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STUDY OF A ROAD TEST TRACK WITH AND WITHOUT CRUMB RUBBER. SOLUTIONS FOR NOISE POLLUTION

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Abstract

End-of-life tires are waste materials that pollute landscapes when they are disposed of in tire dumps. However, its life cycle is not finished when they are scrapped. The rubber of end-of-life tires could be used for new purposes as construction material in road rehabilitation. A gap-graded mix characterization was carried out in this work by means of laboratory and field performance tests. The mixture has a high content of crumb rubber (CR) by weight of bitumen. Crumb Rubber was added to the binder by a wet process. Close proximity methodology has been used in *in-situ* characterization of the acoustic behaviour. Moreover, absorption and dynamic stiffness tests were also conducted to determine the noise generation mechanisms involved in noise. According to the results achieved, a reduction of the noise emitted by the tire/pavement interaction could be accomplished with the construction of roads with mixture with CR added by a wet process. In addition, this would result in a decrease of the amount of waste tires in landfills.

Key words: crumb rubber, end-of-life tire, noise pollution, tire/road noise

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1. Introduction

Noise is one of the forms of pollution that can be found in cities, whatever their size. The importance of this pollution comes from its ability to alter the natural conditions of the environment. It could cause physiological and psychological disturbance as auditory effects and psychiatric disorders on citizens. An average of 43 % of the population in Europe is exposed to noise levels greater than 55 dB(A), meanwhile 20 % are subjected to more than 65 dB(A) (Thompson et al., 2004; Vallet, 2001). For most people, the noise which has the greatest impact on their environment comes from transport (European Commission, 1996).

Among different means of transport, traffic noise is, by far, the most important noise source in both urban and suburban settings of all developed countries; road traffic noise disturbs more people than all other forms of noise nuisance combined (García, 2001). Furthermore, within the noise produced by moving vehicles, tire/road noise is the predominant noise source for cars at speeds above 40 km/h.

On the other hand, each year, Europe generates 3.3 million tonnes of end-of-life (EOL) tires that contaminate the environment. Used tires are recyclable materials, thus, its use could reduce waste disposal in landfills. The use of crumb rubber from recycled tires in pavement construction and rehabilitation has grown in recent years all over the world (Chiu, 2008; Paje et al., 2010; Pasquini et al., 2010). In Spain, a National Plan promotes the use of materials from end-of-life tires recycling, to ensure that 55 % of rubber is used for recycling purposes by 2015 (45 % for bituminous mixtures) (Spanish law, 2009). Crumb rubber could be incorporate in asphalt paving mixes by both wet and dry process. In wet process the rubber is added to bitumen as additive, then, the binder modified is mixed with aggregates.

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In dry process, crumb rubber is a part of the aggregate in the mix, replacing a portion of fine aggregates, before the addition of the bitumen (Paje et al., 2013). Besides reusing a waste material like rubber from waste tires, the use of bituminous mixes with crumb rubber shows an improvement in the physical, chemical and performance properties of asphalt pavements. In addition, contribute to reduce the thickness of pavement overlays, thus it is more cost-effective (Mashaan et al., 2013a, 2013b; Moreno et al., 2011).

In recent years, several studies have been carried out on the traffic noise in order to achieve a deeper knowledge of the volume of population affected, and the sound levels generated by the traffic. Some of them use noise prediction models or Neural Network Approach (Ramírez et al., 2013; Kumar et al., 2013) meanwhile others use measurements performed in real conditions, as those done according to Close proximity methodology (CPX) (Licitra et al., 2014; Miró et al., 2009).

This paper aims to study the effect of the crumb rubber added in a bituminous mixture on tire/road noise. The high content of crumb rubber modifies the binder (20 % by weight of binder, around 1.5 % of the total weight of the mix) and its acoustic performance properties. Two test track sections of a gap-graded bituminous mix for road surfacing were laid. The first one was made with a conventional binder (reference section) meanwhile the second one was designed with a crumb rubber modified binder (CRMB section).

