Validation of reference tyres and temperature correction for Close-ProXimity (CPX) method

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ABSTRACT

In the ROSANNE project (acronym for "ROlling resistance, Skid resistance, ANd Noise Emission measurement standards for road surfaces") Work Package four deals with texture influence, reference tyres and surfaces. One objective is to study the performance of various reference tyres, to ascertain their reproducibility and stability over time. In the light of the ongoing writing of ISO/TS 11819-3 regarding reference tyres, research was performed to fill up some gaps. CPX measurements were repeated with new P1 and H1 tyres at various kilometers run-in on 10 road surfaces to verify the influence of run-in. Additionally measurements were performed with three sets of P1 tyres on these 10 road surfaces to verify the reproducibility. Influence of mounting direction of new P1 tyres was verified on a porous mastic asphalt to supplement available research. Work Package two deals with measurement methods for noise emission properties. One task is temperature influence and correction. In the frame of the ongoing writing of ISO/TS 13471-1 about temperature correction for CPX method, a measurement campaign was done on a poroelastic road surface. 24 measurements were performed with P1 tyre with air temperature range from 9 to 22 °C.

Keywords: road, tyre, temperature I-INCE Classification of Subjects Number(s): 11.7.1, 24.6, 52.3, 81.2.1

1. INTRODUCTION

The paper focuses on work performed in the frame of the EU financed ROSANNE project (1). This project deals with developing and harmonizing measurement methods for skid resistance, noise emission and rolling resistance of road pavements as a preparation for standardization. Only performed research regarding reference tyres and temperature correction for CPX noise measurements according to ISO 11819-2 is discussed here.

ROSANNE aims at developing and improving standards in the field of CEN and ISO groups. The authors are member of working groups ISO/TC 43/SC 1/WG 33 (Measuring method for comparing traffic noise on different road surfaces) and ISO/TC 43/SC 1/WG 27 (Effect of temperature on tyre/road noise testing) for which the work presented in this paper is relevant as at the time of the investigation the drafting of ISO 11819-2, ISO/TS 11819-3 and ISO/TS 13471-1 was going on.

A small part of the research is related to the European PERSUADE project (2) which aimed at developing a PoroElastic Road Surface (PERS) with high noise reducing properties together with increased lifetime under road traffic (3). Various PERS test sections were constructed (4) and monitored (5, 6). The monitoring raised the question which temperature correction could be applied for noise measurements on such a special new road surface. This is related to a task foreseen in ROSANNE regarding temperature correction.

Section two introduces the test locations and road surfaces which were tested with CPX measurements while section three gives an overview of the test tyres which were used along with their main characteristics.

Section four deals with the performance of test tyres and reports the results of the research conducted with respect to tyre run-in, tyre mounting and reproducibility.

Section five concerns the investigation regarding temperature correction on PERS.

In section six some conclusions are given.

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2. TEST LOCATIONS

2.1 Thin noise reducing asphalt layers on a regional road in Kasterlee

The regional road N19 Turnhout-Kasterlee in Belgium is a road with two lanes in each direction. A stretch of 2 km long is divided into 10 sections of each 200 m length.

Two sections can be considered as reference surfaces: stone mastic asphalt with a maximum aggregate size of 10 mm (SMA10, test section one) and double layer Porous Asphalt (2-layer PA, test section five). The eight remaining sections are paved with noise reducing thin asphalt layers.

More information about the test sections and the project, for which they were constructed, is reported by Bergiers (7).

It should be noted that test sections two, three, four and five are in bad condition. Shortly after the writing of the paper they were planned to be replaced by another pavement. At the time of the measurements 2-layer PA was in the worst condition and thin layers two and three showed some raveling.

2.2 A porous mastic asphalt on a highway in Lohmar

On the highway A3 Lohmar in Germany a special road surface was constructed in 2013, namely a Porous Mastic Asphalt (PMA), which is a mastic asphalt with an open structure.

The idea is to have a closed structure at the bottom of the top layer, combined with an open structure at the surface, which results in a good acoustic quality. Large stone aggregates are used in combination with very fine aggregates with dimensions of maximum 1 mm and a reduced proportion of filler.

Ripke reports about a first trial with this special road surface in (8).

2.3 A poroelastic road surface on a country road in Herzele

In the frame of the PERSUADE project (2), a test section with a PoroElastic Road Surface (PERS) of 40 m length was constructed in September 2014 on a country road in Herzele Belgium.

PERS is a non-conventional pavement, consisting of rubber granules bound with a synthetic resin, such as polyurethane. It is elastic and has a high void content.

Noise reductions up to 9 dB(A) have been measured on this test section in comparison with and old asphalt concrete at the reference speed of 50 km/h (6, 9).

3. Test tyres

In Table 1 an overview is given of the test tyres that were used for the measurements.

