture and on the percentage of voids necessary to obtain a balance between flow resistivity and texture. Table 2 shows a selection of the tested formulations.

Table 2. Urban mixture designs.

Name	Max size of aggregates	Thickness (cm)	Binder content (%)
U1	8 mm	3	5.4
U2	8 mm	2	5.6
U3	6 mm	2	5.8
U4	6 mm	2	5.1
U5	4 mm	2	4.8
U6	4 mm	2	5.3

In the case of the peri-urban mixtures, to comply with the requirements, the void content, maximum aggregate size and layer thickness were analysed. The maximum aggregate size is related to the surface texture, the void content to the absorption coefficient and the layer thickness to the frequency at which the absorption peak occurs. A selection of the formulations tested so far is shown in Table 3.

Table 3. Peri-urban mixture designs.

Name	Upper layer	Bottom layer	Thickness (cm)	Fibres
PU1	PA8	PA11	2 + 3	PULP
PU2	PA6	PA11	2 + 3	PULP
PU3	PA6	PA16	2 + 4	PULP
PU4	PA6	PA22	2 + 5	PULP
PU5	PA6-2	PA11-2	2 + 2	PULP

2.2. Photocatalytic materials

To help reduce air pollution by NOx in urban areas, the use of photocatalytic materials in the asphalt mixtures is also evaluated. Photocatalytic pavements have received considerable attention due to the large area available and the vicinity of the road surface to the exhaust gases released by vehicles. Three main techniques are currently explored to produce photocatalytic asphalt mixtures: (1) spraying of aqueous solutions of semiconductors over the road surface, (2) bulk incorporation into the aggregate fraction (during the mixing process) and (3) bitumen modification.

Thus, for the selection of the most adequate material and application technique, two photocatalytic materials were tested. The first one (PM-1) is sprayed on while the other (PM-2) is incorporated into the mixture. The use of the PM-

1 was carried out according to the instructions provided by the manufacturer, while PM-2 was used in a similar way to the described in previous research articles carried out by the University of Minho, Portugal (Carneiro et al. 2013; I. Rocha Segundo et al. 2018; I. G. da Rocha Segundo et al. 2019). This means that, for this study, the dosage of 180 g/m^2 was used for PM-1, while 3% by bitumen weight was used for PM-2.

For evaluating the photocatalytic efficiency of the produced mixtures, a laboratory test was carried out based on measuring the degradation of Rhodamine B (RhB) as a function of time irradiation with an artificial sunlight, such as in previous researches (Carneiro et al. 2013; I. Rocha Segundo et al. 2018; I. G. da Rocha Segundo et al. 2019).

Different tests (three replicates) have been carried out including blank, reference (REF) and experimental samples (PM-1 and PM-2). The blank sample consisting in a RhB solution alone, the reference samples immersing asphalt specimens (without photocatalytic material) in RhB solutions and experimental samples immersing the asphalt specimens PM-1 and PM-2 (with photocatalytic material) in the RhB solution. In addition, the capacity of the different samples to abate nitrogen oxides was also evaluated using the ISO 22197-1 standard (three replicates of REF, PM-1 and PM-2).

2.3. Microplastics

The ability to collect and store microplastics of Porous Asphalt (PA) mixtures is being evaluated. The proposed methodology comprises several stages, from the laboratory to the field. The first step was the definition of a protocol for the sampling, detection and quantification of microplastics present inside the PA. The second step involves a comparative assessment of the capacity of AC, PA and 2LPA mixtures to retain microplastics in their voids or surface texture, including the impact of rainfall events. Finally, core samples will be collected at different cycles during the APT at UGE to evaluate the amount of microplastics retained at real scale.

In relation to the protocol definition, different alternatives have been evaluated, so far, for detection and quantification of microplastics, including Micro-Computed tomography, Scanning Electron Microscopy (SEM) and thermogravimetric analyser (TGA). As for the collection of microplastics, some devices were found at the literature for dust collection. One of them was a sampler for PM10 particles developed by Amato (Amato et al. 2009). Although its usability in PA mixtures is uncertain it was considered the best adapted to this study specific requirements.

An ad-hoc equipment is being used for the generation of tire wear on the surface of the different asphalt mixtures. The dispersed particles are then collected with the sampler and its amount, on the surface and within the pore network is weighted and analysed.

