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Effect of road pavement defects on tyre-road noise

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ABSTRACT

Tyre-road noise is the main source of noise in vehicles at speeds above 40 km/h and therefore a major contributor to noise annoyance. As the road surface is submitted to traffic loading and weather, its characteristics change, and different types of distresses become visible on the surface, affecting the tire-road noise. This study aimed at analysing the tyre-road noise measured in different types of road pavements through acoustic and psychoacoustic indicators. The close proximity method (CPX) was used to measure noise at three speed levels (30km/h, 50 km/h and 65 km/h), in three types of road pavements, over two types of distresses (alligator cracking and ravelling). The effects of type of pavement, speed and distress on each acoustic and psychoacoustic indicator were analysed. It was confirmed that the pathologies have a relevant contribution to the tire-road noise. Also, the psychoacoustic indicators are more sensitive to the testing conditions. These results are a valuable argument to compel road managers to practice a preventive road maintenance policy.

Keywords: Noise, Annoyance, Pavement distress, Psychoacoustic indicators, CPX
I-INCE Classification of Subject Number: 10

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1. INTRODUCTION

Traffic noise is one of the most relevant contributors to environmental noise, and therefore with negative effects on health [1], as the tire noise component is predominant in the range of speeds practiced in urban environments. The tire-road interaction noise has been the object of several studies. In these studies, several influencing factors were identified [2], such as speed, traffic composition, and pavement surface characteristics and condition. The first two factors are already extensively studied, while the third one, regarding the characteristics and conditions of the pavement surface, still requires a considerable research effort. Furthermore, it is recognized that macrotexture and porosity are two fundamental characteristics of the surface layers of pavements in the control of tire-road noise [3].

Over time, the surface of the pavements changes and develops degradations [4] that result from the successive traffic passages and also from climate action. The degradations are not only responsible for changes of the mechanical resistance but also roughness, texture, and surface regularity of the pavement, and therefore, of the tire-road noise emission.

Besides causing discomfort to the drivers and decreasing safety, discontinuities [5] and distresses [6] of the pavement surface appear to influence road traffic noise due to the perceptible intensification of tyre vibrations, which is expected to increase the auditive discomfort of road users. To analyse the changes caused by distresses on tyre-road noise and how they are perceived by road users, a study of distressed pavements based on acoustic psychoacoustic indicators was done.

This study analyses the tire-road noise generation influenced by two degradations (alligator cracking and ravelling), considering two factors: type of pavement, and traffic speed.

2. MATERIALS AND METHODS

2.1 Methodology

To analyse the effect of pavement distresses on noise, several sections with different distresses were selected in roads with distinct pavement types. Afterwards, Close ProXimity (CPX) tire-road noise measurements were carried out and the sound files registered were manipulated. Finally, acoustic and psychoacoustic noise indicators were extracted and the influence of degradation was analysed.

2.2 Road sections

A total of 21 road sections with different distresses, were selected in 6 national roads: 6 sections in thin Gap Graded Asphalt (GGA), 8 sections in Asphalt Concrete (AC) and 7 sections in Gap Graded Asphalt Rubber (CGAR). Two distresses which are typical of urban areas were chosen – alligator cracking (high severity), and ravelling (Figure 1).

Figure 1. Example of pavement with alligator cracking (left) and ravelling (right)

Also, minimum one section of each pavement without distresses was considered as reference. In Table 1 all the combinations that were investigated, are presented.

Table 1. Number of distresses observed by pavement type

	Distress		
Pavement type	Alligator cracking	Ravelling	Without distress
AC	3	2	2
GGAR	1	2	2
GGA	2	1	1

2.3 Data acquisition

The method used to acquire tyre-pavement noise was the Close Proximity Method (CPX) described in ISO 11819-2: 2000: "Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 2: Close Proximity Method". For the acquisition of the noise generated by the tyre-pavement interaction, two Free-field ½" Type 4190 microphones were connected to the Pulse Type 3560-C portable platform using AO-0419 cables (all from Brüel & Kjær). The Pulse platform was powered by a portable battery, and connected through a network cable to a laptop computer. The microphones were connected to the Pulse platform, which in turn was connected to a portable computer where the sound acquisition was controlled through the Brüel & Kjær's Labshop 14.1.1 software. The tests were done with a Continental ContiEcoContact3 195/65-R15 tyre applied to a light vehicle to represent normal road traffic noise [7].

The data acquisitions were made for three different speeds (30, 50 and 65 km/h) on each test site at least twice. The audio files were then cut into time fragments equivalent to 50 metres (6,00; 3,60; 2,77 s), which is a length in the range of those used in road engineering for performance assessment of the pavement condition. Only those respecting the speed level and free of unwanted noises were considered. At last, the A-weighted equivalent sound pressure level (L_{Aeq}), *Loudness*, *Roughness*, and *Sharpness* were calculated using the Matlab® based audio analysis packages AARAE and Psysound3 [8].