Tyre sets S1 and S2 are test tyres owned by the German Federal Highway Research Institute BASt (courtesy of Marek Zöller). The others are owned by BRRC.

Tyre types P1 and H1 are reference tyres as specified in ISO/TS 11819-3 (10): “Standard Reference Test Tyre” (SRTT) P225/60R16 and “Avon Supervan AV4” 195R14C respectively.

The run-in direction of tyre sets S1, S2 and S4 is such that sidewalls with DOT marks (including production week/year number) are facing the microphone. Tyre set S3 is run-in according to the arrow which is marked on the tyres indicating the rotational direction, implying that for the left tyre the sidewall with DOT mark is not facing the microphones. On tyre set S1 no such preferred rotational direction arrow is marked. Only most recent P1 tyres have this arrow marking (S2 and S3). Tyre sets S2 and S3 have the same DOT number although the shore A hardness (H_A) differs slightly.

Table 1 – Overview of test tyres used.

Tyre set	Tyre type	H_A left-right (measured May 2015)	DOT	Owner	Rotational direction (arrow)	Run-in direction
S1	P1	65.5-65.5	1811	BASt	No	DOT
S2	P1	63-62	0314	BASt	Yes	DOT
S3	P1	65.5-65.5	0314	BRRC	Yes	Arrow
S4	H1	60-60	3813	BRRC	No	DOT

4. Performance of reference tyres

4.1 Run-in

4.1.1 Measurement program and conditions

CPX measurements were performed at 80 km/h on the road N19 (see 2.1) with new P1 and H1 tyres to verify the influence of run-in. Tyre sets S3 and S4 were used (see Table 1).

A measurement campaign with tyre set S3 was done at 0, 100, 200, 400, 600 and 1200 km run-in in one week (beginning of April 2015), except for 1200 km, which was performed two months later (end of May 2015, temperature range 9.9 – 20.0 °C). The P1 tyres were mounted according to the arrow which is marked on the tyre, indicating the preferred rotational direction. Three runs were performed.

A measurement campaign with tyre set S4 was done at 0, 100, 300 and 400 km run-in on two consecutive days in April 2015 (temperature range 18 to 24 °C). Two runs were performed.

In Table 2 an overview is given of the measurement days and corresponding air temperatures.

Table 2 – Overview of dates and air temperatures of measurement campaigns with P1 and H1.

P1			H1		
Run-in [km]	Measurement date	Air temperature [°C]	Run-in [km]	Measurement date	Air temperature [°C]
0	08-04-15	9.9	0	17-06-15	22.5
100	09-04-15	17.5	100	17-06-15	24.3
200	09-04-15	19.2	300	18-06-15	18.5
400	10-04-15	20.0	400	18-06-15	18.0
600	13-04-15	13.8			
1200	27-05-15	18.6			

4.1.2 Results

All results are corrected for temperature to a reference temperature of 20 °C. For dense asphalt mixtures a temperature correction coefficient of -0.10 dB(A)/°C is used and for porous asphalt mixtures -0.05 dB(A)/°C (11). Test section five is the only porous asphalt mixture (two-layer PA).

Unfortunately air temperature differences up to 10.1 °C and 6.3 °C are registered for P1 and H1 respectively. For P1 a maximum deviation of 10.1 °C is noted with respect to the reference temperature while for H1 a deviation of maximum 4.3 °C is registered. It would have been better if all measurements had taken place at the reference temperature. Temperature correction implies some uncertainty: e.g. the selected correction coefficient has been determined with a certain error according to a model and the actual properties of the road surfaces may not be entirely representative for the selected road surface category.

Figure 1 shows the $L_{CPX:P,80}$ values for the 10 test sections and P1 at various kilometers run-in. For most test sections a small increase of $L_{CPX:P,80}$ is shown up to 200 km run-in, after which a small decrease is shown.

Test section five, which is the only porous test section, shows a small increase at 400 km run-in after a larger decrease of about 1 dB(A). Probably the temperature correction coefficient of -0.05 dB(A)/C° is too low because the surface is not porous anymore due to clogging. When applying the temperature correction coefficient for dense asphalt surfaces a more consistent result is found.

Unfortunately all reported differences are very small and of the order of the temperature corrections made, which yields a big uncertainty. The measurements at 100, 200, 400 and 1200 km were performed at similar temperatures (maximum 2.5 °C difference). When only looking at these, a certain tendency can be seen and one can state that the $L_{CPX:P,80}$ values stabilize after 400 km run-in.

Figure 2 shows the $L_{CPX:H,80}$ values for the 10 test sections and H1 at various kilometers run-in. For most test sections a significant increase is shown. The differences measured between 0 and 300 kilometers run-in are of the order of 0.5 to 1.5 dB(A) for H1, except for test section one, which is the reference surface SMA10. All the other test sections are noise reducing pavements. The influence of run-in seems to be larger for noise reducing pavements. After 300 km run-in the influencing effect stabilizes.

