Mechanical impedance and CPX noise of SMA pavements

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ACOUSTICS 2012

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CPX noise is the sound measured in close proximity to the tire/pavement contact patch when a vehicle is rolling. The mechanical impedance or dynamic stiffness of the pavement is one of the factors involved in the generation of this type of noise. The reduction of the impact noise generation mechanism can be achieved with the construction of mixtures with lower dynamic stiffness. On the other hand, SMA mixtures, widely used in Europe, have come into use recently in Spain as a surface layer. The aim of this work, carried out by the Laboratory of Acoustic Applied to Civil Engineering (LA^2IC), is to establish a stiffness indicator of the bituminous mixtures according to European Standards. Thus, the dynamic stiffness has been studied using bituminous mixtures, and the results have been compared with a test made on different SMA samples. Dynamic stiffness was measured with an impact hammer, an accelerometer and a data acquisition system. Laboratory results have been analyzed in order to establish the accuracy of the method and the relationship with the CPX noise.

1 Introduction

Noise pollution is one of the main disturbance factors in urban areas. The importance of this pollution comes from its ability to alter the natural conditions of the environment and cause physiological and psychological disturbance. The sources of noise pollution are numerous, however, the most important, according to the volume population affected, are transportation systems like motor vehicles.

Tire road noise is the noise resulting from the interaction between the tire and road surface [1]. Generally, tire/pavement interaction is the principal source of noise for speeds above 40 km/h in the case of most modern cars.

The main characteristics of the road that influences the noise are superficial texture, acoustic absorption and dynamic stiffness [2]. Therefore, to reduce the rolling noise it is necessary to know these properties and their influence on the noise levels.

This work aims to establish a stiffness indicator for core samples of bituminous mixtures. SMA mixtures (Stone Mastic Asphalt) were used for this purpose since this type of mixture is widely used in Europe. However, in Spain such mixtures are beginning to be used as a road surface layer, for example in some experimental test tracks of the province of Valencia [3].

This paper continues the research of the Laboratory of Acoustic Applied to Civil Engineering (LA^2IC), using the auscultation technique developed in previous works: geo-acoustic auscultation [4]. In addition, a technique to measure dynamic stiffness has been developed.

2 Experimental set-up

Resonance frequency has been achieved by impacting the specimens in the center point of the upper face and measuring acceleration directly at the mass, on the same face. The force is measured in the tip of the hammer (see Figure 1).

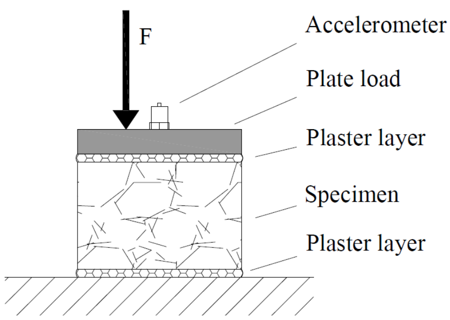

Figure 1. Representation of the experimental set-up

The experimental set-up was composed of a piezoelectric accelerometer Brüel & Kjaer type 4370 with an upper frequency limit of 16,000 Hz. An impact hammer (B & K 8202) was used in order to obtain the force applied. For the measurements a rubber impact tip was chosen, with a frequency range from 0 to 500 Hz. The multi-analyzer Pulse system type B & K 3560 B-T06 with the conditioning amplifier NEXUS were used to record specimen response and hammer excitation, and to produce the fast Fourier transform (FFT) spectra of vibration signals. Finally, a trigger was used to synchronize the acquisition of the force and acceleration signals. Figure 2 shows the experimental set-up.

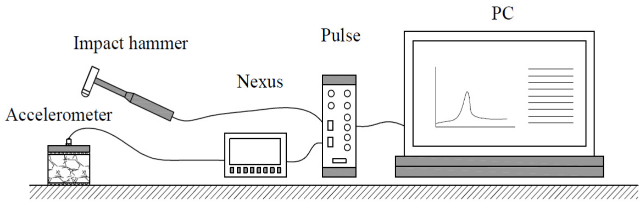

Figure 2. Experimental set-up

3 Characteristics of the SMA mixtures

The standard EN 13108-5 [5] defines the characteristics of the SMA mixtures to be used as paved surfaces in roads. The requirements include the characteristics of binder, aggregates and additives, as well as the granulometry, air voids content and binder content.