2.4 Data analysis

To support the data analysis for sound indicators were selected: A-weighted sound pressure level (L_{Aeq}), *Loudness*, *Roughness,* and *Sharpness*.

The A-weighted equivalent sound pressure level is an average of the total sound energy measured over a specified period, weighted by the A-curve [9]. *Loudness* is a psychoacoustic indicator that quantifies the perceived intensity of a sound. It essentially shows how strong or intense an auditory noise is to an individual [10]. The *Sharpness* is a psychoacoustic indicator to measure the high frequency components of a given sound. It can be interpreted as the ratio of the high-frequency components to the overall sound level. It can be also understood as the "centre of gravity" of a spectrum on a frequency scale. The higher the centre of gravity, the sharper the sound and vice versa [10]. *Roughness* is related to sensory dissonance [11]. It is the beating sensation produced by the interaction of two or more components that are sensed within a certain distance in the inner ear. That is, *Roughness* describes sounds with modulations between 20 and 300 times per second.

Loudness has been assessed in accordance with ISO 532-1:2017, *Sharpness* was calculated using the Zwicker and Fastl model [12], and *Roughness* using the Daniel and Weber model [13].

3. RESULTS AND ANALYSIS

Next, for each acoustic and psychoacoustic indicator, the results are presented and the effects of speed, distress and type of pavement are analysed.

3.1 Equivalent sound pressure level

To compare globally the noise levels generated by the distresses, alligator cracking (ACR) and ravelling (R), on the three types of pavements selected (AC, GGA, GGAR), the average A-weighted equivalent sound pressure level of the distressed and non-distressed pavement sections (N) was calculated. In Figure 2 those values are presented together with the fitting curve.

It is clear that distressed pavements generate more noise. Also, the difference of the noise level between distressed and non-distressed pavements reduces with the speed, about 4,0 dBA at 30 km/h and 1,5 dBA at 65 km/h. Therefore, the impact on L_{Aeq} of distresses, such as alligator cracking and ravelling, is higher at low speeds. Also, the equivalent sound pressure levels of cracked and ravelled pavements are similar. Furthermore, the standard deviation was higher for the distressed pavements, ranging from 1,4 to 1,6 dBA. For the non-distressed pavements, it was about half.

The noise level of the distressed pavements, likewise the non-distressed, can be described by a linear model (Figure 2) with a high determination coefficient (R^2 = 0,98).

In this case, the contribution of each distress type to the overall noise is similar (Figure 3). In average, the noise measured in pavements with alligator cracking (ACR) and ravelling (R) is similar at each speed level.

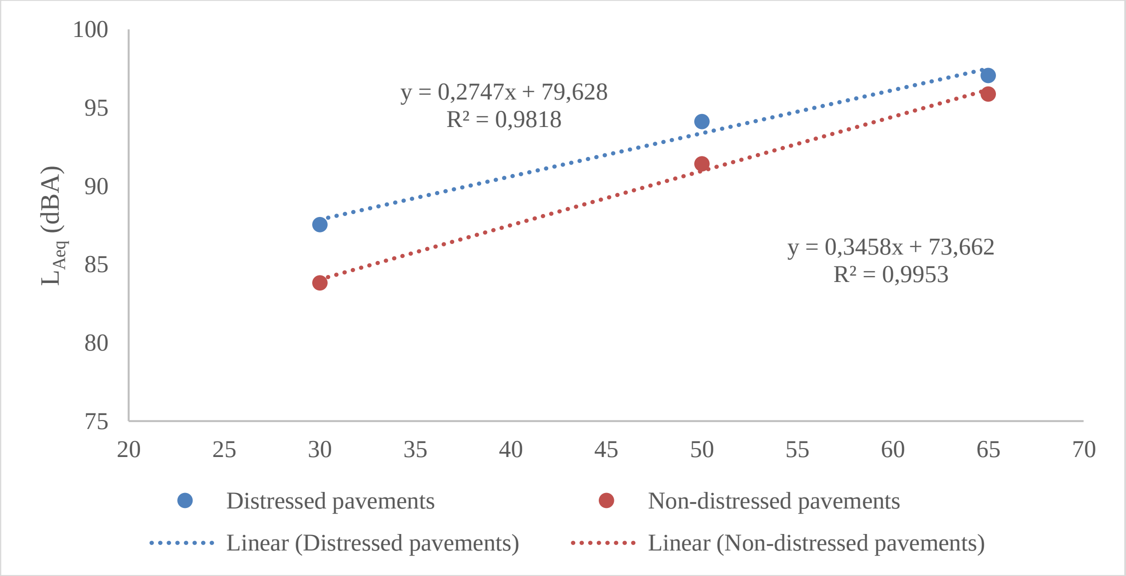

Figure 2. CPX average A-weighted equivalent sound pressure levels of distressed and non-distressed pavements