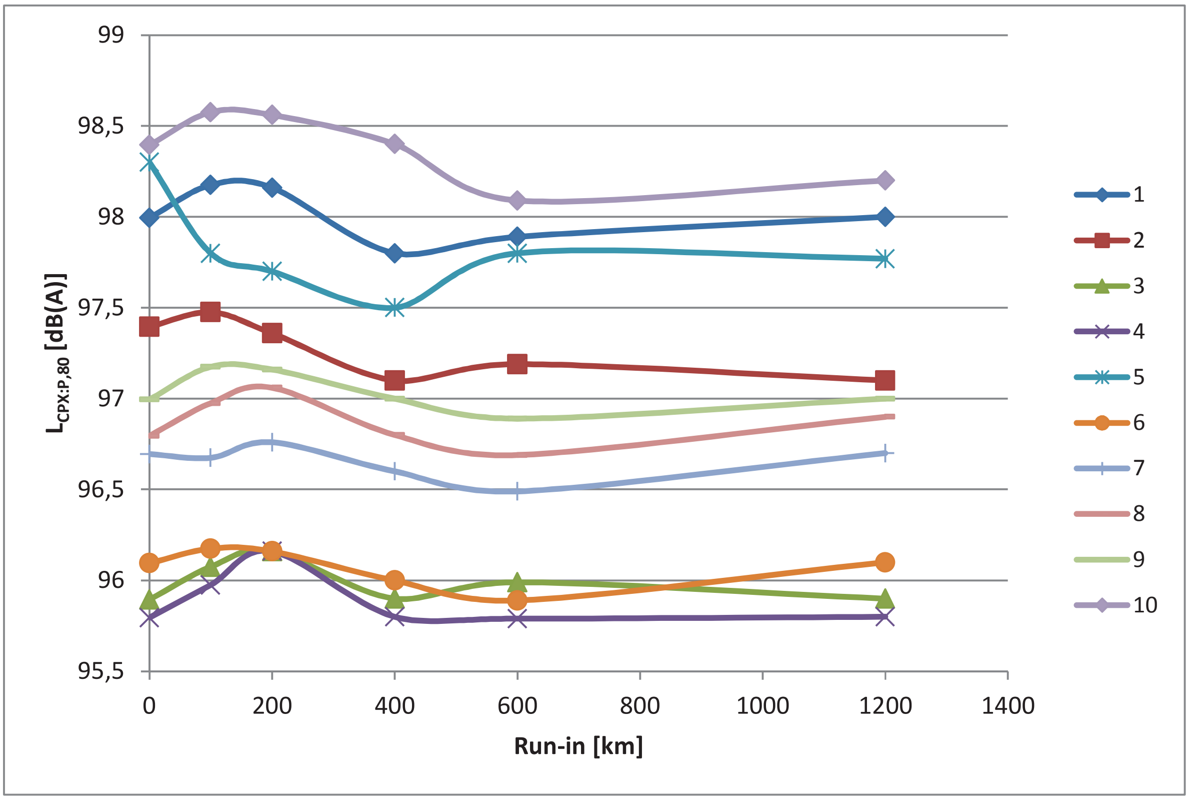

Figure 1 - $L_{CPX:P,80}$ as a function of kilometers run-in for 10 various test sections for P1 tyre at 80 km/h.

