Pavement temperature influence on close proximity tire/road noise

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1. Introduction

In the last decades different studies have demonstrated that the road traffic is one of the main noise contributors to the overall urban noise [1]. Belonging to this type of noise, the sound emission generated by the interaction between the pavement surface and the different tires of light vehicles rolling at speeds above 40 km/h is the dominant effect [2]. To provide further knowledge of the acoustic characterization of road surfaces it is important to control each parameter that can affect the final resulting sound emission. The tire/pavement noise depends mainly on the type of tire, the different design parameters of the road surface, like macrotexture or air voids content, and their states of conservation [2–6]. Nevertheless, a variable factor like the pavement temperature can become decisive in the final sound behaviour of an asphalt road. The pavement temperature is directly related to the air temperature. In some places, climate conditions can cause high differences in the surface temperature, from around 0 °C in winter to above 50 °C in summer. Moreover, a rolling tire will increase its temperature due to different mechanisms of friction until reaching a constant value according to the type of tire and the pavement temperature, texture and polishing. Works carried out by different authors conclude that an increase in pavement temperature leads to a reduction of the sound levels emitted by the tire/pavement interaction up to 0.12 dB(A)/°C for asphalt surfaces [7–10].

During the last years the LA²IC has been developing different studies focused on carrying out acoustical characterization of different road surfaces, research on the mechanisms involved in the sound generation and on the design of pavements that generate lower levels of tire/road noise [11–14]. In the present study, close proximity measurements of the sound generated by the interaction between tire and road surface have been carried out with the trailer Tiresonic Mk4 LA²IC-UCLM rolling at a speed of 50 km/h. The analysis of the results shows that increasing pavement temperature leads to a reduction in the close proximity sound levels assessed at a rate of 0.06 dB(A)/°C. Moreover, spectral analysis confirms that both the mechanisms associated with vibration and impacts and those related to the friction and adhesion between tire and pavement in the contact patch could be affected by the variation of the surface temperature.

2. Experimental setup

2.1. Test section and asphalt surface

The test section selected for this study is an urban track located in a residential area of Ciudad Real (Spain). The situation of the test track, the surface texture details and the GPS coordinates of the test track are shown in Fig. 1. The road surface is constructed with a semidense asphalt surface type S-12 (Spanish denomination). This type of mixture presents 6–12% air voids content, a maximum aggregate size of 20 mm and an average thickness of surface layer of 70 mm. More design specifications for this type of asphalt surface can be found in reference [12]. The road surface was laid
4 years before the acoustic measurements were performed. The macrotexture of the road surface is an important parameter related to tire/road noise, hence it has been determined in different points along the test track by a portable laser texture scanner produced by Ames Engineering. The test section presents a rough texture surface with an average value of mean profile depth (MPD) of 0.9 mm (standard deviation of 0.1 mm).

The ageing of the pavements due to weather effects and traffic conditions can cause changes in the surface properties that could have influence on the acoustic assessment. For this reason, the different measurements have been performed during a summer morning thus minimizing the influence of other variables such as the state of conservation of the road surface. Moreover, the test section was selected because its lack of shadow areas, caused by trees or surrounding buildings, where the pavement temperature would be lower, thus allowing the different measurements to be carried out at uniform pavement temperatures along the track.

2.2. Close proximity trailer Tiresonic Mk4-LA2IC

The measurements of the tire/pavement noise were carried out following the CPX methodology used in previous acoustic characterizations of road surfaces [11–14]. Trailer Tiresonic Mk4-LA2IC (Fig. 2) is made up of a semi-anechoic chamber which isolates tire/pavement sound from the external traffic or wind noises. The CPX method provides measurements of tire/pavement sound levels ($L_{CPR}$) in close proximity to the contact patch, and should supply insight into the acoustical characterization of asphalt pavements. The pressure levels emitted by the rolling of a reference tire are continuously measured by two BSWA MP201 ½ in. microphones located close to the tire in the range from 200 Hz to 16 kHz. The energy-mean of the third-octave band levels, A-weighted ($L_{Aeq}$), can be determined up to a rate of every 0.1 s at each microphone and the $L_{CPR}$ are arithmetic averages of the two microphones [11–13]. The microphones placed inside of the semi-anechoic chamber are located at a horizontal distance of 20 cm from the plane of the nearest tire sidewall and at a height of 10 cm above the road pavement surface. Front (FM) and rear (RM) microphones are positioned at angles of 45° and 135° to the rolling direction, respectively. A portable NI Compact Rio control and acquisition system with a four channel module and a cRio mobile module for global position determination with a precision of 2.5 m CEP (circular error probability) for longitude and latitude are used to geo-register continuously the close proximity sound levels. A digital tachometer is used during the test to measure the instantaneous vehicle speed.

