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# Acoustic assessment of a Cold-In place Recycled pavement; dynamic stiffness field assessment

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## ABSTRACT

**Traffic noise is one of the main environmental problems in urban areas. The use of low-noise surfaces is probably the best option against noise in these areas, reducing the noise generation in the interaction between the tire and the pavement. On the other hand, the Cold-In place Recycled bituminous mixtures (CIR) are considered as environmentally friendly bituminous mixtures due to their construction temperature (ambient temperature) and the use of reclaimed asphalt pavement. This paper presents the acoustic assessment of an experimental section with a CIR pavement used as wearing course. The field auscultation of the tire/pavement sound levels by means of the Close ProXimity method (geo-referenced measurements) allows us to define the tire/pavement noise levels produced in this type of pavements, as well as their homogeneity. Besides Close ProXimity measurements, the dynamic stiffness has been also studied on the experimental CIR section in order to know the driving-point response of the studied surface. On the other hand, dynamic stiffness has been also evaluated at different points of the CIR surface (simultaneously), by means of several accelerometers, in order to measure the in-situ transfer function of dynamic stiffness in these pavements.**

**Keywords:** Close Proximity (CPX), Cold-In place-Recycling (CIR), Dynamic stiffness, Surface characteristics, Tire/pavement noise,
**I-INCE Classification of Subject Number:** 13

## 1. INTRODUCTION

Tire/pavement interaction noise contributes significantly to the traffic noise produced by passenger vehicles when their speed is greater than 40 km/h. Besides, noise generation mechanisms are influenced by pavement characteristics, such as air void content, texture profile and stiffness. Many tire/pavement sound studies are focused on the road texture; however, for a complete road surface characterization, the sound absorption and dynamic stiffness should also be measured [1, 2].

Low-noise road surfaces are a good option against traffic noise. These surfaces include porous asphalt that can absorb sound energy [3]. Nevertheless, there are other surfaces that may mitigate tire/pavement noise. For instance, gap graded pavements with crumb rubber [4, 5], softer surfaces such as the poroelastic pavements [6] or the Cold-In place-Recycled pavements (low-temperature pavements).

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Low-temperature pavements are fabricated at lower temperatures than conventional bituminous mixtures (hot mix asphalt), thus, using this type of materials, we reduce the fuel consumption and the greenhouse emissions. Moreover, the use of reclaimed asphalt pavement (RAP) reduces the use of virgin materials (aggregates). These construction technologies allow us to protect the environment. There are different types of low-temperature pavements: cold, half warm and warm mixtures. Cold mixtures are fabricated at ambient temperature, whereas half warm mixtures are fabricated at temperatures below 100 Celsius degrees (Fig.1) [7].

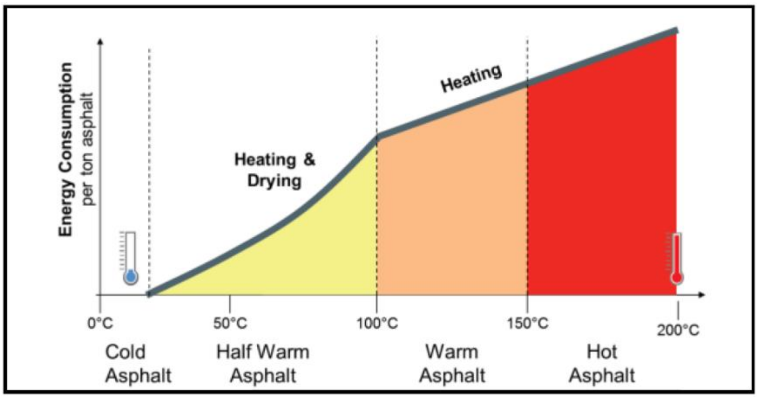

*Figure 1: Energy consumption versus temperature of fabrication of bituminous mixtures*

The aim of this study is to have a better understanding of the sound generation mechanisms of an in-service experimental road fabricated with low-temperature bituminous mixture with RAP (Cold-In place Recycled-CIR). The study is focused on the functional characteristics of this pavement, such as tire/road noise (Close ProXimity method-CPX), macrotexture (Mean Profile Depth-MPD) and roughness (International Roughness Index-IRI). The sound absorption and the dynamic stiffness (*driving-point* and *transfer functions* [8]) are also assessed. All these parameters may influence on the generation and propagation of tire/pavement noise. The functional assessment was carried out two months after the CIR pavement construction.

## 2. EXPERIMENTAL DESIGN

### 2.1 Experimental test track section

A deteriorated Asphalt Concrete mixture AC22 (see Fig. 2) was rehabilitated in CM-412 road with a new Cold-In place mixture with Reclaimed Asphalt Pavement (CIR pavement). Before the construction of the CIR pavement, the AC22 pavement surface was milling (10 cm) at ambient temperature. Then this material was milled to the desired size and mixed with a bituminous emulsion. The CIR pavement was compacted to project density and finally, a surface protection treatment was applied before the road was opened to traffic.