The studied materials to develop a procedure to establish a stiffness indicator are SMA mixtures with different characteristics of aggregates and binders. In order to characterize these mixtures, two samples of each type of SMA mixes were compacted:

- (A) - SMA 16 MB: aggregate with a maximum size of 16 mm. Rubber powder modified bitumen.
- (B) - SMA 16 CB: aggregate with a maximum size of 16 mm. Conventional bitumen.
- (C) – SMA 11 MB: aggregate with a maximum size of 11 mm. Polymer modified bitumen.
- (D) – SMA 11 CB: aggregate with maximum size of 11 mm. Conventional bitumen.

4 Mechanical analysis

4.1 Stiffness

The characteristics of air void content, apparent density and stiffness of the samples studied have been determined according to UNE EN 12697 standards and are shown in Table 1.

Table 1. Characteristics of the SMA samples.

Mixture	Apparent Density (kg/m^3)	Air void content (%)	Stiffness (MPa)
(A) SMA 16 MB	2307	4.9	2515
(B) SMA 16 CB	2342	4.5	3752
(C) SMA 11 MB	2475	4.4	2643
(D) SMA 11 CB	2496	4.6	5162

The 12697-26 [6] standard (Annex C) describes a method for determining the stiffness modulus of bituminous mixtures by an indirect tensile test. This method is applicable to cylindrical specimens of different diameters and thickness. After conditioning the specimen, five pulse loads are applied on the specimen, recording the variation of the applied load and the horizontal diametral deformation. For each pulse load the stiffness modulus was obtained using the formula:

$$S_m = \frac{F \times (\nu + 0.27)}{(z \times h)} \qquad (1)$$

where S_m is the stiffness modulus; F is the maximum value of the applied load; z is the horizontal deformation amplitude; h is the thickness of the sample and ν is the Poisson ratio.

Figure 3 shows the surface texture of the samples studied. The first are SMA 16 (samples A and B), whereas the latter two are SMA 11 (samples C and D):

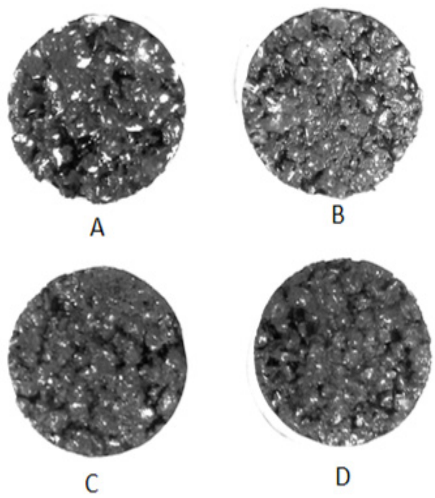

Figure 3. Samples studied. A: SMA 16 MB; B: SMA 16 CB; C: SMA 11 MB; D: SMA 11 CB.

4.2 Dynamic stiffness

Dynamic Stiffness is a phenomenon involved in tire/road noise. It cannot be regarded as a pure generation mechanism, but a related amplification or reduction mechanism [7].

The EN 29052 part 1 [8] describes the test method in order to determine the dynamic stiffness of resilient materials used under floating floors. The dynamic stiffness s is defined as:

$$s = \frac{(F/S)}{\Delta d} \qquad (2)$$

where F is the force applied perpendicularly to the sample, S is the surface of the sample and Δd is the resulting dynamic variation of the sample thickness.

The test method allows for the evaluation of the resonance frequency f_r of the fundamental vertical vibration system constituted by the resilient material (spring) and the load plate (mass). The apparent dynamic stiffness s'_t is defined in Eq. (3) according to EN 29052-1. m'_t is the load mass per unit area.

$$f_r = \frac{1}{2\pi}\sqrt{\frac{s'_t}{m'_t}} \rightarrow \quad s'_t = 4\pi^2 m'_t (f_r)^2 \qquad (3)$$

The specimens tested were circular samples of diameter 100 mm. The samples were different from those described in the standard (200 mm x 200 mm), but have been used since they are representative of samples commonly used in asphalt characterization tests.

