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Rolling noise of 15 heavy duty vehicle tyres on 12 different road surfaces

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Abstract The rolling noise levels of 15 heavy duty vehicle (HDV) tyres, 5 steering, 5 traction and 5 trailer types, were determined with Controlled Pass-by measurements on 12 asphalt concrete surfacings that differed in texture levels and in acoustic absorption characteristics. The speed ranged from 40 to 90 km/h and SEL and L_{max} levels were determined, both total A-weighted values and in 1/3 octave bands. The objective of the program was to fill a database with reliable measurement data on rolling sound levels of HDV tyres, together with the road and the tyre surface properties. In this paper some primary investigations into the effect of the different surfaces on the three types of tyres and on the calculated SEL level of a truck passage on the surfaces composed of representative set of tyre types will be presented . The effect of texture and of road surface absorption is demonstrated in two sets of 1/3 octave spectra, one with varying texture and one with varying absorption.. It was concluded was that texture variation has a limited effect, especially on the drive axle tyres, but that introducing road absorption is very effective in suppressing rolling noise of HDV tyres.

1. INTRODUCTION

It is generally acknowledged that the road surface is one of the dominating factors that influence the generation of rolling noise of road vehicles. This has led to extensive studies to understand the mechanisms and optimize the road surface properties. However, these studies were mainly done for passenger car tyres. This is a serious constraint since in was found that the road surface effect on rolling noise levels of car tyres exhibits nearly no correlation with the effect on HDV tyres, meaning that a low noise surface for cars, can be a noisy one for HDV's. (see fig 1).
Since rolling noise from HDV's dominates the noise emission of highways, especially during the sensitive night period, understanding the road surface effect is of major importance for road engineers. Within the framework of the Netherlands Noise Innovation Program, the Netherlands Ministry of Transport has contracted M+P to perform an extensive measurement program to investigate road surface effects on representative types of HDV tyres.

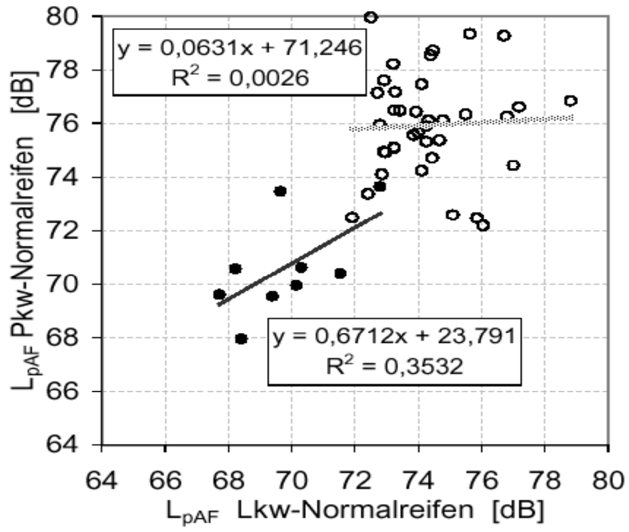

Figure 1: Relation between rolling noise of truck tyres (LKW-Normalreifen) and of passenger car tyres ("PKW-Normalreifen) on several surface. Open dots are dense surfaces, solid dots porous surfaces [1].

The measurement program was performed on a test area in Sperenberg (Germany). On that site about different types of road surfaces were laid within the German BASt project "study of road surface texture effects on the rolling noise of passenger car tyres" [1].
The objective of the HDV-tyre measurement program is achieving a reliable database of measurement results and road surface and tyre characteristics that can be used as source for further study of the tyre/road interaction noise of HDV tyres.

2. MEASUREMENT PROGRAM

The measurements consisted mainly of Controlled Pass-By measurements according to the measurement procedure described in the EU tyre noise directive 2001/43/EC and related ISO-standard 13325. The speed range, number of measurements and choices of road surfaces however were extended considerably.
The program was performed in the fall of 2003 and consisted in total of about 8.000 individual controlled pass-by measurements.

test vehicle

The vehicle, a two-axle tractor of the type IVECO STRALIS AS 440 S 48 T/P, was equipped with four test tyres of the same type, two at each axle. The load of the tyre was modified by adding concrete blocks on the frame an resulted in a load of about 70% of the maximal load of the tyre. The air pressure of the tyre was adapted to the load, according to the formula given in the ISO standard 13325.

A picture of the test vehicle is given in figure 2.