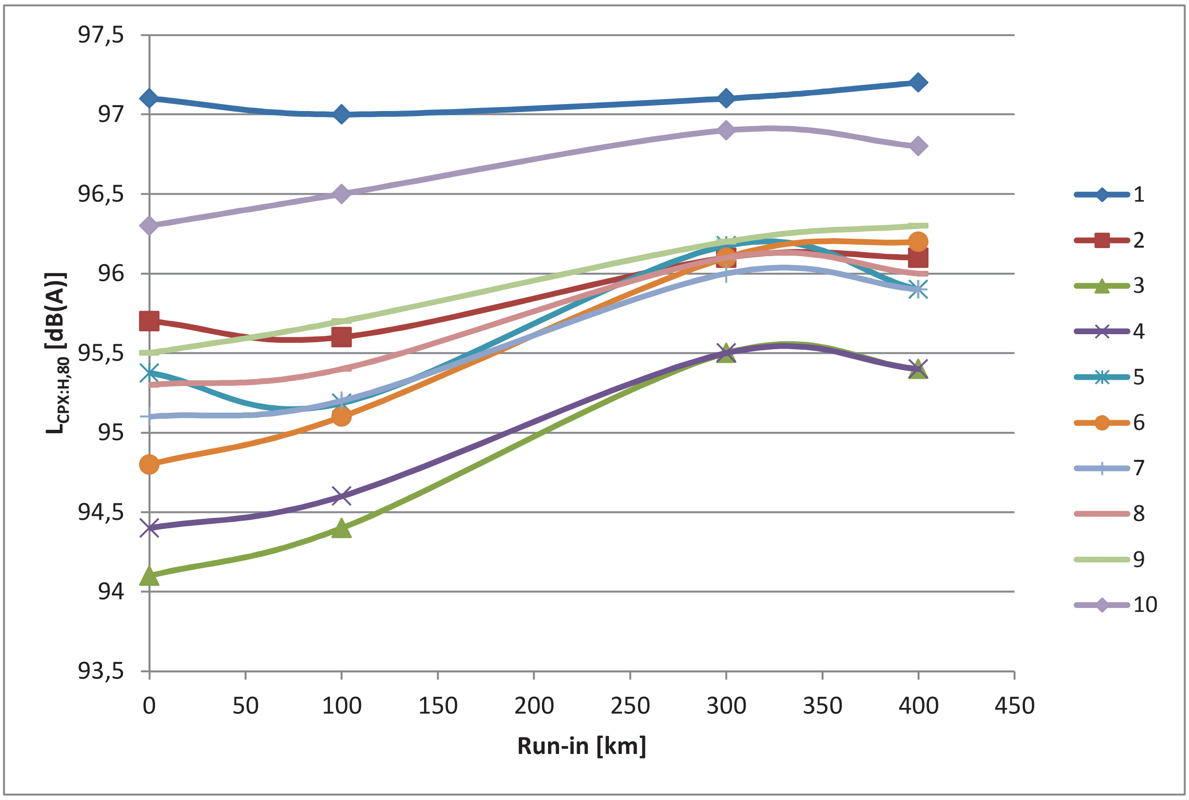

Figure 2 – $L_{CPX:H,80}$ as a function of kilometers run-in for 10 various test sections for H1 tyre at 80 km/h.

Based on all these findings it is recommended to perform at least 400 km run-in of a new tyre before using it to perform CPX measurements, as well for P1 as for H1.

4.2 Mounting direction

4.2.1 Measurement program and conditions

Research was performed by BASt and BRRC to investigate the influence of mounting direction for P1 tyre, because a rational direction mark (arrow) was added on recent P1 tyres by the manufacturer, which was not present before.

CPX measurements were performed by BRRC in June 2015 at 80 km/h at the highway A3 Lohmar on a PMA, see section 2.2, with tyre set S3 (see Table 1). Measurements were performed on two selected locations: one in direction Köln from kilometer points 17.0 to 16.0, the other in direction Frankfurt from kilometer points 15.2 to 17.5. At each location six runs were performed: three runs with regular tyre mounting, three runs with left tyre mounted on the right side and right tyre mounted on the left side without rim change. The latter implies that the measurement was performed with rolling direction opposite to the arrow marking and against run-in direction.

These measurements are meant to supplement previous research performed by Marek Zöller from BASt (12, 13). BASt reported about measurements on the same locations with BASt trailer using various mountings of tyre sets S1 and S2 (13) in June 2014 and November 2014 respectively. The shore A hardness of the tyre sets was lower than presented in Table 1 as the BASt measurements already took place in 2014: H_A 62 for tyre set S1 and H_A 61 for tyre set S2.

Unfortunately a longer section was measured by BASt in direction Köln compared to the one measured by BRRC as unforeseen road constructions obstructed to measure the whole section. However it is not expected that this will cause large deviations as the section that was measured by BRRC was still 1 km long.

4.2.2 Results

In the BASt research (13) CPX levels showed an independency from the alignment of the microphones (DOT or opposite side) for S1. Differences up to 2 dB(A) were reported between left and wheel track due to various wearing in the wheel tracks. CPX levels for S2 showed an offset of 1.5 dB(A) compared to S1. As at that time H_A differed only by one shore A between S1 and S2, it only explains 0.2 dB(A) of difference, see hardness correction in section 4.3.2. The left tyre of S2, which was run-in not respecting the arrow marking, showed a strong dependency on the rolling direction and alignment towards the microphones (difference up to 2.3 dB(A) depending on mounting position), while this was not the case for S1. It was not clear whether this difference was due to the run-in direction which was not respected or due to not respecting the rotational direction as indicated by the arrow marking.

Therefore BRRC performed measurements with S3, which is run-in respecting the arrow marking. The results are shown in Figure 3. Differences up to 2 dB(A) were found for the left tyre depending on mounting position, confirming the BASt results. In the BRRC case the highest value is seen for the tyre rotating in the run-in direction and respecting the arrow marking. In the BASt case the highest value is seen for the tyre rotating against run-in direction but respecting the arrow marking. This indicates that rather the rotational direction plays a role than the run-in direction.

