Temperature influence on tyre/road noise of selected tyres

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ABSTRACT

Air and road temperatures substantially affect road vehicle noise emission. The temperature influence on tyre/road noise depends mainly on tyre-road combination. It is different for dense and porous pavements, for bituminous and cement ones. It differs also depending on tyres. The correction procedures for temperature effect are still under consideration and preparation.

Tyre/road noise measurements using CPX method were performed to establish correlation between noise emission and ambient temperature for a set of ten selected tyres (characterized by a wide range of noise levels and including the two ISO reference tyres) on a SMA8 dense pavement within the recommended air temperature range from 5ºC to 30ºC with a step of about 5ºC. Both air and road temperatures were taken into consideration. The results of this experiment were presented and discussed in the paper. A good correlation between air and road surface temperature was outlined. A linear relationship between noise emission and temperature was observed for eight tested tyres. The derived temperature correction factor was varied from -0.067 dB/ºC to -0.145 dB/ºC with an average of -0.107 dB/ºC (-0.09 dB/ºC for the two ISO reference tyres). There was no correlation for the remaining two tested tyres.

Keywords: Tyre/road noise, Temperature influence, Measurement methods

I-INCE Classification of Subjects Number(s): 11.7.1

1. INTRODUCTION

Air and road temperatures, as well as tyre temperature, substantially affect tyre/road noise emission [1, 2]. The influence of temperature on tyre/road noise was noticed already in the 1980’s when performing noise measurements. Since that time numerous tests were conducted to show the temperature effect. Researchers have considered the effect of ambient air, road surface and tyre temperature on tyre/road noise and found pretty good correlation between noise emission and air, road or tyre temperature [1, 2, 3, 4]. For practical reasons the air temperature have been chosen to correct the measured noise values.

The temperature influence on tyre/road noise depends mainly on tyre-road combination. It is different for dense and porous pavements, for bituminous and cement ones. It differs also depending on tyres. But it would be very impractical to use different correction factors for each tyre-road combination.

Noise measurements using both the SPB and CPX method shall be performed when the ambient air temperature is within a range from 5ºC to 30ºC according to corresponding ISO standards [5, 6]. Reporting of the air temperature is mandatory for both methods and it is also recommended to measure road surface temperature. The obtained sound pressure levels should be normalized to a reference temperature of 20ºC. But the correction procedures are still under consideration and preparation. It is assumed that the noise-temperature relation is essentially linear phenomena and the temperature correction formula can be described as follows:

$$L_{A\,(20^{\circ}C)} = L_{A\,(T)} - CT_t \cdot (T - 20^{\circ}C) \quad (1)$$

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where $L_{A\ (20°C)}$ is the sound level in dB normalized to the reference temperature of 20ºC, $L_{A\ (T)}$ is the sound level recorded at a temperature of T degrees Celsius and CT_t is the temperature correction factor derived based on linear regression analysis of the noise-temperature relationship.

There are numerous publications dealing with temperature influence on noise emission [1, 2, 3, 4, 7, 8, 9]. According to the available literature, the temperature correction factors are within a range from -0.001 dB/ºC to -0.14 dB/ºC. For some specific tyre-road combination also positive values of this factor can be found.

The Working Group ISO/TC 43/SC 1/WG 27 of the International Standard Organization was established to propose a standardized method for correcting the effect of temperature on road vehicle noise measurements. The last proposal of temperature correction factors elaborated by this group is as follow [10]:

-0.10 dB/ºC for dense asphalt surfaces,
-0.05 dB/ºC for porous asphalt surfaces,
-0.07 dB/ºC for cement concrete wearing courses.

The same correction factors have been proposed for SPB and CPX method.

The temperature influence on vehicle noise emission is also one of the main tasks of the ongoing EU-founded FP7 project ROSANNE "ROlling resistance, Skid resistance, ANd Noise Emission measurement standards for road surfaces" [11] where the Work Package 2 of this project deals with measurement methods for the noise emission properties of road surfaces. The work presented in this paper was performed in relation to this project.

2. MEASUREMENTS

Tyre/road noise measurements using CPX method were planned and conducted to establish correlation between noise emission and ambient temperature. Both air and road temperatures were taken into consideration.