Figure 2: left: picture of test vehicle, right: extra weight mounted to meet the 70% tyre load requirement.

test tyre population

The set of test tyres consisted of a set of 15 tyres, five of a steering type, five of a traction type and five of a type used on trailers. The distribution of make and type represents the usage of tyres on highways in the Netherlands, determined in an inventory of about 2000 tyres applied on long haul HDV's. To improve the representativity, we also included some artificial worn tyres and one slick tyre.

Table 1: overview of test tyre population, first character indicate manufacturer, second character indicate type, third character indicate numbering. Added are indications on special characteristics of the tyre.

Tyre type	size	character				
Steering type	315/80-22,5	Cs	Gs	Ms	Ms worn	Ms slick
Traction type	315/80-22,5	Cd	Gd	Md1	Md1 worn	Md2 m+s
Trailer type	385/65-22,5	Ct1	Ct2	Gt	Mt	Mt worn

Cs Gd Md1 MD1 worn Ct1

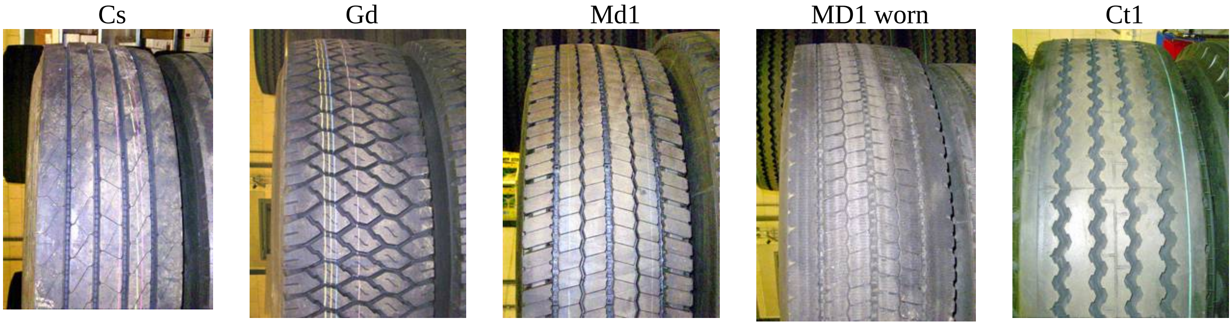

Figure 3: picture of a sample of test tyres

Since the objective of the measurement program was to generate reliable and complete data input for a possible scientific tyre/road investigation project, we also performed 3-dimensional laser scanning of the tread profiles of the tyre. Such profiles are required to model the force interaction in the tyre/road contact patch, an essential part of tyre/road noise modeling as for instance is done in [2]. An example of a scanned tread profile is given in figure 4.

Figure 4: part of a scanned 3-dimensional tread profile of a tyre (shown is tyre Gd). Resolution of the scan is 1 mm in horizontal direction and 0.01 mm in vertical direction.

test surface population

The test sections that for this project were selected from those available on the Sperenberg test area, based on their relevance for the data base and the availability for HDV passages. An overview is given in table below (Table 2).

Table 2: overview of test sections and test surface descriptions.

Surface type	Surface description
PAC 4/8 40 mm	Porous asphalt concrete, grading 4 to 8 mm, 40 mm thickness
PAC 4/8 – 11/16 70 mm	Double layer porous asphalt concrete, top layer 4-8 mm, 25 mm thick, bottom layer 11-16 mm, 45 mm thick
“Novachip 0/8”	Thin porous asphalt, 4-8 mm grading, 20 mm thickness
ISO 10844	Surface build according to ISO 10844 guidelines and meeting ISO 10844 specifications.
SMA 0/3	Split Mastic Asphalt, grading 0 to 3 mm
SMA 0/5	Split Mastic Asphalt, grading 0 to 5 mm
SMA 0/8 + 1/3	Split Mastic Asphalt, grading 0 to 8 mm with 1/3 mm spit sanding
SMA 0/11 + 1/3	Split Mastic Asphalt, grading 0 to 11 mm with 1/3 mm split sanding
SMA 0/8	Split Mastic Asphalt, grading 0 to 8 mm
SMA 0/8 + epoxy resin	Split Mastic Asphalt, grading 0 to 8 mm, texture partly levelled with epoxy resin
DSK 0/5	“cold asphalt” design with 0-3 mm grading
DSK 0/3	“cold asphalt” design with 0-3 mm grading