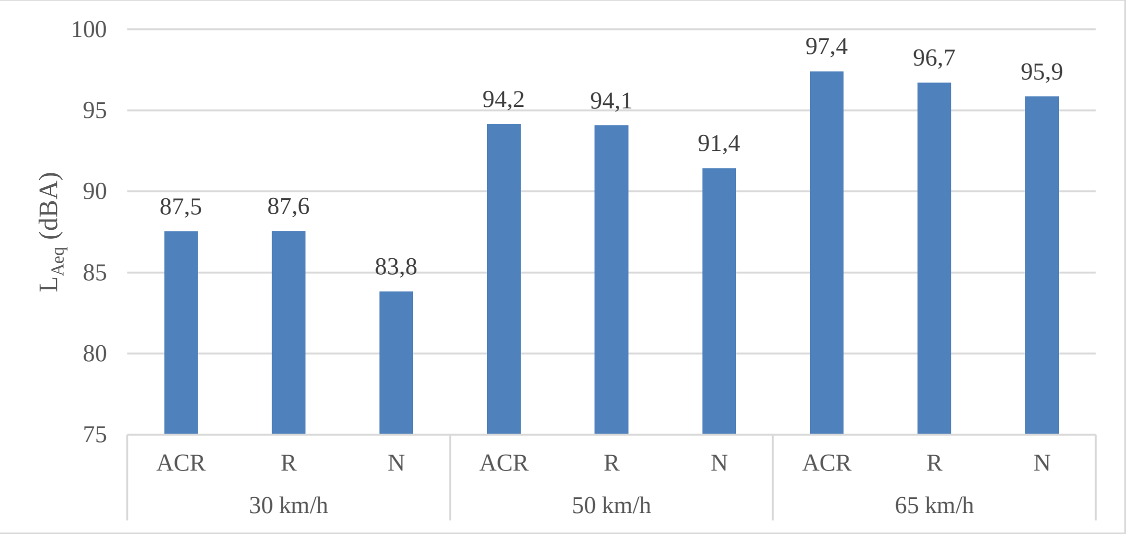

Figure 3. CPX equivalent sound pressure levels averaged by type of distress

However, when also investigating the influence of the pavement type, as presented in Figure 4, ravelled AC and GGAR pavements generate more noise whereas in the case of GGA it is the alligator cracking. When comparing the noise levels with the non-distressed condition, ravelling on GGA seems to have a very limited impact on noise.

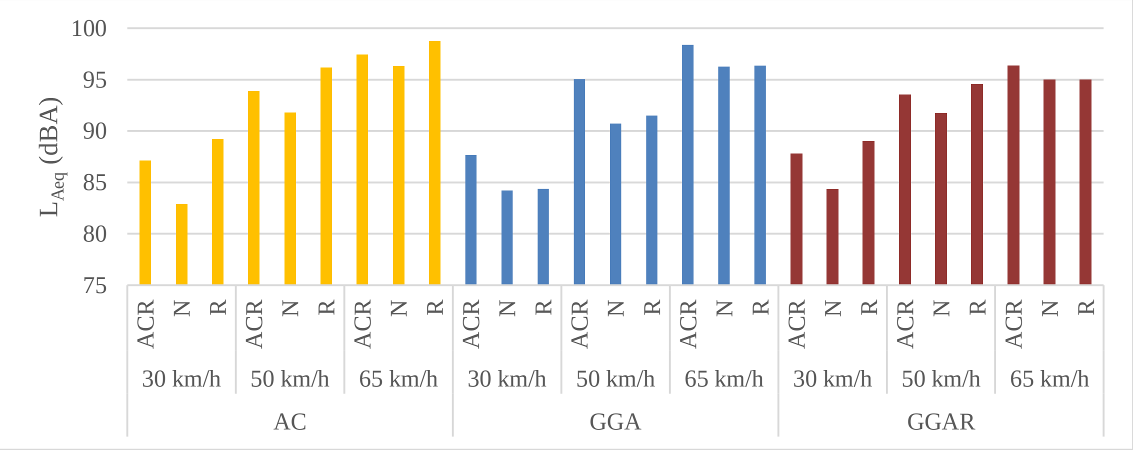

Figure 4. CPX equivalent sound pressure levels by pavement, speed and distress type

3.2 Loudness

The average *Loudness* of the distressed pavements is also higher than for non-distressed pavements (Figure 5). Again, the effect of distresses is higher at low speeds than at high speeds. The standard deviation was around 7 sone for all speeds on distressed pavements, while the non-distressed had a much lower value, 1,67 sone at 30 km/h and 3,8 sone at 50 and 65 km/h. Similar to the equivalent noise level, *Loudness* can be described by a linear model with an excellent determination coefficient (R^2 = 0,99).

In average, pavements with ravelling and alligator cracking have the same *Loudness* (Figure 6), approximately 68, 97 and 120 sone respectively at 30, 50 and 65 km/h. Therefore, these distresses represent a loudness increase up to 25%.