In this study, the tire selected was a Pirelli P6000 205/55 R16 with an inflated pressure in cold conditions of 240 kPa. The test track was an urban section hence the reference speed selected for this analysis was 50 km/h. The sensitivity of the whole acoustic measurement set up was checked with an acoustic calibrator 4231 B&K before and after the measurements over the tested road surface. Throughout a morning, different measurements were carried out, which were taken in different instances in order to allow time
for the pavement temperature to increase, as well as to ensure a constant temperature for the reference tire, avoiding its warming up by rolling.

One day before the test, a repeatability study of CPX measurements was performed. To avoid the possible influence of the pavement temperature on the analysis, five consecutive measures along the test section were carried out with the Tiresonic Mk4-LA2IC cruising at a speed, as constant as possible, of 50 km/h (reference speed). Fig. 3 shows the evolution of the close proximity sound levels ($L_{CPX}$) registered every 0.4 s for the different measures (A-E) on the test section. In the inset, the averaged sound levels associated with each measurement are shown. In spite of the spot differences in $L_{CPX}$ along the test track, which are due to transversal deviations from the contact path between measurements, the average levels remain rather constant, presenting a standard deviation among them of 0.1 dB(A). This result demonstrates that any sound levels differences, found in the present study, will be due to the pavement temperature and not to the accuracy of the acoustic measurement equipment.

2.3. Temperature measurements

The evaluation of the pavement temperature was carried out immediately after each set of measurements of tire/pavement sound emission. The measurements of temperature were taken with a DVM77 infrared thermometer of Velleman Components that allows a measuring range of −30 to 270 °C with an accuracy of 2 °C. Surface temperature measurements were taken at different points
along the test section to obtain an average value. However, the pavement temperature in the section practically maintained a constant value due to the lack of shadow zones, where the temperature would have been lower.

The measurements of close proximity sound levels were performed with the reference tire in cold conditions. To ensure a constant tire temperature, approximately 90 min of waiting time between different acoustic measurements were used, to allow that the tire temperature falls down. The tire temperature in cold conditions was measured on top of the profile tread blocks and in the tire grooves. The temperature distribution in the tire was found to be quite homogeneous with a mean value in measured conditions of 30 °C.

3. Results and discussion

3.1. Close proximity noise levels

In this section, the results of close proximity measurements carried out to evaluate the influence of the surface temperature on the acoustical behaviour of the selected semidense asphalt pavement are presented. This characterization was realized in an interval of 6 h during a summer morning, the minimum and maximum pavement temperatures being 15 °C and 47 °C, respectively. In order to avoid the warming up of the reference tire by rolling, breaks of 90 min between the different series of measurements were carried out. In the present study, in order to achieve a complete
characterization, the influence of pavement temperature on tire/road noise levels has been analyzed in two different situations; that of accelerating along the track and that of rolling at a constant reference speed of 50 km/h. Only one measurement was performed for each purpose and for each temperature condition.

First of all, to analyze the influence of the pavement temperature on the sound behaviour continuously increasing the rolling speed, various measurements were performed. The results obtained from these different tests, in which the speed was increased continuously from 30 to approximately 90 km/h over the entire test segments, are shown in Fig. 4. The noise emission from tire/road interaction is speed dependent [11–14], thus the constant $B$ obtained experimentally can be considered a characteristic parameter of the road surface analyzed. The value of $B$ is obtained directly from the slope of the linear regression between close proximity sound levels and speed (see Fig. 4). Moreover, $B$ is used to correct the inevitable deviations in the instantaneous speed and to normalize the close proximity sound levels ($L_{CPTR,ref}$) to the selected reference speed. The correction follows the procedure described elsewhere [11–14]:

$$L_{CPTR,ref}(t) = L_{CPTR}(t) - B \cdot \log_{10}(v(t)/v_{ref})$$

where $L_{CPTR}(t)$ is the instantaneous averaged tire/pavement sound level from rear and front microphones, $v_{ref}$ is the selected reference speed, $v(t)$ is the instantaneous speed in each case and $B$ is the speed constant (noise–speed slope).

Fig. 4 shows a similar evolution of the close proximity levels independent of the temperature, where the constant $B$ obtained varies between $B_{15°C} = 34.7$ and $B_{47°C} = 35.5$. A first conclusion that may be drawn from these results is that in this semidense asphalt surface, the acoustic behaviour with the speed, in close proximity at the emission of tire/road noise, is independent of the temperature of the pavement surface.