3. Results and discussion

3.1. Low-noise asphalt mixture

The mechanical performance in terms of void content, water sensitivity and plastic deformation of the urban mixtures (U1 to U6) is shown in Fig. 3, while Fig. 4 presents the functional properties. All the mixes present a good mechanical behaviour, being especially good the results obtained in the wheel tracking test.

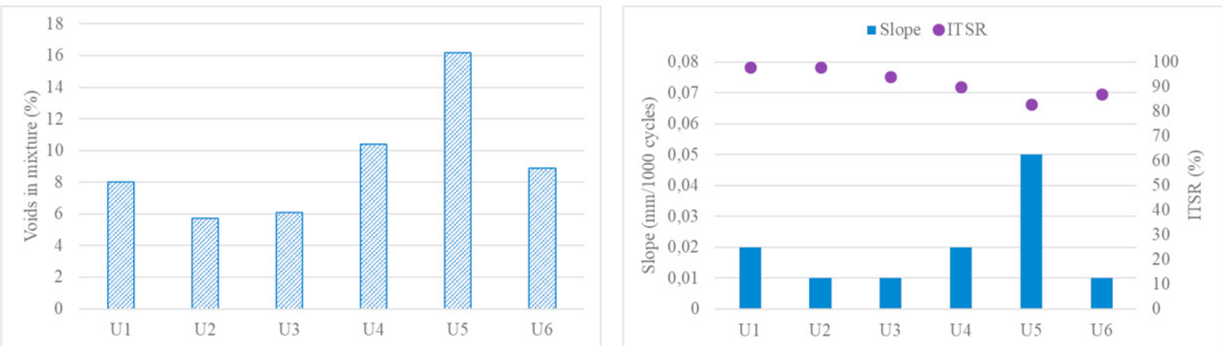

Fig. 3. Results of mechanical performance of urban mixtures

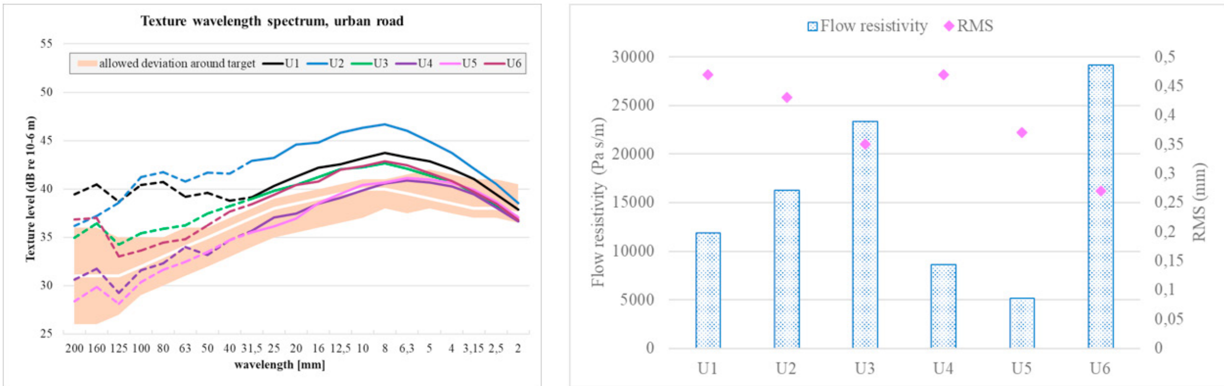

Fig. 4. Results of functional properties for urban mixtures

From the 6 mixtures, only U5, with a maximum aggregate size of 4mm, fulfilled all functional targets. For higher aggregate sizes, the desired balance between the texture and flow resistivity was unachievable.

As for the peri-urban mixtures, the research is ongoing. The results concerning the mechanical performance of the top layers (PU1 to PU5) are shown in Fig. 5, presenting all of them good mechanical performance, highlighting the results obtained in particle loss despite the high void content.

Preliminary functional results of PU1 to PU5 can be checked in Fig. 6. On the one hand, thickness of the samples is inversely related to the frequency of maximal absorption, that is why PU-5 fulfils the requirement in frequency of the peak absorption. A high void content is better to achieve a higher level of absorption, while is a drawback in the achievement of the texture target. In contrast, flow resistivity does not seem to be a limiting property for this type of mixtures, since all values have been lower than 400 Pa s/m.