The experiment started in the winter of 2013 (first measurements are dated November 19, 2013) and finished in the summer of 2014 (the last measurements were performed on July 8, 2014). Measurements were performed in six selected measurement days within the entire period. Due to unfavorable weather conditions for testing in the spring of 2014 (a lot of days with precipitation) the distribution of test days in the entire campaign period was uneven. Half of measurement days were in June 2014. Nevertheless the temperature distribution was even within the entire range.

Tests were performed using the one wheel *Tiresonic Mk4* CPX trailer [12] (complied with ISO/DIS 11819-2) at a test section located on the fast lane of two lane road on the outskirts of Gdańsk city in Poland (see Figure 1).

Figure 1 – The CPX test vehicle *Tiresonic Mk4* at the test section and close-up of test surface (the diameter of coin is 21.5 mm)

The test section of SMA with 8 mm maximum aggregate size was laid in the summer of 2012 (it was 1½ ÷ 2 years old when measured). Measurements performed in the right wheel track of the fast lane (left lane) at a 200 m long distance with two test speeds: 50 and 80 km/h. At least 8 runs per speed/tyre/temperature combination were made to confirm repeatability.

Ten car tyres were selected for the experiment, including the two reference ones according to the proposed ISO standard [13]. The detailed data of tested tyres are presented in Table 1, their photos are shown in Figure 2. The selection was based on tyres of similar size, currently available on the market, labeled one up to three bars regarding the external noise emission (ranging from 68 to 73 dB) and class "A" to "E" regarding both: fuel efficiency and wet grip. Two of them are tyres that were specially designed for electric vehicles (designated 1076 and 1083). The ISO reference tyre P1 is designated as SRTT while the H1 tyre is denoted as AAV4.

The load of each test tyre was fixed to 3200 N and inflation pressure was adjusted to 200 kPa in cold condition according to the standard.

Table 1 – Parameters of tyres selected for experiment

Designation	Manufacturer	Tread	Size	Date code	Shore Hardness	EU Labelling			
						Fuel efficiency	Wet grip	External noise	Noise level
AAV4	**AVON**	**SUPERVAN AV4**	**195R14C 106/104N**	**4911**	**69**	-	-	-	-
SRTT	**UNIROYAL**	**TIGER PAW**	**P225/60R16 97S**	**3612**	**70**	-	-	-	-
1066	WANLI	S-1200	195/60R15 88H	4812	70	E	E	)))	73
1067	CONTINENTAL	ContiEcoContact 5	195/60R15 88H	1213	68	B	B	))	71
1071	VREDESTEIN	QUATRAC 3	195/60R15 88V	3712	67	E	C	)	68
1073	AVON	ZV5	195/65R15 91V	4112	67	C	C	))	71
1076	CONTINENTAL	Conti.eContact	195/50R18 90T	3512	63	A	B	))	71
1079	BRIDGESTONE	ECOPIA EP001S	195/65R15 91H	4612	57	A	A	))	69
1081	DUNLOP	Sport BlueResponse	195/65R15 91H	2413	66	B	A	)	68
1083	MICHELIN	ENERGY E-V	195/55R16 91Q	1212	64	A	A	))	70

Figure 2 – Photos of tyres selected for experiment

Tyre/road noise emission (SPL and 3rd octave bands) was measured using two microphones at "mandatory" positions. Noise measured for each segment was synchronized with speed, road and air temperatures as well as with GPS coordinates. Fully computerized measuring and data acquisition system, based on portable 4 channel *B&K PULSE* equipment, was used in the *Tiresonic Mk4* CPX trailer.

During measurements air and road surface temperatures were acquired with a precision of 0.1°C. Air temperature sensor was located on the moving CPX vehicle at a height of 1.4 m. The road surface temperature was measured „in the wheel track" using a non-contact infrared sensor also located on the test vehicle.

3. RELATIONSHIP BETWEEN AIR AND ROAD SURFACE TEMPERATURE

During the experiment the air temperature was changing in a range from 3 to 28°C. At the same time the acquired road surface temperature was within a range from 10 to 36°C. In steady conditions the air and road temperatures are at least directly proportional but in real life exceptions often exist especially in warm days. Significant changes in air temperature during daytime in June and July were observed when performing measurements. At the same time changes in road surface temperature were of smaller magnitude. The relationship between air and road surface temperature is presented in Figure 3.