This study consisted on the following steps. First, the tire/road noise levels were recorded at the sections studied three years after its construction. Then, complementary studies were conducted in laboratory and *in-situ* conditions (absorption and dynamic stiffness). Finally, environmental considerations about the use of crumb rubber modified binder were made.

Close proximity (CPX) sound levels of the reference and CRMB mixtures will be compared and related with dynamic stiffness and sound absorption tests, in order to determine the major sound generation mechanisms and the influence of crumb rubber from waste tires. The goal is to assess if CRMB mixture, with crumb rubber in high content by wet process, could contribute to mitigate noise pollution.

2. Bituminous mixtures studied

The test track section studied is a two-lane way located on the road CM-3102 (Ciudad Real, Spain), between posts KP 1+000 and KP 2+600 (see Fig. 1). A wearing course of a gap-graded mixture, containing crumb rubber (CRMB) in a percentage of 20 % by weight of bitumen (air void content around 6 %), was laid with a thickness of around 3 cm. CR was incorporated by wet process. The CRMB track section was about 1600 m long, but in the middle of it, a 150 m long reference surface course was laid. This reference surface was designed with the same gap-graded mixture, but without crumb rubber added to bitumen, that is, conventional penetration grade bitumen was employed. The global position coordinates (GPS) of the test track registered by the measuring instruments of the test vehicle during field measurements are shown in Fig. 1. The mixes studied are type BBTM according to standard EN-13108-2, and they had three years old when tests were performed. Their main characteristics of the mixes studied are presented in Table 1.

The samples used in the sound absorption coefficient measurement were taken from the road pavement at different locations by a special drill, and brought to the laboratory. Samples were covered laterally with a thin film of Teflon to eliminate the air gap between both, the core sample and the inner surface of the tube. Acoustic characteristics of the samples studied were achieved by means of the 4206 Bruel&Kjaer impedance tube (Paje et al., 2008). Fig. 2 shows a detail of the core sample extraction.

It is known that the addition of rubber could improve the temperature susceptibility and the rutting resistance of the bituminous mixtures in hot climates, and could provide better low temperature performance (Behl et al., 2013). However, the addition of rubber powder not only improves the mechanical characteristics of the pavements, but also could improve its environmental behaviour if less tire/road noise is produced on it.

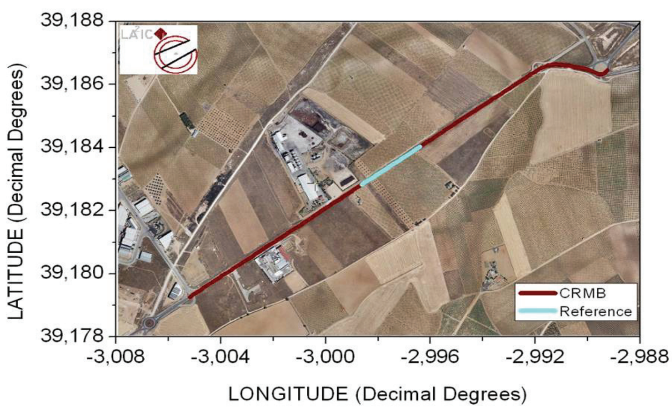

Fig. 1. Location with GPS coordinates of the test track with (CRMB) and without crumb rubber from EOL tires

Table 1. Characteristics of the mixtures studied

Section	*Mixture*	*Binder*	*% Crumb rubber by bitumen weight*	*% bitumen by mix weight*
CRMB	BBTM 11A	CR modified binder 35/50	20	8.3
Reference	BBTM 11A	Conventional binder 50/70	0	5.2

Fig. 2. Detail of the core sample extraction, asphalt pavement and core samples extracted

3. Evaluation methods

The study of the test track section has been done by means of several methodologies. The aim is to study the noise levels by means of the CPX measurement technique and assess if the CRMB mixture could mitigate noise pollution. On the other hand dynamic stiffness and absorption coefficient are also studied in order to achieve a deeper knowledge of the noise generation mechanisms related.