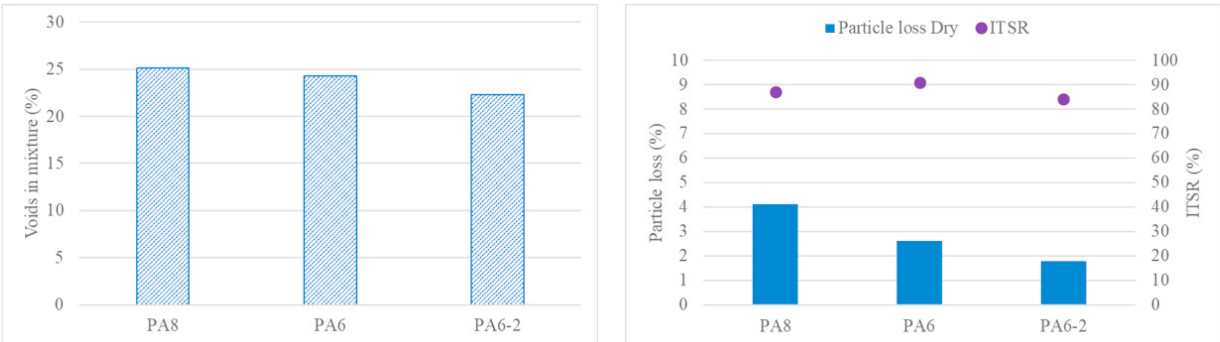

Fig. 5. Results of mechanical properties for peri-urban mixtures

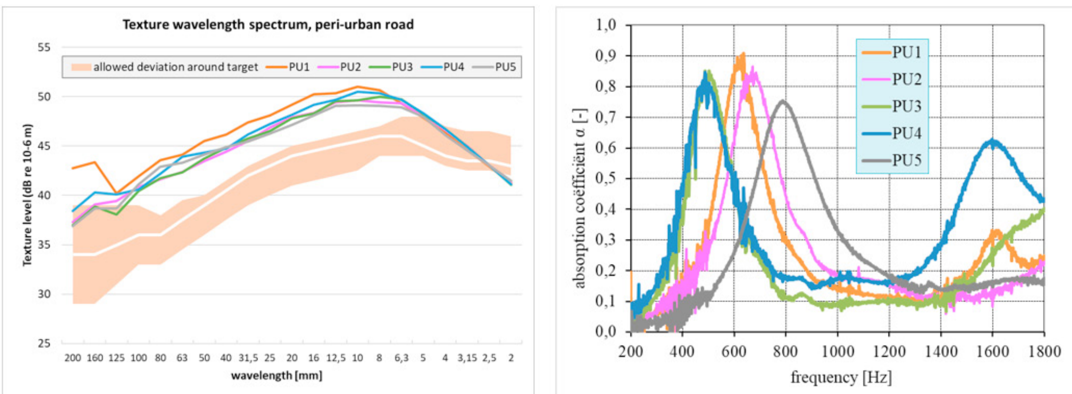

Fig. 6. Results of functional properties for peri-urban mixtures

3.2. Photocatalytic materials

The results concerning the photocatalytic efficiency of the different asphalt materials are shown in Fig. 7. Based on the results, only the semiconductor material sprayed on the surface of the asphalt mixture (PM-1) presents a significant photocatalytic activity resulting in RhB degradation or NOx abatement depending on the test used. It is worth highlighting the consistency obtained between the two tests employed to measure the asphalt mixtures photocatalytic efficiency.