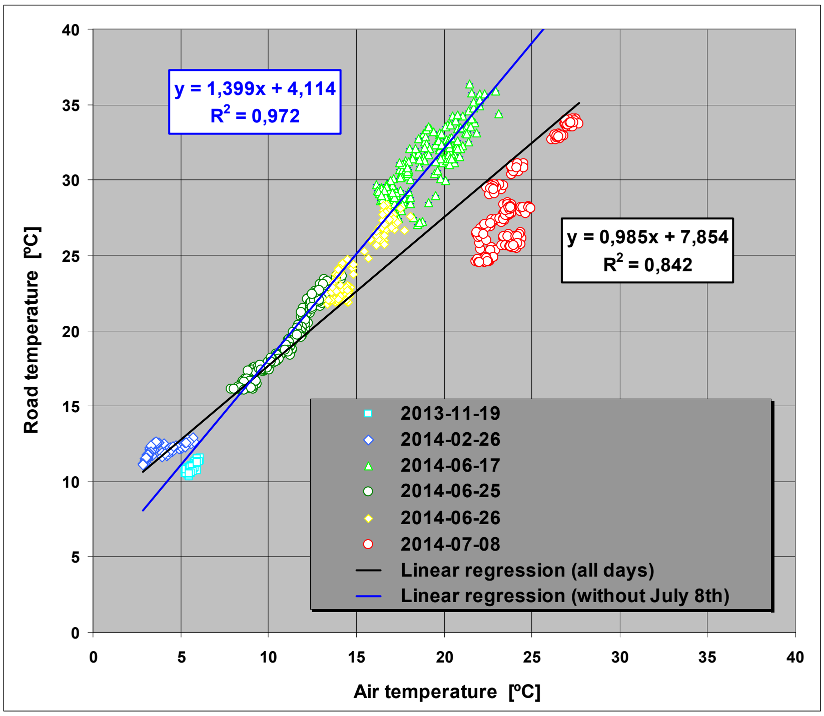

Figure 3 – Relationship between air and road surface temperature

Analyzing the data in Figure 3 one can observe that road surface temperature measured on July 8th do not correspond to air temperature. That day, tests were performed in the evening when road surface already dried up after a short rain shower. Air temperature was again relatively high but the rain has cooled down the pavement. Similar conditions may be present in real life quite often when performing measurements. One can also easy imagine possible similar situations e.g. when a test section is located in a shadow and is much cooler than located in an open area, or quite opposite situation – road section is exposed to direct sunlight and it remains still very warm in the evening while the air temperature has significantly dropped down.

Nevertheless generally, there is a very good relationship between air and road surface temperature. The coefficient of determination for linear regression is 0.84 for all points and 0.97 when excluding data acquired during the day with rain shower. One can expect that it should be no big differences between correlations of noise emission with air temperature and with road surface temperature.

4. TEMPERATURE EFFECT ON NOISE EMISSION

As it was mentioned before, the linear relationship between temperature and noise emission was taken into account and temperature correction factors were derived based on linear regression analysis. When performing evaluations of correlation between temperature and noise emission for particular tyre the coefficient of determination R^2 was assessed according the values given in Table 2.

Table 2 – Evaluation of coefficient of determination R^2

Coefficient of determination R^2		
Unsatisfactory	$R^2 < 0.5$	☹☹
Poor	$0.5 < R^2 < 0.6$	☹
Satisfactory	$0.6 < R^2 < 0.8$	😐
Good	$0.8 < R^2 < 0.9$	☺
Very good	$R^2 > 0.9$	☺☺

Detailed data obtained during the measurements for ISO reference tyres (SRTT and AAV4) are presented in Figures 4-7. The linear regression lines were plotted to show the temperature effects on tyre/road noise (equations are given in the figures).