When comparing measurements from both institutes, performed in the run-in direction (BASt not respecting the arrow and BRRC respecting the arrow), differences up to 3.9 dB(A) are found. A part of this difference may be related to the 4 shore A hardness difference which may explain about 0.8 dB(A), see hardness correction in section 4.3.2 . Another part may be explained by a winter which was in between the measurement campaign of BASt and BRRC yielding about 1 dB(A) of noise deterioration of the road surface. However the remaining 2 dB(A) remains unexplained. It demonstrates the importance of the mounting direction of the reference tyres since the arrow marking was introduced for recent tyres.

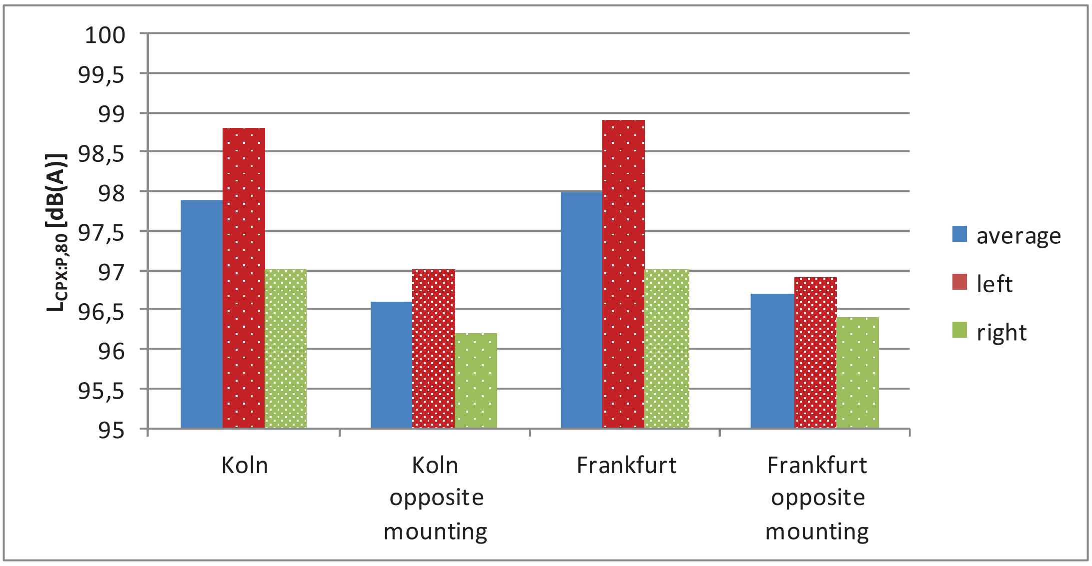

Figure 3 – $L_{CPX;P,80}$ of S3 (average, left and right tyre) at 80 km/h. The measurement direction is given on the horizontal axis. The pattern fill (dots) indicates the tyre which was used (left/right).

ISO/TS 11819-3 (10) which is under preparation, defines the mounting position. It is recommended to perform more research in controlled conditions in laboratory on a drum to investigate whether the instructed mounting position of P1 compromises the comparison between measurements performed with "former" P1 tyres and with "recent" P1 tyres. It is now instructed to be according to rotational direction marking and it used to be opposite for the left tyre with DOT sides facing the microphones.

4.3 Reproducibility

4.3.1 Measurement program and conditions

CPX measurements were performed at 80 km/h on the road N19 (see 2.1) with three different sets of P1 tyres to verify the reproducibility of the reference tyres. With each tyre set three measurement runs were performed.

Tyre sets S1, S2 and S3 were used (see Table 1). Tyre sets S2 and S3 are recent tyres on which the preferred rotational direction is indicated with an arrow mark on the tyres. Their shore A hardness differs slightly. Set S1 and S2 are run-in such that the sidewalls with DOT marks are facing the microphones. Tyre set S3 is run-in according to the arrow marking direction.

The measurements with tyre sets S1 and S2 were performed on the same day within two hours. The measurement with tyre set S3 was performed 3 weeks afterwards. However no large temperature difference was registered. Air temperature ranged from 18.6 to 19.0 °C.

4.3.2 Results

All results are corrected for temperature to a reference temperature of 20°C. For dense asphalt mixtures a temperature correction coefficient of -0.10 dB(A)/°C is used and for porous asphalt mixtures -0.05 dB(A)/°C (11). Test section five is the only porous asphalt mixture (two-layer PA). However as all registered temperatures were close to the reference temperatures, no large corrections had to be made.

All results are corrected to a reference shore A hardness of 66 ($H_{A,ref}$)with a correction coefficient of -0.2 per shore A according to TS/ISO 11819-3 (10). The H_A values of the various tyre sets are reported in Table 1. The following formula is used:

$$L_{CPX,corr} = L_{CPX,meas} - 0.2 \times (H_A - H_{A,ref}) \quad (1)$$

where $L_{CPX,corr}$ and $L_{CPX,meas}$ are the corrected and measured L_{CPX} levels respectively.