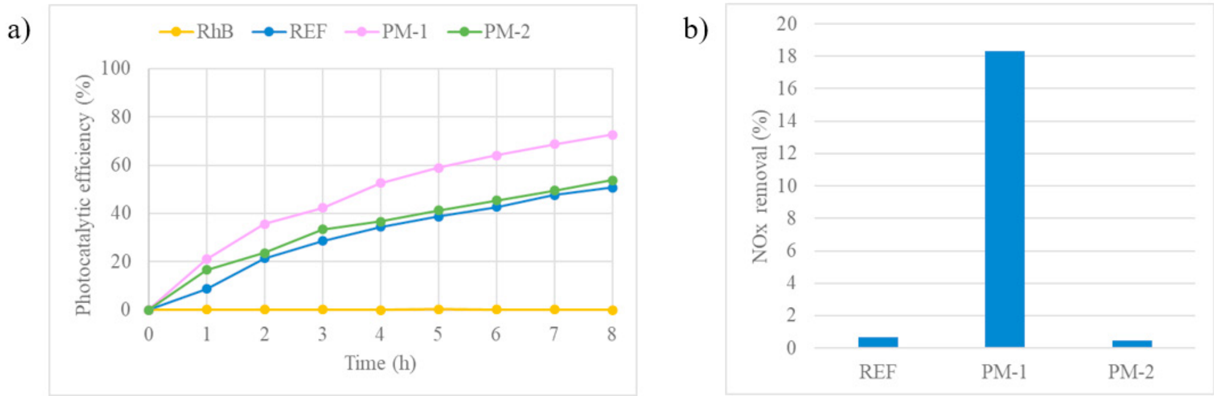

Fig. 7. (a) photocatalytic efficiency based on RhB degradation; (b) NOx removal of the ISO test.

In view of these results, it was concluded that the incorporation of photocatalytic material into the mixture is not efficient. This is probably due to the low contact between the pollutant and the photocatalytic material when the latter is distributed within the asphalt mixture and coated by the bitumen. For the oxidation reaction to take place, physical contact between the semiconductor, the pollutant, water and oxygen is needed. Thus, the photocatalytic material inside the mixture or covered by the bitumen could be considered as lost material. On the other hand, despite the good photocatalytic efficiency of PM-1, caution should be taken and the long-term durability of the slurry needs to be evaluated. In this sense, the photocatalytic efficiency of core samples at the fatigue carrousel of UGE will be evaluated at different cycles during the test.

3.3. Ability of PA mixtures to store/retain microplastics

This research is ongoing. Samples of asphalt mixtures containing grounded rubber in the voids have been analysed by Micro-Computed tomography. The noise generated due to the high density of the aggregates comparing to the other two components makes it impossible to distinguish them (bitumen and rubber), so this method has been discarded. On the other hand, ground rubber from End-of-life tires mixed with bitumen (with and without PmB) and limestone filler have been analysed by SEM and TGA. The images obtained with SEM allows the identification of the rubber particles, being possible to quantify the amount and size of these particles in the sample. However, the procedure is time-consuming and the amount of sample analysed is very small what increases the number of analyses to be done. In addition, the tests done so far involve grounded rubber, so the validation with real samples, in which the morphology of the rubber will likely change, is needed. According to the results obtained with the TGA, the estimation of the mass of rubber in a sample seems feasible. However, there is some uncertainty in the results due to the partly overlap between the degradation curves of rubber and bitumen. In any case, in field samples the concentration of bitumen with respect to rubber is expected to be low and, therefore, the error should be minimal.

Finally, the collection of microplastics at the laboratory and the field will be carried out with the PM10 sampler with some modifications to make possible to collect not only PM10 but all particles up to 1mm.

4. Conclusions

This article presents the objectives and preliminary results of the asphalt pavement solutions proposed by NEMO to reduce noise, exhaust and non-exhaust emissions. The main goal of this study is the development of two low-noise asphalt mixtures, one specifically designed for urban and the other for peri-urban roads. In these mixtures, the use of photocatalytic materials to provide them with the ability to reduce exhaust emissions is evaluated. Finally, the capacity of the peri-urban road to store microplastics and reduce their dispersion is also estimated. Thus, various experimental mixtures modified with HL and Pulp fibres, with different particles sizes, voids and particle size distributions were tested in terms of their mechanical and functional performance. The main findings are summarized below:

- A urban mixture (U5) with noise-reducing properties and similar mechanical performance than the reference mixture was developed. On the other hand, the used of PMB, fibres and HL are essential in the formulation of the peri-urban mixture, as it allows a higher void content without compromising mechanical performance.
- The use of photocatalytic materials incorporated into the mixture is inefficient, so their use should be on the surface. However, it would be necessary to study the durability of these surface materials over time due to the weather conditions and the wear suffered by passing vehicles, as well as the skid resistance if it is used on the lane.
- The assessment of the ability of PAs to retain microplastics is still ongoing. From the analytical methods used for the detection and quantification of microplastics, SEM and TGA seem feasible even though they present both advantages and drawbacks. Although further testing is needed, TGA has been found to be the most promising technology. As for the collection of microplastics from inside the PA pore network, the aspiration way seems to be the most suitable.

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