The sample tested was placed under a steel load plate (mass per unit area 200 kg/m^2 according to EN 29052-1). Force was applied by means of an impact hammer (see Figure. 4), while the frequency was evaluated by means of an accelerometer.

Figure 4. Detail of the experimental set-up for the mechanical test according to EN 29052-1.

The dynamic stiffness tests were carried out on four samples prepared by varying the characteristics of bitumen and aggregates. The samples were covered with a thin waterproof plastic. A thin plaster layer was placed over the waterproof sheet in order to compensate superficial irregularities.

In Figure 5 the resonance frequency as a percent of the maximum acceleration value is shown. The figure also includes the coherence function, which is an indicator of the accuracy of the measurement. Although the coherence function may be lower than that calculated in other studies [9] for frequencies above 500 Hz, the result is near to unity at the position of the first resonance frequency, below 200 Hz.

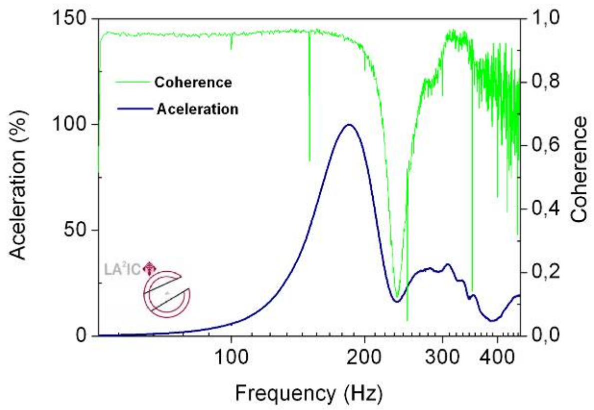

Figure 5. Acceleration versus frequency. The coherence function is also plotted (right axis).

The results of the dynamic stiffness test are listed in Table 2. The table also includes the density, which may play an important role in the resonance frequency.

Table 2. Results of the dynamic stiffness test on the SMA samples.

	Density (kg/m^3)	Thickness (mm)	Resonance frequency (Hz)	Apparent Stiffness s'_t (MPa/m)
AI	2176	6.11	183.5	254
AII	2187	6.05	190.0	273
BI	2177	6.80	218.0	359
BII	2125	6.94	214.0	346
CI	2395	6.39	174.0	229
CII	2352	6.48	163.0	201
DI	2339	6.51	162.5	200
DII	2316	6.53	156.5	185

The samples are made from a bituminous mixture thus the flow resistivity can be considered higher than 100,000 Pa. Consequently the apparent dynamic stiffness, s'_t, coincides with the dynamic stiffness s'.

As expected, the value of the dynamic stiffness decreases with density for every type of bituminous mixture sample. See reference [10].

5 Close proximity tire-road noise

In order to determine whether dynamic stiffness is involved in road noise generation, close proximity measurements [11] were carried out with a reference tire Pirelli P6000. The measurements have been performed by the test trailer TiresonicMk4-LA²IC [12] while the tire was rolling over different sections of an experimental test track at 50 km/h.

The test section has been measured four times with similar results, ensuring reproducibility. The measurements were recorded by two microphones situated near the contact patch [13] inside TiresonicMk4-LA²IC. The different sections were analyzed in each one-third-octave-band between 200 Hz and 10 kHz. The average, over the test track, of the one-third-octave-band frequency spectrum for speed 50 km/h is shown in Figure 6.

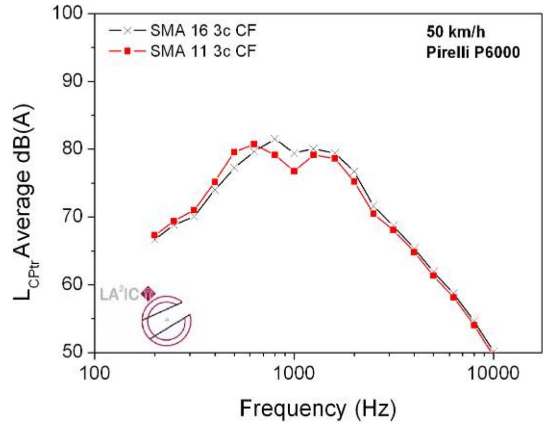

Figure 6. One-third-octave-band spectra from different mixtures measured in close proximity to the tire/pavement contact patch.