All results with temperature and hardness corrections are shown in Figure 4. Good correlations are found when comparing the results of the different tyre sets, see Figure 5.

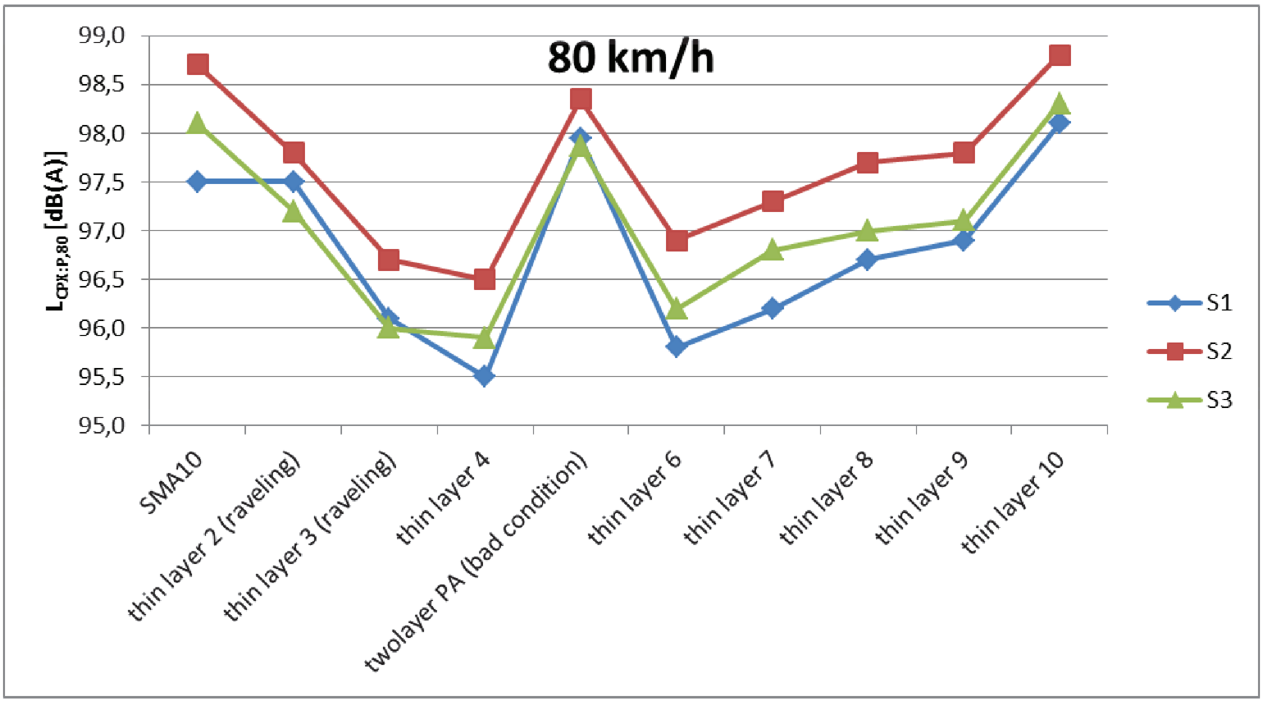

Figure 4 – $L_{CPX:P,80}$ values for three tyre sets on 10 different pavements at 80 km/h.