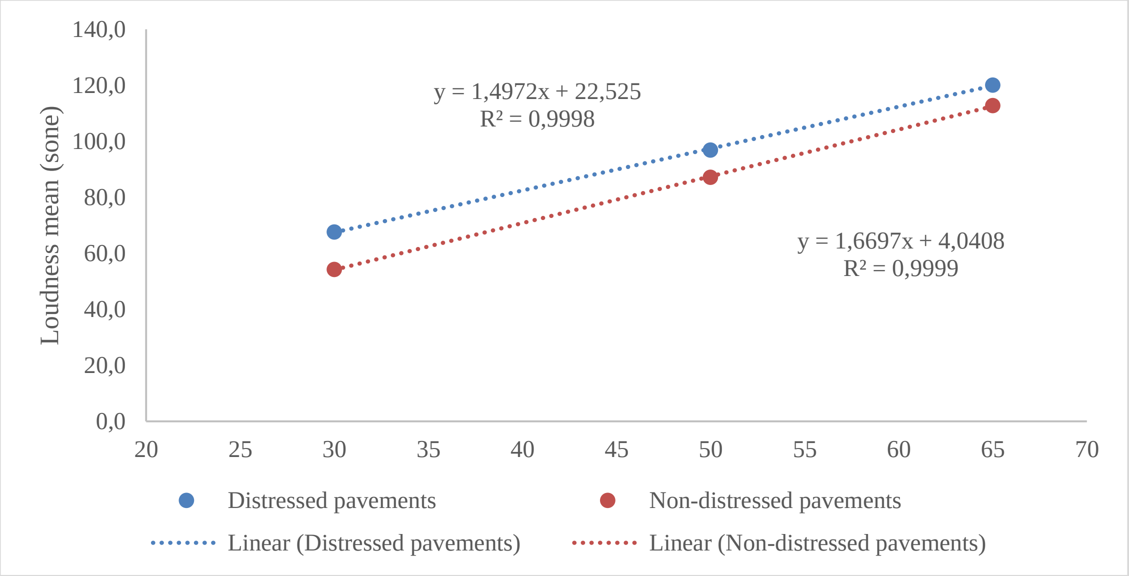

Figure 5. Average Loudness of distressed and non-distressed pavements

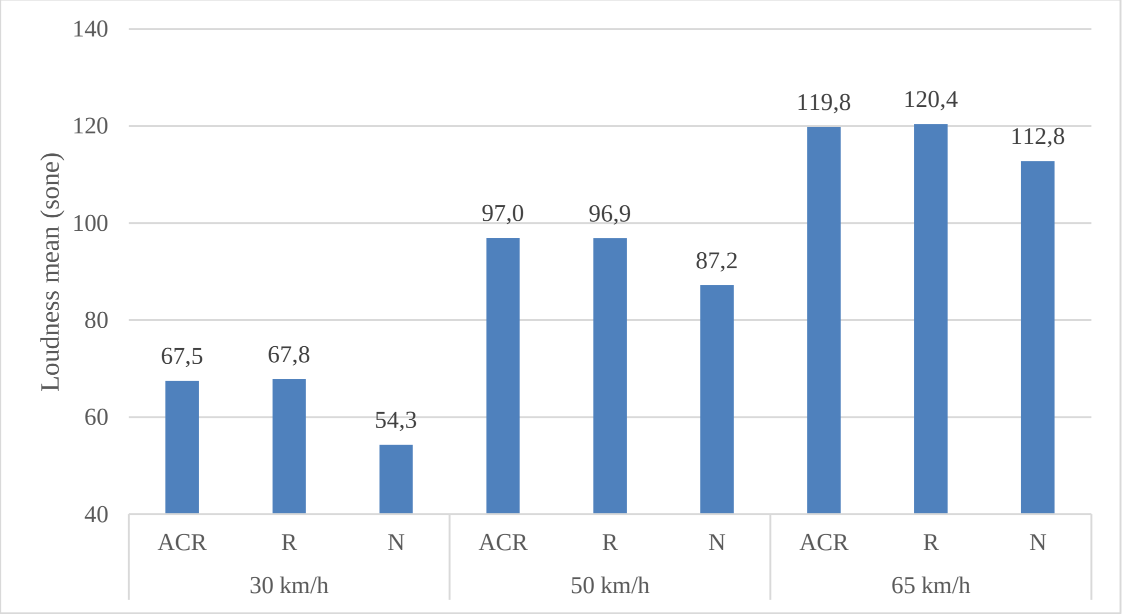

Figure 6. Loudness averaged by type of distress

Nevertheless, the effect of distresses on *Loudness* is different for the three pavement types (Figure 7). The GGAR shows the smallest effect, and seems relevant only at 30 km/h. The *Loudness* is higher on pavements with alligator cracking, for the GGA, while with ravelling it is for the AC.