3.1. Close proximity methodology

Continuous tire/road close proximity measurements (CPX) were carried out. In this sense, Testing equipment and monitoring techniques were used for the field acoustical characterization. The equipment used is the Tiresonic Mk4-LA^{2}IC, a trailer made up of a semi-anechoic chamber wich isolates tire/road sound from the external traffic noise or wind noise (Fig. 3) (Paje et al., 2009). Inside semi-anechoic chamber, a reference tire and two microphones (rear and front) are located at a specific distance.

During measurements, the energetic averaged A-weighted sound pressure level generated by the tire/road interaction was evaluated through integration for a period of time of 0.2 seconds. The signals of the two microphones were averaged arithmetically. The reference speed selected for the close proximity measurements was 50 km/h.

Close proximity sound levels (L_{CPtr}) from the tire/road interaction were analyzed in third octave bands between 300 Hz and 5 kHz. Also, a study of the continuous evolution of L_{CPtr} with speed was carried out, and the sounds levels along the trajectory were correlated with their GPS coordinates.

3.2. Dynamic stiffness

Dynamic stiffness S can be expressed in terms of complex numbers between the force vector (F) and displacement vector (d) of a tested surface (Eq. 1):

$$S = \frac{F}{d} \tag{1}$$

To obtain the dynamic stiffness of pavements in *in-situ* conditions (Vazquez et al., 2013), a new set-up has been employed. The measurement equipment has a vibration exciter, an amplifier and an impedance head. A multi-analyzer system was used to carry out the measurements. A laptop controls the tests and records the results. The vibration exciter is placed upside down, facing the surface to be tested.

The impedance head is in contact with the ground by means of a circular plate fixed to the surface. The experimental set-up allows us to measure the *driving-point* dynamic stiffness, since the displacement of the tested surface is measured at the point of application of the driving force. Fig. 4 shows the experimental set-up during dynamic stiffness tests on the road with crumb rubber from EOL tires.

The equipment records the results of force and motion of the surface during dynamic tests and the multi-analyzer performs the Fast Fourier Transform (FFT) of the incoming signals. The results of force and motion are expressed in function of the excitation frequency. The test track sections were tested by application of a swept signal generated by the dynamic exciter, with a spectrum resolution of a line per Hertz.

3.3. Sound absorption

To evaluate the acoustic characteristics of compacted core samples, an impedance tube was employed. The impedance tube consists of a 100 mm inner diameter with a loudspeaker mounted at one end. The impedance tube allowed measurements between 50 Hz and 1600 Hz. Two condenser microphones placed along the tube at fixed locations were used to simultaneously measure the sound wave pressure. A multi-analyzer system was used to obtain the normal incidence acoustic properties by calculating the two-microphone transfer function between the input signal of the loudspeaker and the microphone output at each of the two measurement positions located near the sample (Luong et al., 2014; Paje, 2013).

Sound absorption was determined over the extended frequency range with a frequency resolution of 1 Hz. Fig. 5 shows the impedance tube and the core samples extracted from CM-3102 to evaluate their acoustic characteristics.