Next, the evolution as function of pavement temperature of the corrected close proximity levels ($L_{CPTR,ref}$) for a speed of 50 km/h along a selected reference test section of 200 m is presented in Fig. 5. Each close proximity level corresponds to the arithmetical average of the levels obtained in rear and front microphones for the reference tire Pirelli P6000. In this part of the study the energy–mean was registered every 0.2 s. Repeatability in the different
measurements with a high sound emission point, at a distance of 175 m, is clearly observed. This distance corresponds to an area with surface defects. In general, one observes that with increasing pavement temperature, the close proximity sound levels appear to decrease. Again, as mentioned above, the differences observed in the profiles are due to the unavoidable transversal deviations of the contact path along the section. In this type of evaluation it is, in practice, very difficult to roll exactly along the same points in different measurements.

The characteristic close proximity rolling noise index, $L_{CPn}$, for a reference speed of 50 km/h, obtained as an average level of the reference test section of the semidense asphalt surface at each different pavement temperatures, are shown in Fig. 6. As can be seen, in the same way as with the rolling speed, it appears that a good linear relationship exists between the temperature of the pavement and the sound level representative of the reference test section. Analysis of these data allows modelling of the $L_{CPn}$ levels as a function of pavement temperature:

$$\frac{L_{CPn,ref} - n}{m} = T_{pavement}$$

where $L_{CPn,ref}$ is the characteristic close proximity index at the reference speed, $n$, and at the pavement temperature, $T_{pavement}$. The temperature coefficient $m$ defines the acoustic behaviour of the asphalt pavement with the surface temperature.

In this work, the close proximity levels recorded at a reference speed of 50 km/h along the selected semidense asphalt surface yield an approximate value of $m = -0.06$ dB(A)/°C. This result is in very good agreement with those presented by Anfosso [7], where similar temperature coefficients ($\Delta_{roa/>s}$ in that case) were obtained via pass-by measurements on dense surfaces at pavement temperature ranging from 0 to 40°C.

3.2. Spectral analysis

To improve the analysis of the mechanisms involved in the interaction of the reference tire with the evaluated semidense asphalt pavement, the sound emission during the rolling at the reference speed of 50 km/h for different surface temperatures was analyzed in the 1/3-octave band between 200 Hz and 16 kHz. Fig. 7 shows the close proximity sound levels spectra associated with the reference test section of the studied asphalt pavement at different temperatures. It can be observed that significant differences between the tire/pavement sound spectra associated with the different surface temperatures are obtained in the range of frequencies analyzed above 400 Hz.

Different authors [7,8] suggest that this difference in the sound behaviour is connected to the stiffness of the asphalt pavement, owing to the viscoelasticity and thermo-susceptibility of such materials. This implies that the stiffness decreases as temperature increases, such that mechanisms involved in the sound generation due to impacts and vibrations can be affected and minimized. This aspect could influence low and medium frequencies of sound from tire/pavement interaction. Nevertheless, for the range of 1000 to 3500 Hz, which is attributed to a mechanism associated with air pumping as well as other mechanisms related to the flow of air in and around the tread grooves of the tires, the above mentioned effect of the variation of the pavement stiffness could be less evident. In this frequency range, the effect of the variation of pavement temperature could be connected to a possible decrease in the friction and adhesion mechanisms or the stick-slip effect.

A spectral dependence of the temperature coefficient $m$ has been analyzed in the different studies [7,8]. Thus, performing the same correlation with the pavement temperature (eq. 2) as that used in the overall close proximity noise levels for every third octave band analyzed, in order to obtain the behaviour of the coefficient $m$ as a function of the frequency band. These values of the temperature coefficient $m$ for the evaluated semidense asphalt surface are shown in Fig. 8.

It can be observed that increasing pavement temperature appears to have more influence on the higher frequency interval above 1250 Hz as well as medium frequencies around 500 Hz, where the coefficient $m$ reaches values larger than $-0.06$ dB(A)/°C, obtained with the overall close proximity levels.

4. Conclusion

In this study, the influence of pavement temperature on close proximity sound levels has been assessed. First of all, the evaluation of the sound behaviour as a function of speed (between 30 and 90 km/h) is rather similar, regardless of the pavement temperature. Speed characteristic constants $\beta$ resulted in noise-speed slopes at different surface temperature varying from $B_{30°C} = 34.7$ to $B_{90°C} = 35.5$. In general, the evaluation of measurements carried out on the selected semidense asphalt pavement used as test track, for a reference speed of 50 km/h, shows that an increase of the surface temperature leads to a decrease in the recorded sound levels ($-0.06$ dB(A)/°C). The pavement temperature mainly influences the medium and high frequency noise and the mechanisms responsible for sound generation at these 1/3-octave bands. This could be due to a reduction in impact and vibration mechanisms resulting from a decrease in the stiffness of the asphalt surface. In this sense, the sound emission generated by adhesion and friction between tire and pavement, responsible for high frequency noise, could also be affected. In order to complete the analysis of the influence studied and confirm the effect of the pavement temperature on the acoustical behaviour of roads, this test should be reproduced on different types of asphalt pavements, e.g. porous or thin layers, as well as for different reference speeds.

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References