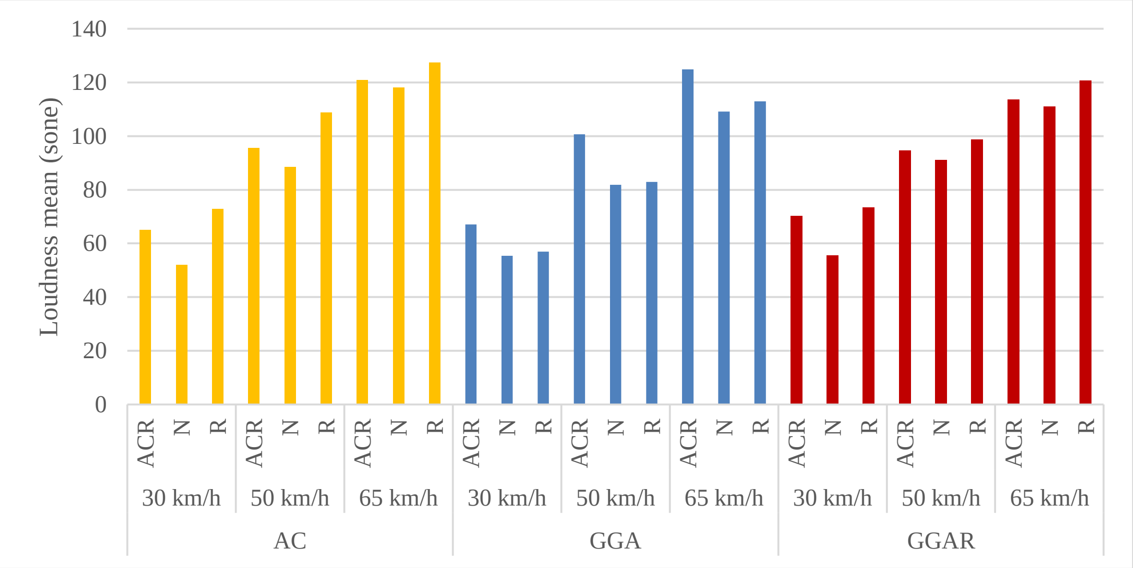

Figure 7. Loudness by pavement, speed and distress type

3.3 Roughness

Figure 8 presents the average *Roughness* of distressed and non-distressed pavements. For this indicator, it is also clear that distressed pavements provide higher values. For both distressed and non-distressed pavements, *Roughness* increases with speed. Despite the very good linear fit, at 50 km/h the *Roughness* of distressed and non-distressed pavements is very close. This result was affected by ravelling (Figure 9) which is lower than the non-distressed condition. The standard deviation of *Roughness* increases with speed for pavements without distresses, but with distresses its value is steady and around 0,07 asper.