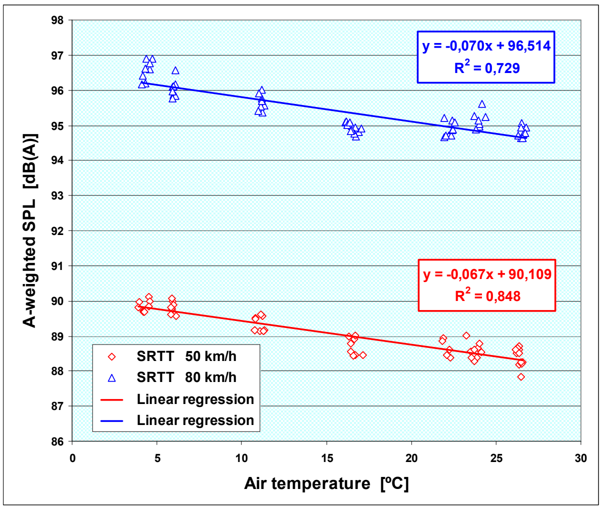

Figure 4 – Air temperature influence on noise emission for SRTT reference tyre

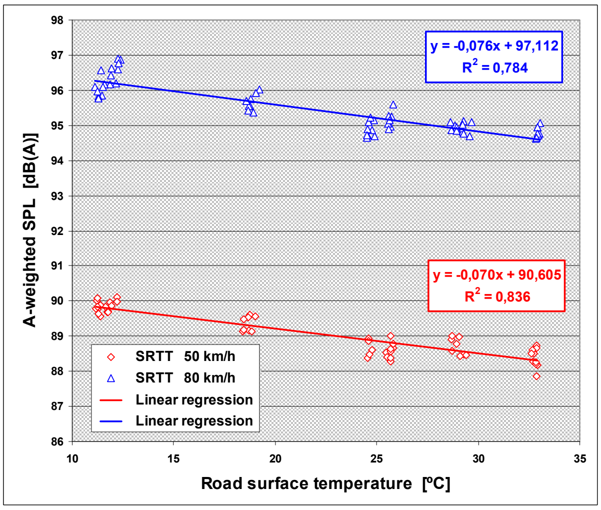

Figure 5 – Road surface temperature influence on noise emission for SRTT reference tyre

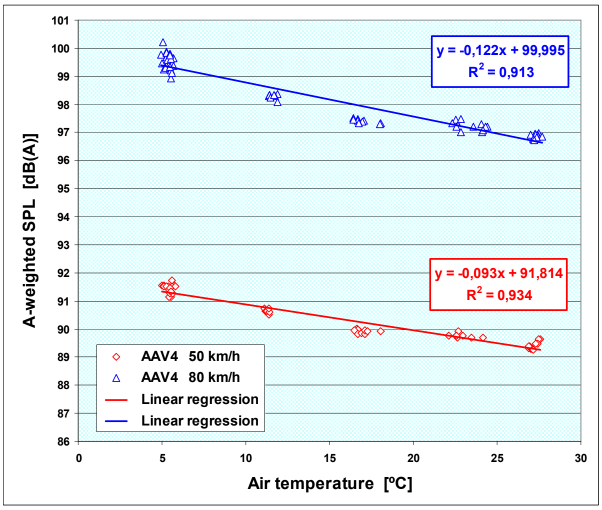

Figure 6 – Air temperature influence on noise emission for AAV4 reference tyre

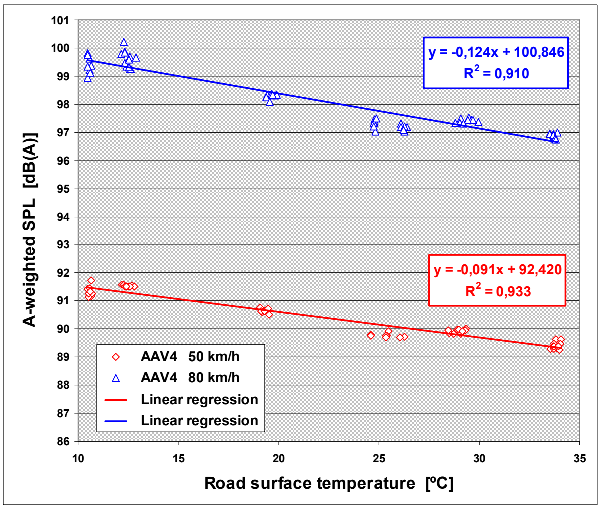

Figure 7 – Road surface temperature influence on noise emission for AAV4 reference tyre

Summarized results of the experiment - the air and road surface temperature correction factors CT_t derived for each tested tyre, separately for two test speeds are presented in Table 3.