The CIR pavement includes a 100% RAP material from the aged AC22 mixture. therefore, no virgin aggregates were used for its construction. On the other hand, the bitumen emulsion added was 3 %. The laying and curing processes were monitored due to its importance on the final performance of the pavement surface.

Marshall specimens were compacted in laboratory from the CIR bituminous mixture employed during paving operations. The sound absorption coefficient was measured using the CIR specimens.

*Figure 2: Experimental section AC22 before rehabilitation with the Cold-In place-Recycled pavement.*

## 2.2 Measurement methods and equipment

Geo-referenced tire/pavement noise measurements have been carried out by means of the Close Proximity methodology (CPX). For this purpose, the Tiresonic Mk4-LA$^2$IC was employed. This equipment is composed by a reference tire ant two microphones inside a semi-anechoic chamber. The microphones are located at specific orientation and distance from the reference tire (Fig.3). The tire/pavement noise produced is registered together with the GPS coordinates of each point of the assessed surface [9].

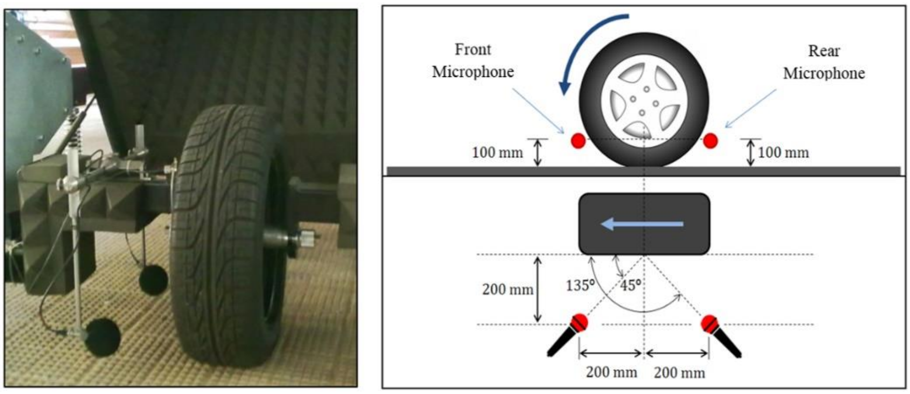

*Figure 3: Reference tire and the microphones inside the semi-anechoic chamber (Tiresonic MK4-LA$^2$IC)*

The longitudinal profiles of the studied test sections were measured by means of a high-speed profiling laser device (LaserDynamicPG-LA$^2$IC). This device is in the front part of the vehicle during measurements. The profile data are registered over the same path where the tire/pavement noise levels are measured. The profile data are also georeferenced.

The sound absorption coefficients and the dynamic stiffness of the studied CIR pavement have been evaluated by means of an impedance tube and an impedance head respectively. Details of the equipment and measurement technique are given elsewhere [10, 11].

# 3. RESULTS AND ANALYSIS

## 3.1 Georeferenced assessment of tire/pavement noise and surface texture

The acoustic behavior of the CIR section has been assessed by means of the Close ProXimity method at 50 km/h. Results are shown in Fig.4. The average tire/pavement noise level measured in the new wearing course is around 88 dB(A) (standard deviation 0.7 dB(A)). This level is considerably lower than that measured in the degraded pavement AC22 (around 93 dB(A)). Therefore, the use of the CIR mixture improved the acoustic performance of the experimental section, at least after two months in service conditions. The macrotexture of the studied section was also assessed in the experimental section by means of the MPD value. The MPD average value was around 1 mm. Finally, the IRI of the CIR mixture was stablish around 3 m/km.