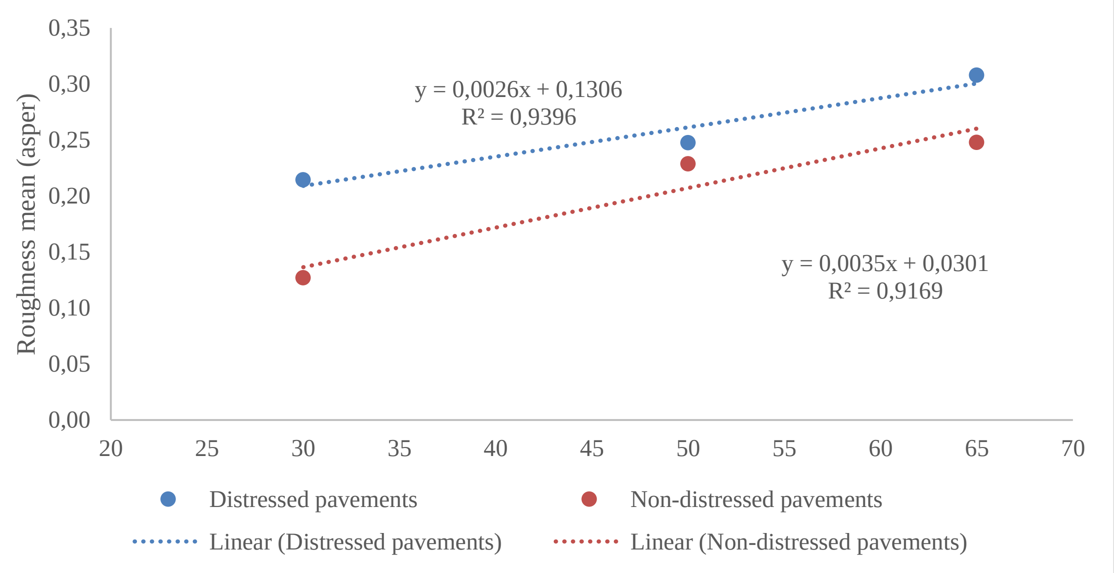

Figure 8. Average Roughness of distressed and non-distressed pavements

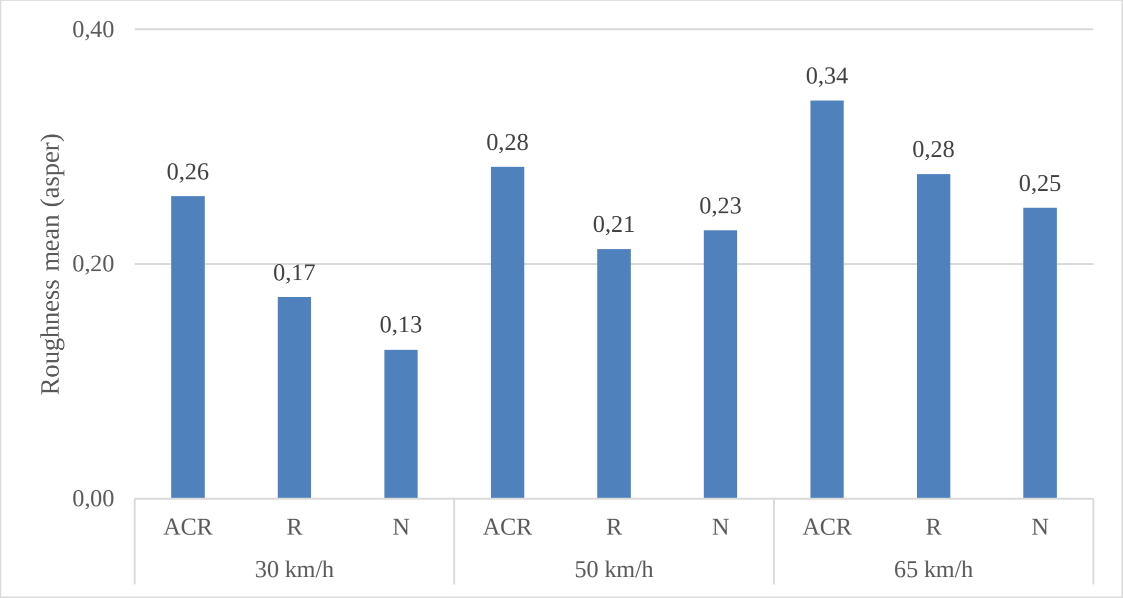

Figure 9. Roughness averaged by type of distress

In its turn, pavements with alligator cracking have much higher *Roughness*, as can be seen in Figure 9. At 30 km/h the *Roughness* is even double compared to the non-distressed situation, and at 65 km/h it is 26% higher. *Roughness* is less sensitive to ravelling. At 30 km/h it is clear that ravelling affects *Roughness*, although at higher speeds a deeper analysis is required.

Figure 10 shows the results of the average *Roughness* for each pavement type and distress. For ravelling, the *Roughness* of GGA and GGAR is similar or even lower than for the not distressed condition. For the AC and GGA pavements this indicator is very sensitive to the presence of alligator cracking at all speeds and for that reason could be a good indicator to identify the presence of alligator cracking.

The average *Roughness* of the 3 pavements is similar - 0,25, 0,24, and 0,23 respectively for AC, GGA and GGAR. Nevertheless, at higher speeds, the GGAR is rougher for the non-distressed condition. This performance may be determined by the presence of rubber in the asphalt. This hypothesis requires further investigation.