Table 3 – Air and road surface temperature correction factors CT_t derived for tested tyres

Tire	Air temperature						Road temperature					
	50 km/h			80 km/h			50 km/h			80 km/h		
	CT_t [dB/°C]	R^2		CT_t [dB/°C]	R^2		CT_t [dB/°C]	R^2		CT_t [dB/°C]	R^2	
AAV4	**-0.093**	**0.93**	☺☺	**-0.122**	**0.91**	☺☺	**-0.091**	**0.93**	☺☺	**-0.124**	**0.91**	☺☺
SRTT	**-0.067**	**0.85**	☺	**-0.070**	**0.73**	😐	**-0.070**	**0.84**	☺	**-0.076**	**0.78**	😐
1066	-0.114	0.87	☺	-0.108	0.84	☺	-0.104	0.86	☺	-0.099	0.82	☺
1067	-0.132	0.75	😐	-0.145	0.71	😐	-0.116	0.80	😐	-0.131	0.79	😐
1071	-0.049	0.73	😐	-0.034	0.53	☹	-0.033	0.54	☹	-0.025	0.40	☹☹
1073	-0.124	0.81	☺	-0.096	0.75	😐	-0.109	0.81	☺	-0.090	0.86	☺
1076	-0.105	0.75	😐	-0.080	0.73	😐	-0.106	0.79	😐	-0.083	0.80	😐
1079	-0.139	0.83	☺	-0.111	0.92	☺☺	-0.122	0.87	☺	-0.090	0.90	☺
1081	-0.141	0.80	😐	-0.134	0.88	☺	-0.128	0.81	☺	-0.119	0.87	☺
1083	-0.039	0.25	☹☹	-0.047	0.55	☹	-0.049	0.44	☹☹	-0.049	0.70	😐

One can observe that for two from the tyres selected for experiment, designated 1071 and 1083, the correlation between temperature and noise emission is unsatisfactory or poor – the coefficient of determination R^2 is very low. Also the calculated temperature factors CT_t diverge much from the remaining. In such a case one can not say about any correlation, and the calculated factors can not be further considered in analysis. The detailed noise and temperature data acquired during measurements of these two tyres are presented in Figures 8-11.

The cause of poor correlation for the two specific tyres is unknown to the authors at the time of writing this paper. One of the tyre, designated 1071, is an all-season very quiet tyre labeled 1 bar (68 dB) for external noise emission. The other one, designated 1083, is a tyre developed specially for electric vehicles labeled "A" both for fuel efficiency and for wet grip. Maybe these features of the two particular tyres have an influence on the obtained results?

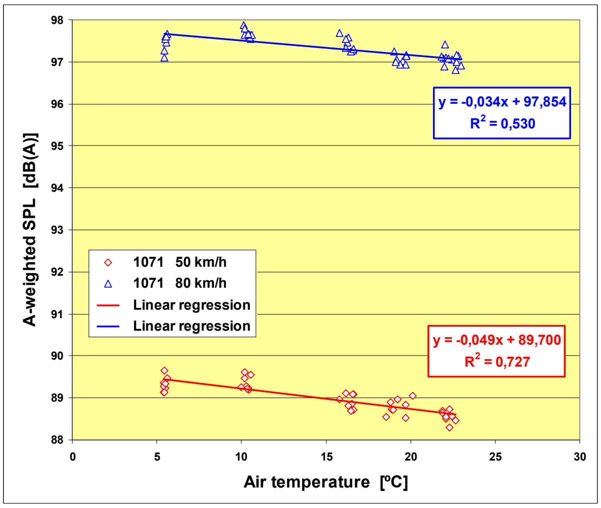

Figure 8 – Relationship between air temperature and noise emission for 1071 tyre

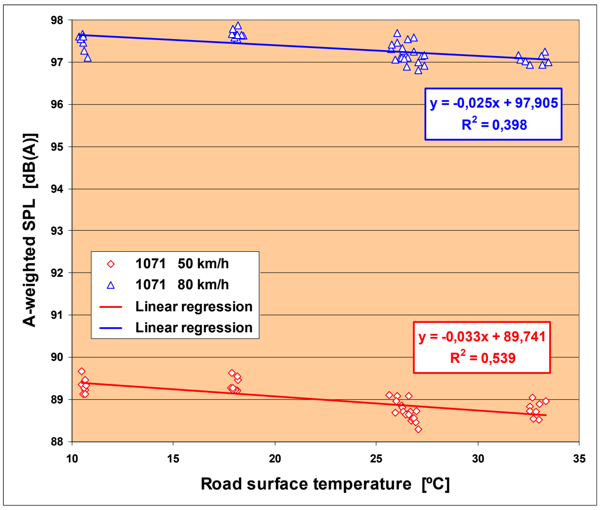

Figure 9 – Relationship between road surface temperature and noise emission for 1071 tyre