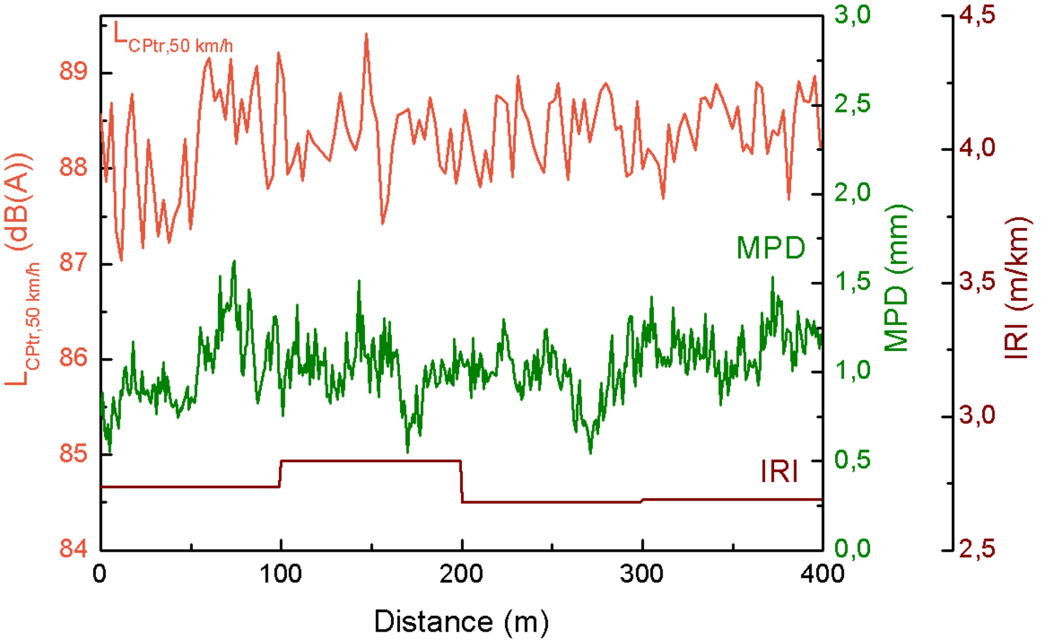

*Figure 4: Tire/pavement noise levels, Mean Profile Depth and International Roughness Index measured in the CIR pavement.*

From the acoustic assessment, the tire/pavement noise spectra of the AC22 mixture and the CIR mixture were calculated ($L_{CPtr}$ values corrected by speed and temperature). These spectra are shown in Fig.5. As shown in this figure, the CIR pavement improves the acoustic performance of the degraded AC22 pavement at all frequency bands. Low frequencies are related to impact and vibration noise generation mechanisms, meanwhile high frequencies are related to aerodynamic mechanisms (sound absorption, sound dispersion and reflections) [4, 9]. Medium frequencies are related to a combination of tire/pavement noise generation mechanisms. These are the main frequencies of the tire/pavement noise, as shown in Fig.5. Moreover, the maximum differences between the AC22 and the CIR mixtures are in medium frequencies (800 – 1250 Hz). According to literature, one of the pavement characteristics that may influence on the tire/pavement medium frequencies is the dynamic stiffness [8].

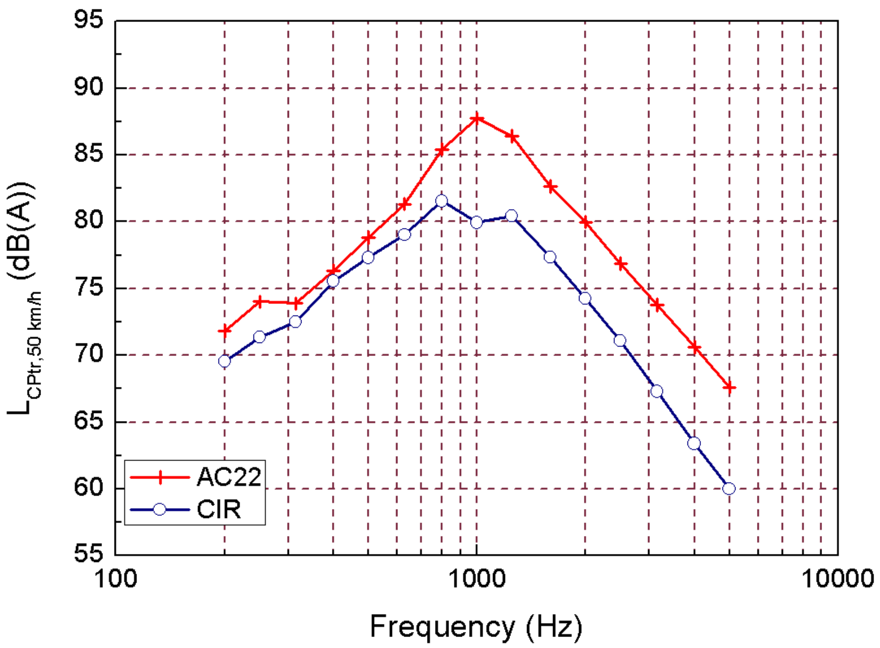

*Figure 5: Tire/pavement noise spectra of AC22 pavement (red) and CIR pavement (blue).*

The dynamic stiffness of the CIR pavement has been evaluated by means of the non-resonant method. The *driving-point response* and the *transfer functions* of the dynamic stiffness have been evaluated. The *driving-point* values refer to the relation between the force vector applied to a given surface and the motion vector of the same point (and direction) of the surface. On the other hand, if vectors force and motion are evaluated at difference points of the surface, the relationship is called *transfer function*. The *driving-point* values were measured by means of an impedance head, whereas the *transfer functions* were measured with several accelerometers with a separation between them of 10 cm. Table 1 shows the devices employed for the dynamic stiffness assessment and its distance from the position of the shaker (pavement excitation).