Fig. 3. Semi-anechoic chamber for the close proximity measurements

Fig. 4. Dynamic stiffness tests on the experimental test track with crumb rubber

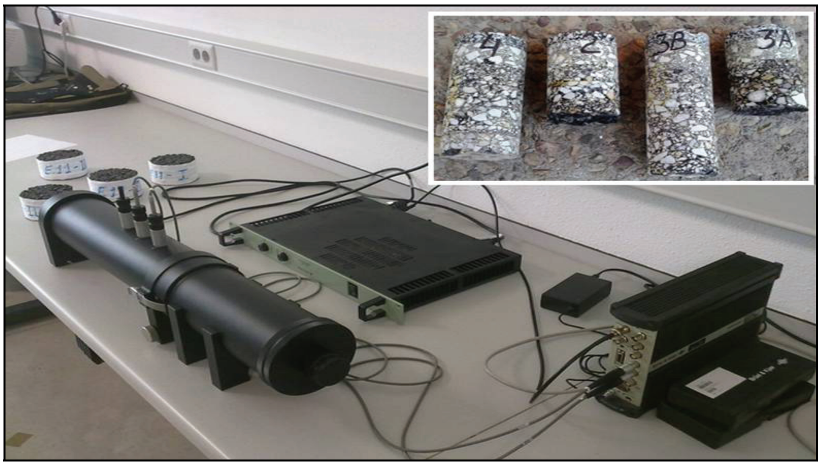

Fig. 5. Impedance tube and core samples from Crumb Rubber Modified Binder

4. Analysis of measurements and discussion

The CM-3102 is a regional road between the towns of Tomelloso and Socuellamos, in Ciudad Real province (Spain). Wearing course was rehabilitated three years after field and laboratory measurements. The results with a pavement BBTM 11A, with high amounts of crumb rubber added by wet process (CRMB) and without crumb rubber (reference) are presented as follows.

4.1. Close proximity sound levels

Close proximity tests were carried out on CM-3102 road, with the Tiresonic Mk4-LA^{2}IC. The aim of these measurements is to study the influence of the crumb rubber (20 % by weight of binder) on tire/road noise and comparing these L_{CPtr} (dB(A)) levels with those obtained from a reference section with conventional binder, that is, without crumb rubber.

Since tire/road noise depends on the speed according to the expression (Eq. 2):

$$L_{CPtr} = A + B\log(V) \qquad (2)$$

L_{CPtr} levels were measured upon continuously increasing speed from 25 km/h to 80 km/h; approximately 30 km/h above and below the reference speed (50 km/h) in order to ensure a good relationship between vehicle speed and tire/road noise. The speed constant B was obtained from the slope of the logarithmic regression of the sound pressure level and speed.

The coefficients of the liner regression of the global sound levels L_{CPtr} and speed are B = 35.4 dB(A) and A = 28.1 dB(A) for the experimental test track (CRMB). Fig. 6 shows the relationship between sound levels and vehicle speed. L_{CPtr} sound levels were performed at 50 km/h. They were corrected for speed variation around v_{ref} = 50 km/h (Eq. 3).

$$L_{Corr}(t) = L_{meas}(t) - B\log\left(\frac{V(t)}{V_{ref}}\right) \qquad (3)$$

The tire/road sound levels can change by variations of the temperature of the surface layer (Bueno et al., 2011). However, the temperature variation between tests conducted on reference and CRMB sections are insignificant and therefore this variation was not been taken into account.

Evolution of sound levels measured in close proximity at 50 km/h can be observed graphically in Fig. 7. Despite the difficulty of taking exactly the same route in the different runs, repeatability of the L_{CPtr} levels was assessed along the test sections, with small differences between two consecutive passes. On the other hand, abnormal noise levels at around 60 m were measured in each of the passes carried out. These levels have not been taken into account since a detailed survey of the area revealed that atypical levels are due to the existence of an access to the test track section from adjacent farmland. Access of farm vehicles on the road can change its surface, producing a localized distortion of the recorded noise levels (Piotr, 2013; Paje, 2013). This effect and a photography of the location of this inhomogeneity of the wearing course in CM-3102 are shown in Fig. 8.

From L_{CPtr}, the main values of the close proximity tire/road noise levels at reference speed of 50 km/h, from CRMB and reference sections are shown in Table 2. These results indicate a better acoustical behavior, in around 1 dB(A), at speed of 50 km/h, of the CRMB mixture due to the high content of crumb rubber. The tests were conducted continuously, the same day and therefore with the same temperature and atmospheric conditions. From CPX measurements it is possible to achieve the sound spectra of the test track sections studied.

The sound spectrum may provide information on the mechanisms involved in the tire/road noise generation: below 1 kHz impact and vibration mechanisms predominate while above 1kHz aerodynamic mechanisms have more weight in the sound emission generation (Paje et al., 2007; Sandberg et al., 2002).