6 Analysis of results and discussion

The results obtained using the proposed experimental set-up have been compared with the stiffness calculated according to the EN 12697-26. Specimens having greater stiffness are expected to have more dynamic stiffness. The aim is to evaluate qualitatively the experimental set-up proposed in this paper.

According to the characteristics of the mixtures, it is expected that the greater stiffness will be obtained in unmodified bitumen mixtures (B and D) while lower values should be achieved in the samples with modified bitumen (A and C).

In Figure 7 the results of stiffness and dynamic stiffness are compared. The behavior of the specimens is similar in both trials for the samples A, B and C, since the rubber powder reduces stiffness. However, in the case of the specimen D (SMA 11 CB), the results are much lower than expected. This could be due to an error in the tests conditions or in the construction of the specimens.

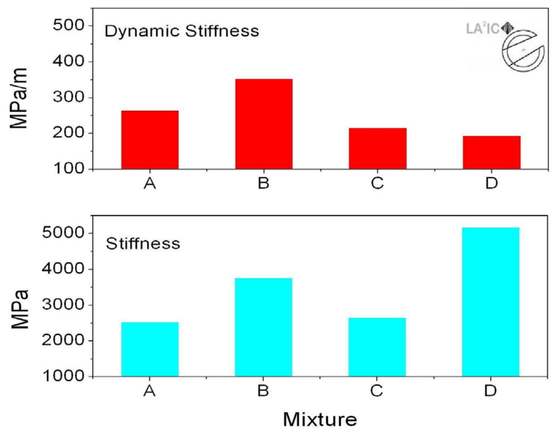

Figure 7. Dynamic stiffness and stiffness of the samples.

Finally, after the acoustic auscultation of the experimental test section, the SMA 11 mix seems to be less noisy than SMA 16 mix according to the one-third-octave-band spectra. This agrees with the results obtained for dynamic stiffness, since the SMA 11 mix tested yielded a lower value of this parameter than SMA 16 mixtures.

The mechanism involved in the sound generation due to impacts and vibrations can be affected and minimized if stiffness decreases [14]. The range up to 1000 Hz is attributed to this type of mechanism, thus it is expected that the SMA 11 mixtures will be less noisy than the SMA 16 mixture in this range.

The one-third-octave-band spectrum shows that the response of the SMA 11 mixture is rather similar to the response of the SMA 16 mixture, but slightly noisier at frequencies below 800 Hz. However, the main reduction for this type of mixture is achieved at 1000 Hz and 800 Hz. Thus, it is possible that dynamic stiffness is involved in the reduction of the one-third-octave-band spectra at 800 and 1000 Hz.

Nevertheless, the results cannot be considered representative of the real performance of the material because of the small surface area of the sample. In any case, this behavior could also be due to other factors such as the surface texture or the sound absorption for normal incidence. Therefore, more tests are needed in order to assess the importance of dynamic stiffness in noise attenuation.

7 Conclusions

Dynamic stiffness is one of the parameters that must be taken into account in order to characterize acoustically the pavement; since it can be crucial to reduce the noise if a certain type of surface texture is required.

The proposed measurement method seems to be able to establish the resonance frequency and the dynamic stiffness of the Marshall samples (cylindrical) [15] by application of the standard 29052-1. The method is apparently suitable for the qualitative comparison between bituminous mixtures. However, it would be useful to compare the results obtained from cylindrical and prismatic specimens of the same asphalt mixture; thereby it would be possible to determine the effect of geometrical shape.

Further information on the possible influence of the dynamic stiffness on noise levels would be provided by detailed studies of the sound absorption coefficient and the texture of the surface.

Nevertheless, the test procedure employed yields small variations in successive measurements of the same sample, thus the design of other measurement techniques, such as the use of vibration exciters, could be appropriate in future research.

Acknowledgments

This work has been funded in part by a research contract between University of Castilla-La Mancha (LA^{2}IC) and ELSAN in the framework of the CDTI project IDI-2010937, “Mezclas bituminosas SMA normalizadas (UNE-EN 13108-5) sostenibles y medioambientalmente amigables” funded by FEDER. The Authors wish to thank Prof. Pintado of University of Castilla-La Mancha for their contribution on mechanical measurements of the tested materials.

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