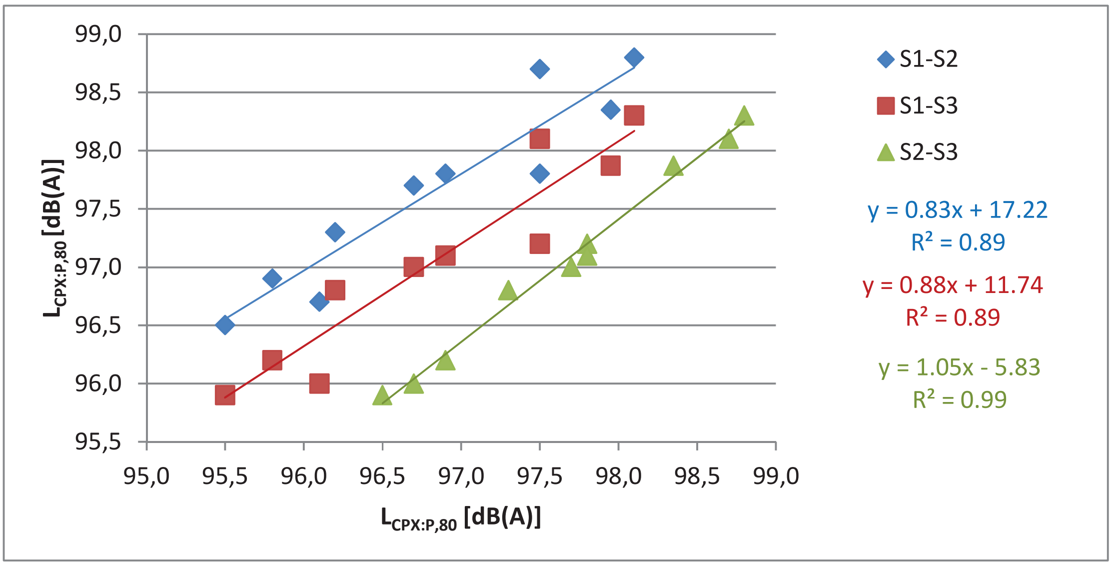

Figure 5 – Correlation between various tyre sets Sx-Sy at 80 km/h. The first mentioned tyre set is each time positioned on the horizontal axis.

An inconsistent result may be seen for SMA10 measured with S1. The reason for this is not known.

When not taking into account the pavements which are inhomogeneous and in bad condition (test sections two, three and five), the ranking of the pavements from low to high $L_{CPX:P,80}$ is the same for the three tyre sets. If one would measure with another tyre set of the same tyre type by using the same CPX measurement equipment, the same road surfaces would be ranked as the most or the least noise reducing.

However the absolute values differ slightly, especially for tyre set S2. For tyre set S2 the most shore A hardness correction was needed yielding more uncertainty. The largest differences are noted between S1 and S2 ranging from 0.7 to 1.2 dB(A), confirming an offset witch was found in earlier research by BASt, see also 4.2.2 (13). The difference between S2 and S3 ranges from 0.5 to 0.7 dB(A). The differences between S1 and S3 are from the order of 0.2 to 0.6 dB(A) and are the smallest. The largest differences between S1 and S3 are shown for the most noise reducing thin layers four, six, seven and eight (7).

S2 was run-in such that the sidewalls with DOT marks are facing the microphone, not respecting the arrow marking on the tyre. This may be an indication that it is better to respect the arrow marking rotational direction. A concern of the authors was that the introduced arrow marking on the tyre was indicating that the reference tyre had changed simultaneously. However as the differences between S1 and S3, tyre sets without and with arrow marking, are not so large, one may assume that the tyre did not change significantly when respecting the rotational direction for the new tyres.

5. TEMPERATURE CORRECTION

5.1 Measurement program and condition

On 24 April 2015 a CPX measurement campaign was organized on a special PERS surface, see 2.3, in Herzele. During six hours the same measurement was repeated in an attempt to determine the influence of temperature on the CPX measurements (one run per measurement). Air temperature ranged from 8.8 to 21.9 °C. Surface temperature varied from 11.0 to 38.6 °C. In total 24 measurements were performed at 60 km/h with P1 tyre set S3, see Table 1.

5.2 Results

The results are shown in Figure 6 (left) and (right) with respect to air temperature and surface temperature respectively. Temperature correction coefficients of -0.07 and -0.03 are calculated for air temperature and surface temperature respectively. An excellent correlation was found between the measurements of air temperature and surface temperature yielding a correlation coefficient of 0.98 (9).

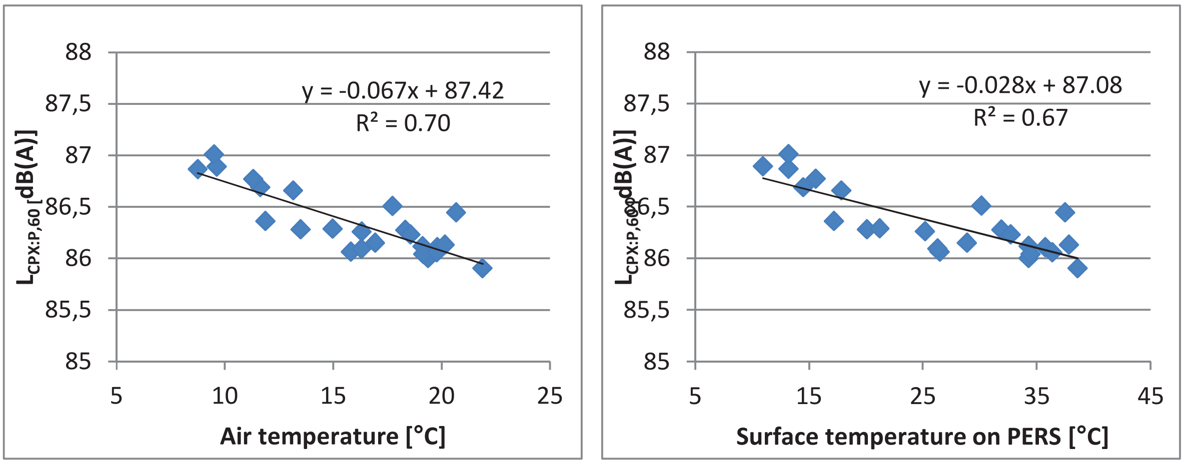

Figure 6 – $L_{CPX:P,60}$ levels as a function of air temperature (left) and surface temperature (right).