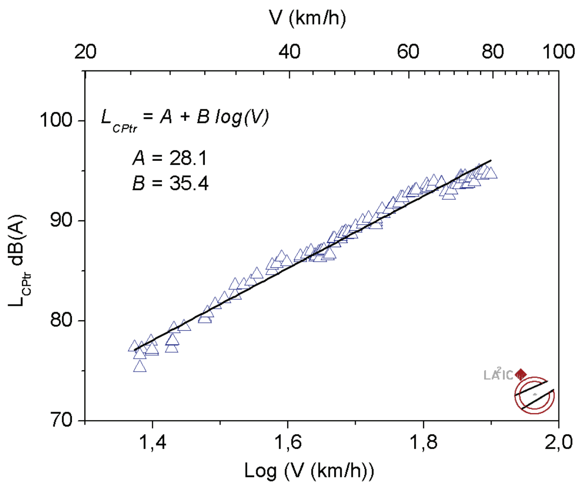

Fig. 6. L_{CPtr} levels as a function of vehicle speed (CRMB)

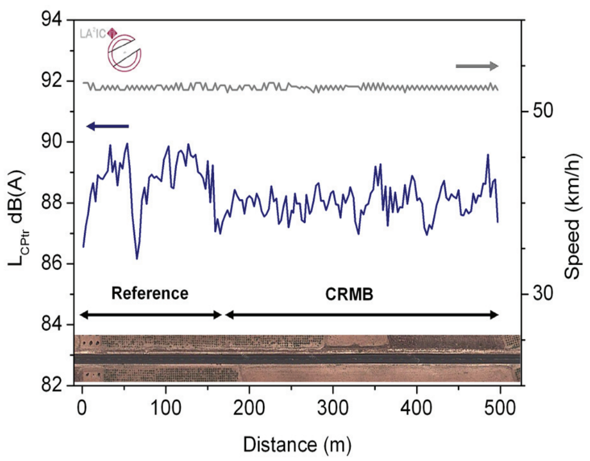

Fig. 7. Vehicle speed and Average L_{CPtr} after speed corrections

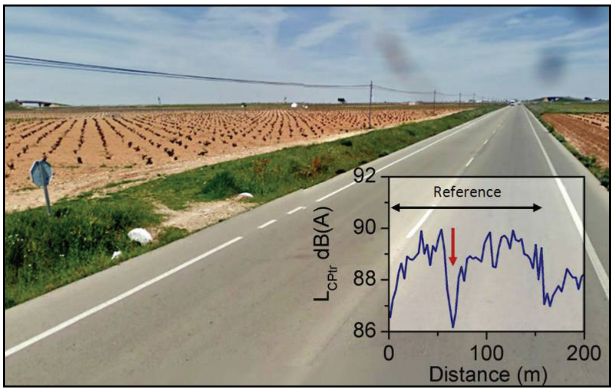

Fig. 8. Access from adjacent farmland to reference section and L_{CPtr} levels

Table 2. Averaged L_{CPtr} from CRMB and reference sections

Section	*Speed (km/h)*	*Test track section length(m)*	*L_{CPtr} dB(A)*
CRMB	50	131	88.1
Reference	50	443	89.0

In this study, the close proximity noise emissions from tire/road interaction, rolling at the reference speed, were analyzed in the frequency range of significance in one-third octave bands.

Fig. 9 shows the sound spectra between 300 Hz and 5 kHz, frequency range where the tire/road noise is predominant. It can be observed that the pavement with a high content of crumb rubber presents significantly lower sound levels at frequencies between 800 Hz and 2 kHz. On the other hand, below 800 Hz, where the bands have less influence on the global close proximity noise, the sound spectrum for the CRMB section presents a higher noise levels.