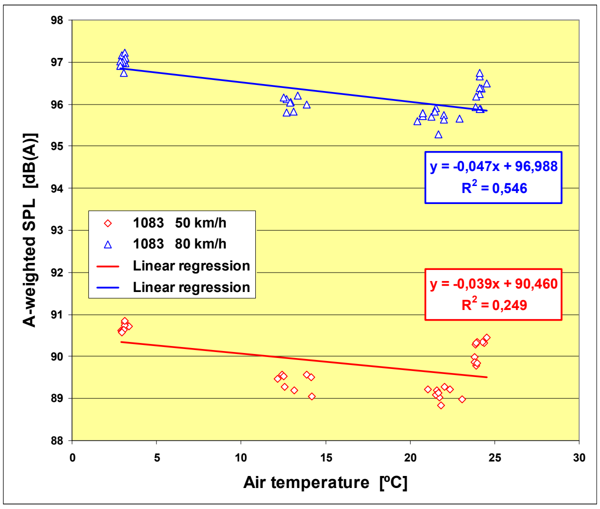

Figure 10 – Relationship between air temperature and noise emission for 1083 tyre

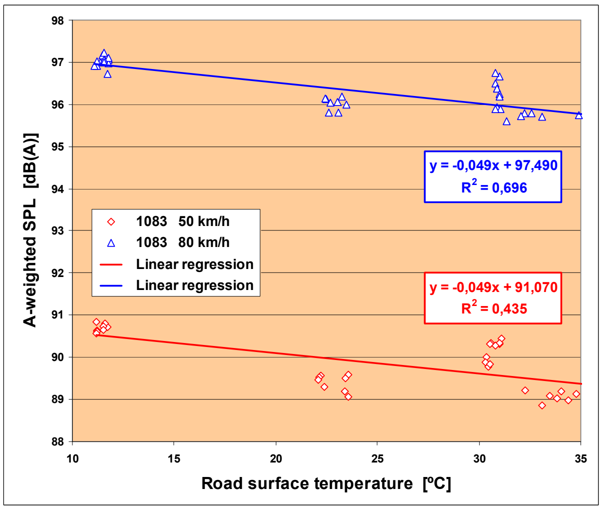

Figure 11 – Relationship between road surface temperature and noise emission for 1083 tyre

All other tested tyres present very good, good or at least satisfactory correlation. The average value of coefficient of determination R^2 for all tyres with acceptable correlation is 0.83 (from 0.71 to 0.93). The values of calculated temperature correction factors CT_t differ depending on measured temperature (air or road), test speed and, of course, on selected tyre. The lowest absolute value is 0.067 dB/ºC, the highest is 0.145 dB/ºC. All derived values are summarized in Table 4.

Table 4 – Summary of temperature correction factors CT_t derived for tested tyres with acceptable correlation

Tire	Air temperature			Road temperature		
	50 km/h	80 km/h	Average	50 km/h	80 km/h	Average
	CT_t [dB/ºC]			CT_t [dB/ºC]		
AAV4	**-0.093**	**-0.122**	**-0.107**	**-0.091**	**-0.124**	**-0.107**
SRTT	**-0.067**	**-0.070**	**-0.069**	**-0.070**	**-0.076**	**-0.073**
1066	-0.114	-0.108	-0.111	-0.104	-0.099	-0.102
1067	-0.132	-0.145	-0.138	-0.116	-0.131	-0.124
1073	-0.124	-0.096	-0.110	-0.109	-0.090	-0.099
1076	-0.105	-0.080	-0.093	-0.106	-0.083	-0.094
1079	-0.139	-0.111	-0.125	-0.122	-0.090	-0.106
1081	-0.141	-0.134	-0.138	-0.128	-0.119	-0.123
Average:	***-0.114***	***-0.108***	***-0.111***	***-0.106***	***-0.101***	***-0.104***

The speed influence on the temperature factor also depends on particular tyre. For some of them lower values of CT_t are noted for higher speed, for other tyres they remain almost unchanged or are slightly higher. When averaged for both speeds, the CT_t factors are similar (difference of 0.006 for air temperature and 0.004 for road surface temperature).