*Table 1: Devices employed for dynamic stiffness measurements and distance from the shaker position.*

| **Device** | Imp. head | Accel.1 | Accel.2 | Accel.3 | Accel.4 | Accel.5 |
|---|---|---|---|---|---|---|
| **Distance** | 0 cm | 10 cm | 20 cm | 30 cm | 40 cm | 50 cm |

Figure 6 shows the dynamic stiffness spectra from the impedance head and the accelerometers. Results are shown up to 400 Hz, since this is the more representative part of the spectra (*driving-point*). At higher frequencies, the *driving-point* dynamic stiffness values reach a constant value. However, this does not occur with the *transfer values*. The *transfer values* of the dynamic stiffness are higher at higher frequencies between 100 Hz and 200 Hz, however the initial slope of the curves (frequencies up to 75 Hz) are rather similar. The slope could be used for comparative purposes if bituminous mixtures with different construction characteristics may be compared. In the most distant positions, the dynamic stiffness increase at higher frequencies might be also due to a resonance effect. As shown in Fig.6, although accelerometers are evenly spaced, the differences between dynamic stiffness get smaller at higher distance from the shaker position. The *driving-point* values of the dynamic stiffness are lower than the *transfer values*.

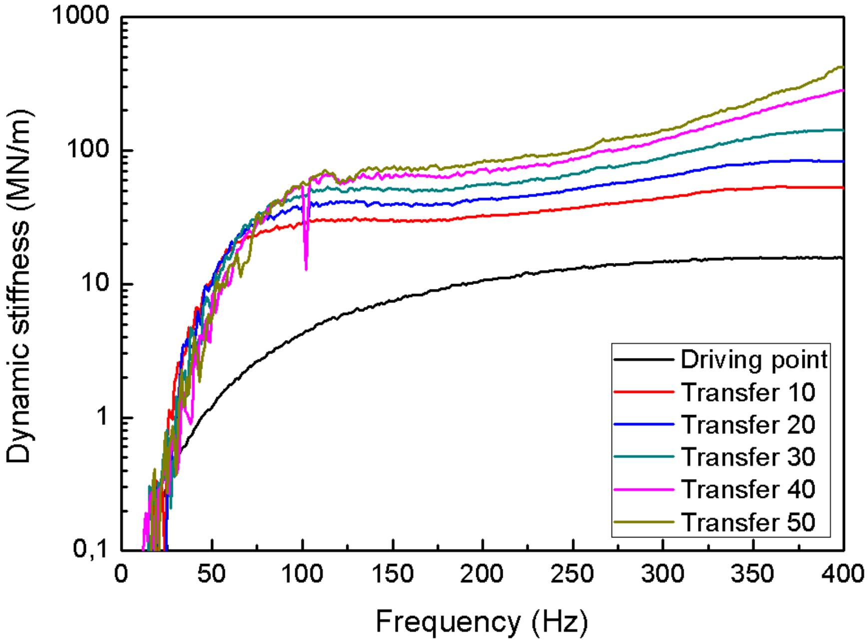

*Figure 6: Measured driving-point values and transfer values of the dynamic stiffness, depending on the distance from the shaker position.*

The acoustic absorption of the CIR bituminous mixture has been also assessed in laboratory (from sample cores). The absorption coefficient was lower than 0.2 at every frequency band of the absorption spectrum, therefore, the absorption may not mitigate the tire/pavement noise produced in this CIR pavement.

## 4. CONCLUSIONS

This paper aims to study the functional performance of a Cold-In place Recycled bituminous mixture. The field assessment includes the tire/pavement noise evaluation by the Close ProXimity method, the profile assessment by the LaserDynamicPG-LA$^2$IC), the acoustic absorption by the impedance tube and the dynamic stiffness measurements by means of an equipment composed by a shaker, an impedance head and several accelerometers.

The CIR bituminous mixture has a good acoustic performance. The average tire/pavement noise level has been reduced around 5 dB(A) regarding the original degraded pavement. On the other hand, the MPD and IRI of the CIR bituminous mixture have been also evaluated. Finally, the dynamic stiffness of the bituminous mixture has been assessed. *Driving-point* values and *transfer values* of the dynamic stiffness are presented in this research work. The *transfer values* of dynamic stiffness are higher when accelerometers (motion vector) are located further from the excitation point (shaker). The initial slope of the dynamic stiffness (*transfer values*) does not depend on the distance from the excitation point. This slope may be used for dynamic stiffness comparison among bituminous mixtures with different construction characteristics.

Despite the insights provided by the results of this research, it might be interesting to assess the skid resistance and/or the rolling resistance of the studied wearing courses, since these are also functional characteristics of pavements

## 5. ACKNOWLEDGEMENTS

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