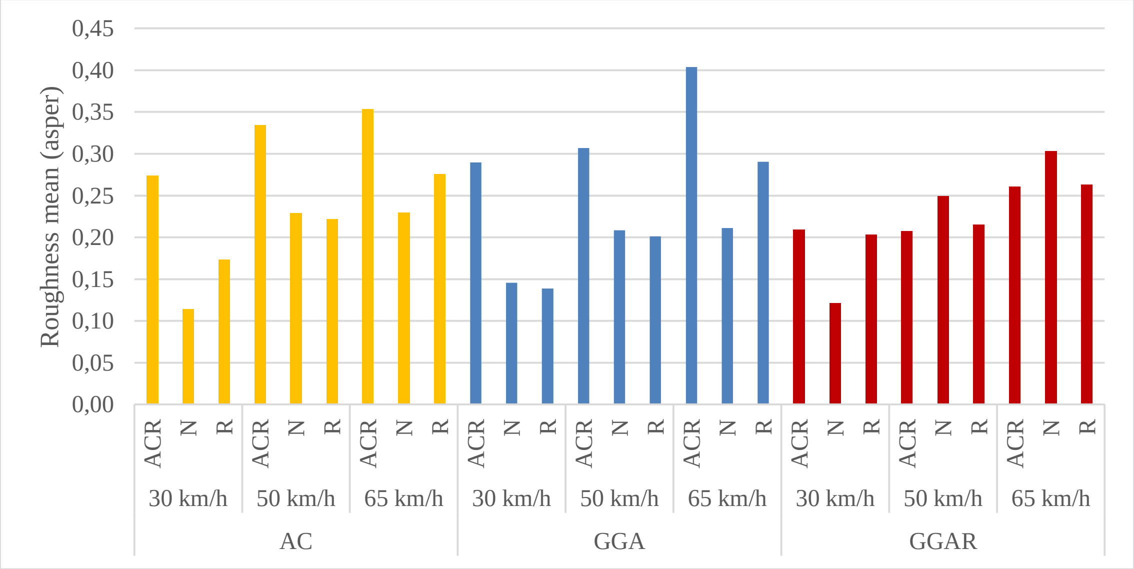

Figure 10. Roughness by pavement, speed and distress type

3.4 Sharpness

As can be seen in Figure 11, *Sharpness* is also higher for the distressed pavements. Despite the good linear fit, the increase of *Sharpness* with speed is very small, particularly for the distressed pavements. At low speed there is an increase of about 10% but at high speed the difference is negligible (2%). Whereas the standard deviation for the *Sharpness* of distressed pavements at all speeds is approximately 0,02 acum, for non-distressed pavements it reduces with speed but it is also much higher. It reached 0,05 acum at 30 km/h.

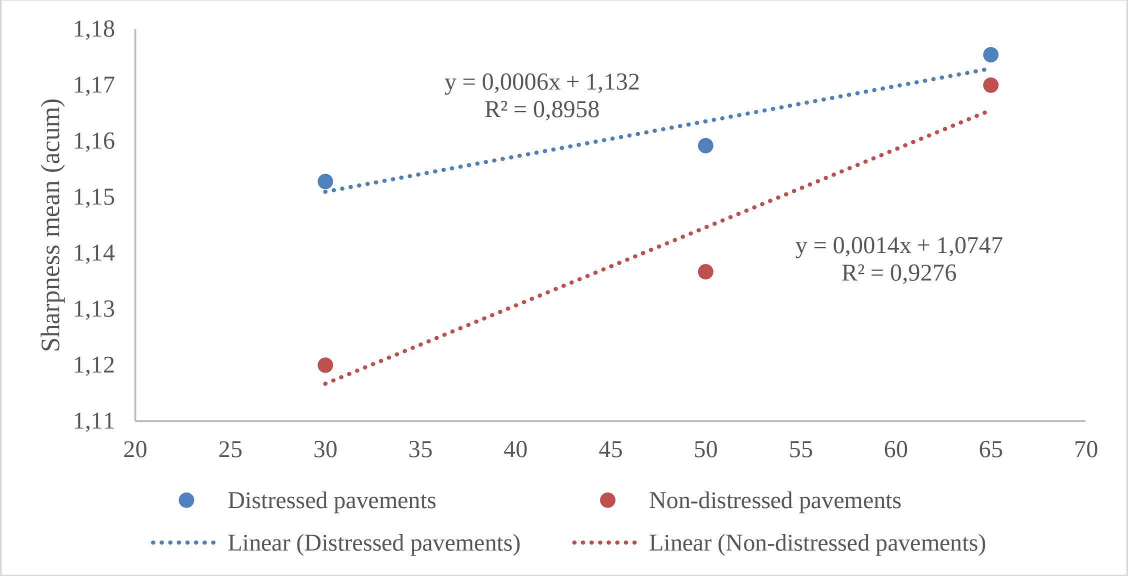

Figure 11. Average Sharpness of distressed and non-distressed pavements

Furthermore, the variation registered in *Sharpness* comes mainly from the effect of alligator cracking (Figure 12). As a maximum *Sharpness* had an increase of about 4%. Ravelling and no distress show similar values, which indicates that high frequencies of noise spectrum are not affected by this distress type.