4.2. Dynamic stiffness measurements

Dynamic stiffness measurements were performed in order to find out if there is a relationship between tire/road noise mitigation due to crumb rubber, and rigidity of the mixtures. Tests were carried out in *in-situ* conditions. The impedance head was fixed to the pavement surface, in order to achieve a good correlation between force and motion signals. The coherence function was close to unity between the frequencies studied (above 0.98), thus, a good relationship between the incoming signals was obtained. The dynamic stiffness spectra and the coherence function of the test track sections tested are shown in Fig. 10.

As shown in Fig. 10, dynamic stiffness is greater with increasing frequency, for both materials: reference and CRMB mixture. Moreover the coherence function ensures that a good relationship between force and motion signals occurs. Nevertheless, no significant differences were found after testing the two wearing courses, since the shape of both dynamic stiffness curves, reference and CRMB, are rather similar.

According to the results obtained, noise generation mechanisms related with dynamic stiffness do not seem to have a relationship with the differences found in L_{CPtr} levels, between reference and CRMB mixtures.

4.3. Acoustic absorption measurements

The acoustic absorption has been measured in the impedance tube on sample cores of 6 cm thickness taken directly from the pavement with a special driller. The wearing course has 3 cm thickness and it was laid over a base course. Fig. 11 shows the sound absorption spectra of the CRMB and reference mixes, measured in normal incidence. The behaviour of both mixes is rather similar, although the experimental mix with high content of crumb rubber presents a lower acoustic absorption towards higher frequencies compared with that of the mix without crumb rubber (reference). Nevertheless, sound absorption coefficients are below 0.2 in the spectral range studied. Absorption coefficient is function of the air void content, and represents the proportion of acoustic energy not reflected by the surface of the material for a normal incidence plane wave (Luong et al., 2014; Paje et al., 2013). Due to the low air void content of the CRMB mixture (around 6%) and the low thickness of the layer, the effect induced by absorption mechanisms during the rolling could be considered not decisive in the noise reduction between the mixtures studied.

4.4. Environmental considerations

Despite the potential uses, approximately 300 million scrap tires are generated annually only in United States, and about 13% of which are discarded in landfills (Shu and Huang, 2014). Europe produced 355 million tires every year, and millions of used tires are illegally dumped or stockpiled (Lo Presti, 2013). The inadequate disposal of tires could be a potential threat to human health and increase environmental risks.

Fortunately, nowadays, waste tires are used for several purposes in civil engineering. Around

200,000 tons of end-of-life tires (EOL) were collected from all Spanish territory in 2010 for reuse/retreading, recycling and energy recovery purposes (Uruburu et al., 2013). In this research work, Crumb Rubber Modified Binder (CRMB) employed in bituminous mixtures uses end-of-life tires, thus, this type of wearing courses could be a profitable use for these waste materials.

The use of rubber powder on pavements is justified because it produces benefits in bituminous mixtures. Temperature susceptibility and resistance to permanent deformation are improved by the addition of crumb rubber, since elasticity is increased at operating temperatures of the mixes. Also, asphalt-rubber pavements have been demonstrated to have lower maintenance costs, higher skid resistance and better night-time visibility (Lo Presti, 2013). On the other hand, crumb rubber modified asphalt mixes could assume negative environmental effects.

These types of mixtures require a higher temperature to blend, thus, potentially increasing the hazardous emissions in hot-mix plants (Shu and Huang, 2014). Furthermore, crumb rubber asphalt concrete leachates contain organic and metallic contaminants, which are moderately toxic. However, the influence of the contamination is limited since the contaminants are degraded in their transport through nearby soils and ground waters (Azizian et al., 2013). In short: crumb rubber in bituminous mixtures could not be a panacea, but it prevents the accumulation of tires in landfills. According to the total weight of end-of-life tires collected from all Spanish territory, and the average composition of used tires in the EU (Spanish Ministerio de Medio Ambiente, 2007), over 150,000 tons of rubber is generated each year from waste tires in Spain. In 2001, eight out of ten used tires were discarded in landfills (Environment Observatory, 2006), meanwhile in 2005, 14.9% of all used tires generated were retreading, the 13.58% was recycled and 16.56% corresponds to energy recovery (Circle of innovation in aerospace technology and nanotechnology, 2008). The situation is slowly improving thanks to government efforts; the II End-Of-Life Tires National Plan (PNNFU, 2008-2015) proposes that around 25 % of end-of-life tires may be use in bituminous mixtures for road surfacing.