It is advised in the draft ISO standard [6] that the air temperature correction is preferred as it is more practical to measure comparing to road surface temperature. It was already proved, also by this experiment, that both the temperatures are well correlated. However the CT_t factor, averaged for all tyres, derived for air temperature is about 7% higher than derived for road surface temperature.

The temperature effect on noise emission of SRTT and AAV4 tyres should be analyzed separately because these tyres are proposed as the candidates for P1 and H1 tyres in the draft ISO standard for measuring the influence of road surfaces on traffic noise using the close-proximity method. The summary of temperature correction factors derived for ISO reference tyres is presented in Table 5. One should remember that the values were obtained for a dense SMA8 road surface.

Table 5 – Summary of temperature correction factors CT_t derived for ISO reference tyres

Tire	Air temperature			Road temperature		
	50 km/h	80 km/h	Average	50 km/h	80 km/h	Average
	CT_t [dB/°C]			CT_t [dB/°C]		
AAV4	-0.093	-0.122	-0.107	-0.091	-0.124	-0.107
SRTT	-0.067	-0.070	-0.069	-0.070	-0.076	-0.073
Average:	*-0.080*	*-0.096*	*-0.088*	*-0.080*	*-0.100*	*-0.090*

The temperature correction factors CT_t for the AAV4 (H1) tyre are significantly higher than for the SRTT (P1) tyre. Also the speed influence on the CT_t value is greater for this tyre comparing to SRTT. But for practical reasons, it should be only one factor independently on a test speed and test tyre. Thus, when averaged, the correction factors CT_t is equal -0.088 dB/°C for air temperature and -0.090 dB/°C for road surface temperature. When rounded to hundredth of dB, as proposed in the standard, the same factor of -0.09 dB/°C can be applied when correcting regarding to air or road surface temperature.

5. CONCLUSIONS

Tyre/road noise measurements using the CPX method were conducted on a SMA dense pavement with 8 mm chipping size for 10 selected tyres. During tests the ambient air temperature was changing in a range from 3 to 28ºC. At the same time the road surface temperature varied within a range from 10 to 36ºC. The following conclusions can be drawn based on the performed experiment:

1. There is a very good relationship between air and road surface temperature.
2. A linear correlation between noise emission and both air and road temperatures can be observed for eight of ten tested tyres.
   - That correlation is very good for AAV4 and good for SRTT reference tyre.
   - There is an acceptable correlation for six other tested tyres (good or satisfactory)
   - There is no such correlation for one tyre dedicated for electric vehicles and only satisfactory for the other one.
   - There is no such correlation for one all-season tyre.
3. The air temperature correction factor is within a range from -0.067 dB/°C to -0.145 dB/°C with an average of -0.111 dB/°C for all tyres with acceptable correlation.
4. For the ISO standard reference tyres the air temperature correction factor is within a range from -0.067 dB/°C to 0.122 dB/°C with an average of 0.088 dB/°C.
5. The road surface temperature correction factor is within a range from -0.070 dB/°C to -0.131 dB/°C with an average of -0.104 dB/°C for all tyres with acceptable correlation.
6. For the ISO standard reference tyres the road surface temperature correction factor is within a range from -0.070 dB/°C to 0.124 dB/°C with an average of 0.090 dB/°C.
7. The difference between air and road temperature correction factors is rather small – the factor derived for air temperature is about 7% higher than derived for road surface temperature.
8. There is about 5% difference in correction factors regarding to test speed (absolute value higher for lower speed) for all tyres with acceptable correlation, both for air and road surface temperature.
9. For the ISO standard reference tyres there is about 20% difference in correction factors regarding to the test speed for air temperature and about 24% for road surface temperature.

ACKNOWLEDGEMENTS

The work presented in this paper was partly performed in relation to the ongoing EU-founded FP7 project ROSANNE "ROlling resistance, Skid resistance ANd Noise Emission measurement standards for road surfaces" (FP7/2008-2013) financed by the European Commission - grant agreement No 605368. The authors are very grateful for the financial support.

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