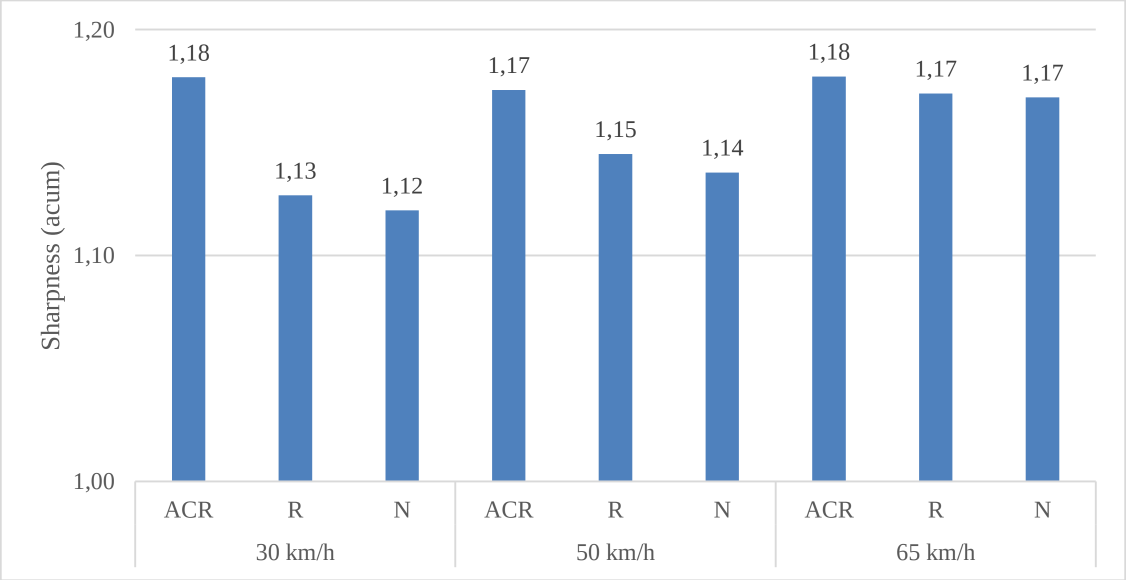

Figure 12. Sharpness averaged by type of distress

The AC and GGAR have clearly high *Sharpness* due to the effect of cracking whereas the GGA is more affected by ravelling at high speeds (Figure 13).

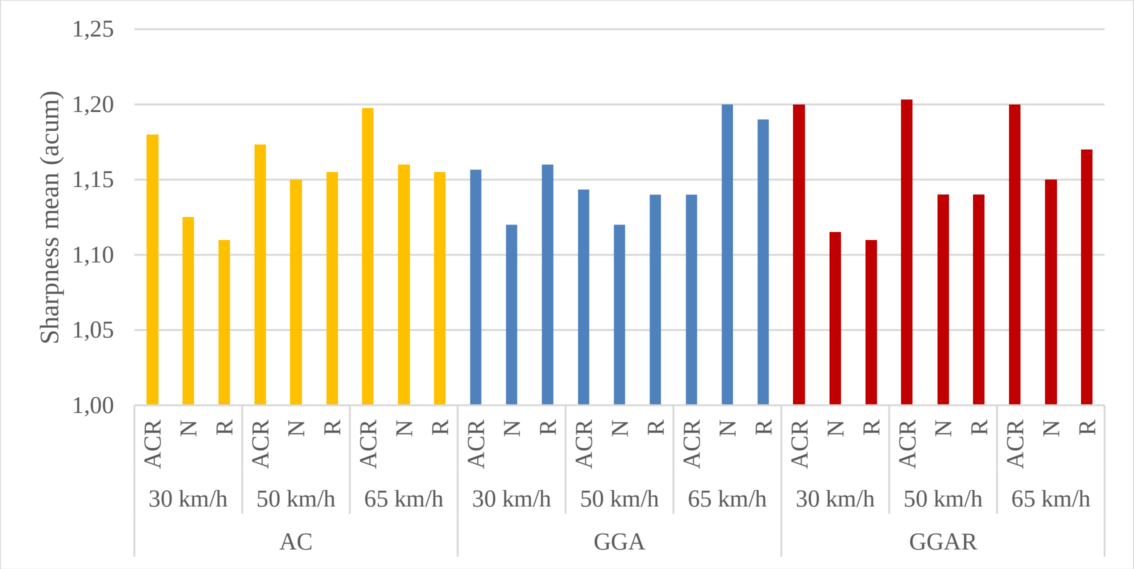

Figure 13. Sharpness by pavement, speed and distress type

4. CONCLUSIONS

In this study the tire-road noise, measured by the Close Proximity method, of 21 road sections with alligator cracking, ravelling, and also without distresses were analysed, considering the factors traffic speed and pavement type. In the analysis acoustic and psychoacoustic indicators were used to incorporate human response to different sound features.

The results showed that distressed pavements have clearly higher noise levels and their effect is generally higher at low speeds, while at high speeds differences with respect to the non-distressed condition are smaller or even negligible.

The performance of the indicators L_{Aeq} and *Loudness* is similar and both indicators have a perfect linear relation with speed. Also, both indicators do not have the ability to distinguish alligator cracking from ravelling, since they provide in average approximately the same values for these distresses, requiring thus a detailed analysis.

Roughness and *Sharpness* also have a linear relation with speed. The first is highly influenced by distresses, while the second changed very little. *Roughness* is capable of distinguishing alligator cracking from ravelling, exhibiting much higher values for the first. In fact, the *Roughness* of ravelled pavements is close to the non-distressed ones. This means that alligator cracking increases the tyre-road noise modulation frequency and therefore the unpleasantness of the sound. In its turn, the high frequencies of the noise spectra change slightly which means that both alligator cracking and ravelling have little effect on the high frequencies in the tyre-road noise.

Nevertheless, further research is required to generalise these results. The sample is limited and the results depend also on tyre characteristics. Consequently, to carry out this study with other tyres and increase the number of sections is essential.

To integrate psychoacoustic indicators as a complement to the acoustic indicators on tyre-road noise analysis, a fundamental next step would be to define comfort limits specifically for this type of noise.

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