In this research work, the amount of crumb rubber (CR) added by wet process was 20 % of the weight of the base bitumen; that is a 1.5 % of the total weight of the mixture. Considering the dimensions of the road studied (CM-3102) and its density (2300 kg/m^3), the total amount of rubber employed by weight is around 11.4 tons every 1000 meters. The geometry and characteristics of the CM-3102 are shown in Fig. 12.

Considering the amount of rubber for the construction of bituminous mixtures, and the rubber used for the construction of one kilometer of the test track section studied in this work; over 3000 km of road pavement could be constructed annually, which accounts for 2% of the national highways of Spain (Spanish Ministerio de Fomento, 2013) (Fig. 13).

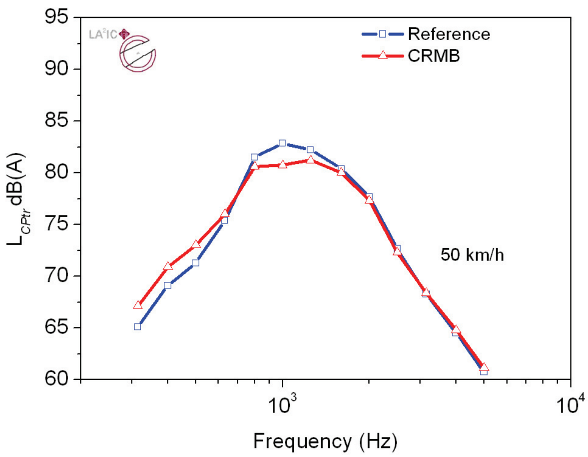

Fig. 9. Sound spectra measured in close proximity to the tire/road contact at 50 km/h

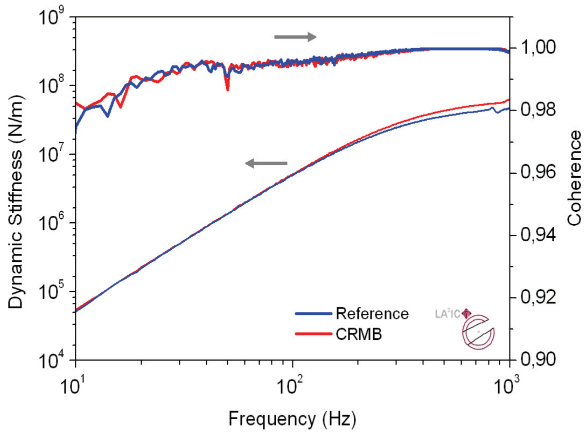

Fig. 10. Dynamic stiffness and coherence spectra of reference and CRMB sections

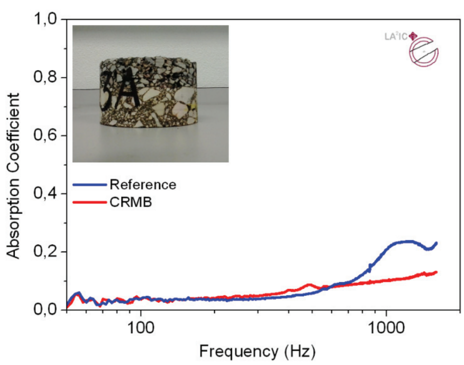

Fig. 11. Acoustic absorption spectra of reference and CRMB sections and detail of a sample