The frequency spectra of several measurements are shown in Figure 7. cpx_01 represents the lowest air temperature (8.8 °C) while cpx_24 represents the highest (21.9 °C). It appears that the temperature effect is the most visible at frequencies of 400-800 Hz and 2000-5000 Hz. The highest influence is noted at these higher frequencies. This is in line with other research (14), where the influence is the highest at low and high frequencies, while the peak frequency, often around 800 to 1250 Hz is less affected.

The air temperature coefficient corresponds to other research (15). Therefore the PERSUADE consortium decided to use a temperature correction coefficient of -0.07 for their final reports (16). Additionally the findings were used for the research regarding temperature influence of the ROSANNE project (17).

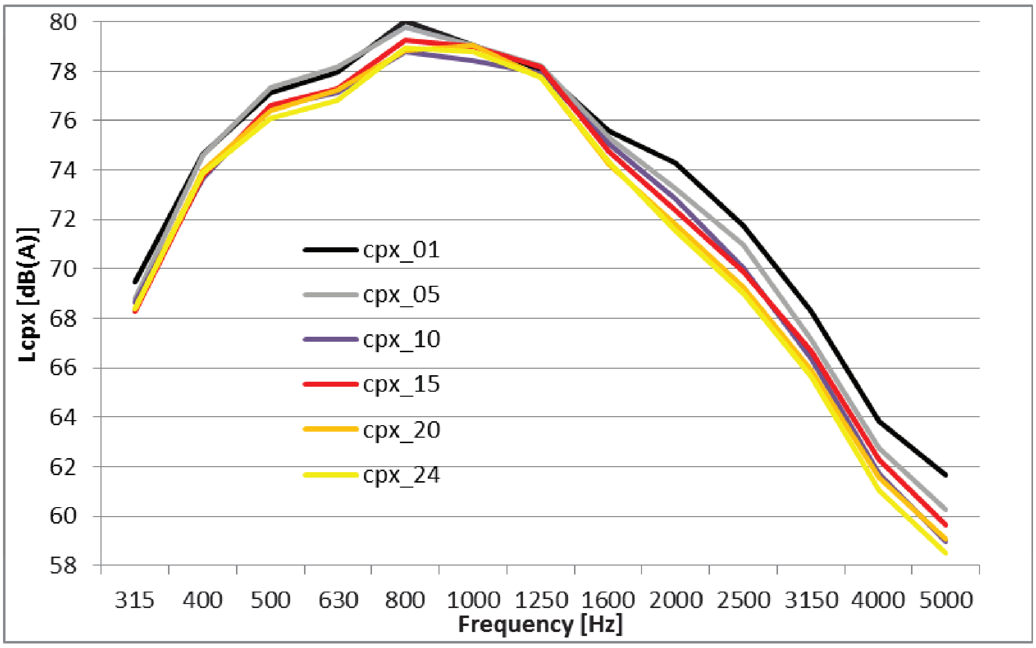

Figure 7 - Frequency spectra of six various measurements (01 to 24 from low to high temperature).

6. CONCLUSIONS

In this paper the performance of various reference tyres was investigated, namely P1 and H1. In the light of ongoing standardization work, an attempt was made to fill up some gaps.

The importance of run-in of test tyres was demonstrated, especially for H1 tyre. It is recommended to perform 400 km of run-in before using the test tyres to perform CPX measurements. What is more, the importance of run-in seems to be larger for noise reducing pavements.

An indication was given that further research is needed to investigate a possible change of reference tyre P1 when the rotational direction indicated with arrow mark was added on the recent tyres. It should be investigated further whether former versus recent P1 tyres and their changed mounting position for the left tyres (according to rotational direction marking or according to DOT side facing microphones) compromise the comparison between old and new measurements. It is recommended to perform a test in controlled conditions in laboratory on a drum to supplement this work. In any case the importance of the mounting direction was shown, especially for the recent P1 tyres with arrow marking. It is recommended to specify this clearly in the standard.

The reproducibility of P1 tyres was found to yield good correlations. The ranking of pavements from quiet to noisy is the same when using various tyre sets and when excluding inhomogene sections in bad condition or subject to raveling. An indication was given that respecting the rotational direction indicated with arrow marking on recent P1 tyres yields the best comparison in absolute values with the former P1 tyres without arrow marking. The largest differences between tyre sets were found for the most noise reducing pavements.

Temperature correction for CPX measurements on a poroelastic road surface was investigated. A temperature correction coefficient of -0.07 dB(A) per °C was found using air temperature. The temperature effect is the most visible at frequencies of 400-800 Hz and 2000-5000 Hz.

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