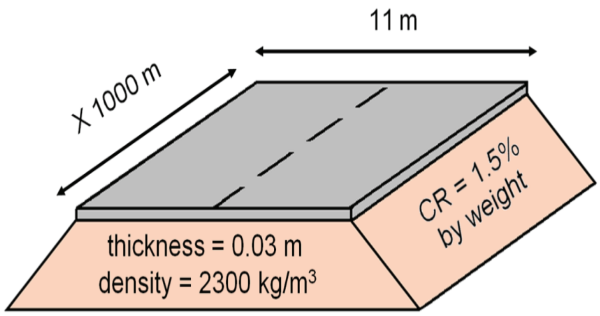

Fig. 12. Section geometry of the CM-3102

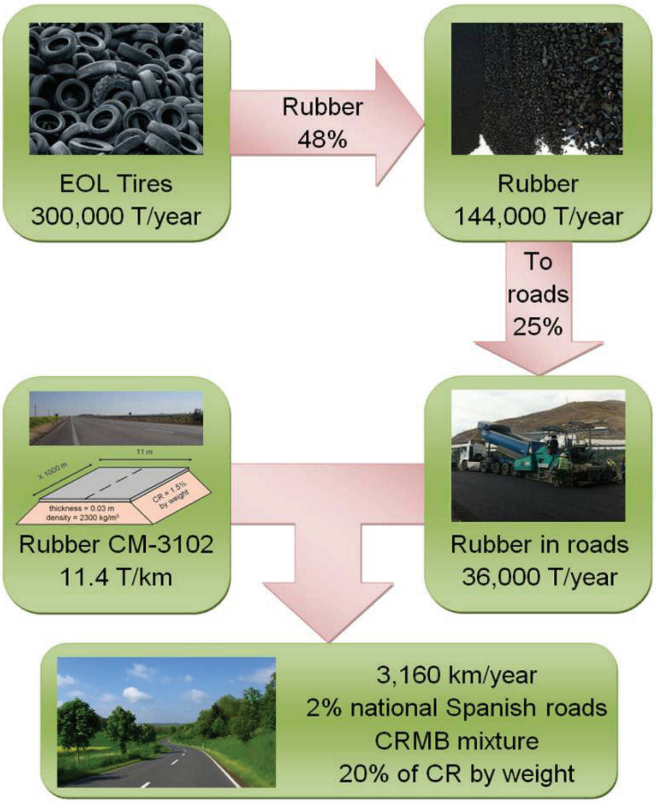

Fig. 13. Annual total length of roads of a gap graded mix with high content of crumb rubber

5. Conclusions

This study investigates the acoustical behavior of two bituminous mixtures with and without crumb rubber, laid on a conventional road in Spain. The following conclusions may be drawn:

– Crumb rubber mixture is quieter than reference mixture (conventional binder) by around 1 dB(A) at 50 km/h, that is, noise pollution reduction could be achieved. The choice of crumb rubber modified binder (CRMB section) or conventional binder (reference section) may be of great importance on the acoustic behavior of asphalt mixtures.

– The noise reduction due to the incorporation of CRMB takes place at frequency domains between approximately 800 Hz and 2 kHz, coinciding with the peak of the typical frequency spectrum generated by traffic noise.

– These types of mixtures (CRMB) could be a good option to reduce the landfill of waste materials like end-of-life tires. The weight of crumb rubber for 100 meters used in the CRMB mixture was around 1140 kg (road width of 11 m). The construction of such roads may avoid the appearance of tire dumps.

– Dynamic stiffness tests have been performed in order to establish a difference between both surfaces (with and without crumb rubber); however, no significant differences were found. Noise generation mechanisms related with dynamic stiffness do not seem to have a relationship with the differences found in L_{CPtr} levels between the wearing courses compared.

– The absorption measured in normal incidence, is below 0.2 in the range of frequencies between 50 Hz and 1.5 kHz: that is, the sound absorption mechanism is not significant in the noise reduction by these types of bituminous mixtures with air void content around 6 %.

– A reduction in tire/road noise has been achieved with CRMB section respect to reference section; nevertheless, noise generation mechanisms responsible for this effect are not so clear. It is possible that this behavior could be due to the texture profile of the wearing courses or other factors (Liao et al., 2014). More studies may explain the differences between sound levels measured in the mixtures tested.

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