For each test track the texture profile was measured with a laser profilometer (according to ISO 13473-1/2/3/4). The three open graded surfaces were also measured with an in-situ acoustic absorption device (according to ISO 13472-1) from which the spherical wave absorption coefficient under perpendicular incidence was calculated.

measurement set-up and procedure

The microphones were positioned at both sides of the test section, at 7.5 m distance from the centre of the test lane, at a height of 1.2 m above the level of the test track. Since the test

tracks were laid on an existing concrete surface, the test tracks were 0,04 m elevated with respect to the environment. The position and the speed of the vehicle was determined with photo cells at the beginning and end of the test sections.
The vehicle passes the tests section with the clutch disengaged and the engine switched off, so no engine noise was emitted. Also care was taken that air release did not take place during the passage of the test section. The vehicle passes the test section in both directions.
The entrance speed was chosen such that the speeds at the microphone position were around 45-50, 55-60, 65-70 and 75-85 km/h. Each speed interval was repeated at least four times so that eventually about 35 measurement results were obtained from each tyre/road combination.
During the pass-by event, the total sound signal was recorded and the $L_{A,max}$ value and SEL value were determined in 1/3 octave bands. Additional air temperature, wind speed and wind direction were recorded continuously and road and tyre temperature were measured intermittently.

3. MEASUREMENT RESULTS

data processing

To increase efficiency, four consecutive test sections were measured in one passage and the eight microphone signals together with the five light switches were processed on-line with a multi-channel data acquisition system and stored in a pre-defined database format, together with the input data on test track, tyre and driving direction. From the sound signal, the 1/3 octave band levels were calculated and stored together with the vehicle data and measurement conditions.
For each tyre/road combination, linear regression on the total level and the consecutive 1/3 octave band levels was applied to describe the level versus speed relation with the formula’s (2)

$$L_{A,\max} = a_{L_{A,\max}} + b_{L_{A,\max}}.\lg\left(\frac{v}{v_0}\right) \quad \text{and} \quad SEL = a_{SEL} + b_{SEL}.\lg\left(\frac{v}{v_0}\right) \qquad (2)$$

The coefficients *a* and *b* were then applied to calculate the levels - both total and 1/3 octave- at the reference speed of 70 km/h. Typically the value of b_{SEL} is about 10 lower then $b_{LA,,max}$. The regression analysis is performed for each of the 180 tyre/road combinations.

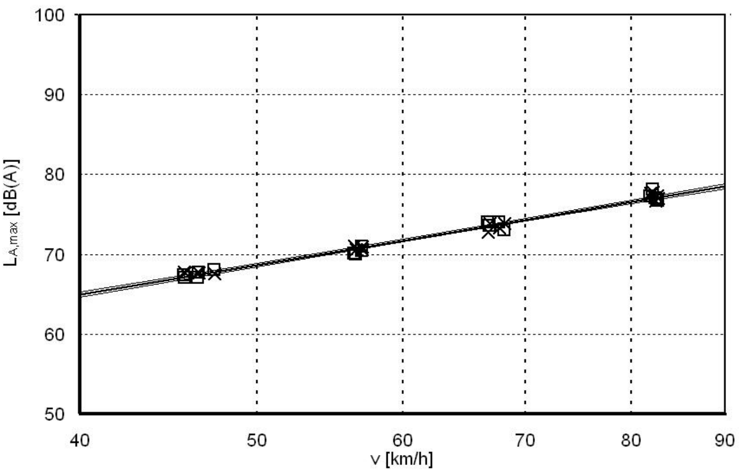

Figure 5: typical example of regression of $L_{A,max}$ versus log of speed together with 95% confidence interval around regression line. Number of measurements: 36, level at 70 km/h: (74,3 ± 0,2) dB(A), 95% confidence interval, slope: 38,6 dB/10-fold speed increment, residual error: 0,4 dB.

database

The results of the measurements were stored in a database in which all relevant data were organized in a structured way. A former project with respect to passenger car tyre research on the same test area [1] has demonstrated the value of such an approach. In addition to this a overall analysis was done on total A-weighted levels and for a limited of road surfaces a spectral analysis was performed.

results of total A-weighted levels on test surfaces

The figure below shows graphs of the average levels of Steering, Driving and Trailer tyres on the test surfaces. In a second graph the average Sound Exposure Levels (SEL) of each tyre type was combined into a total SEL of a tyre set composed of two S-tyres, four D-tyres and four T-tyres, together representing a common tractor-trailer combination.

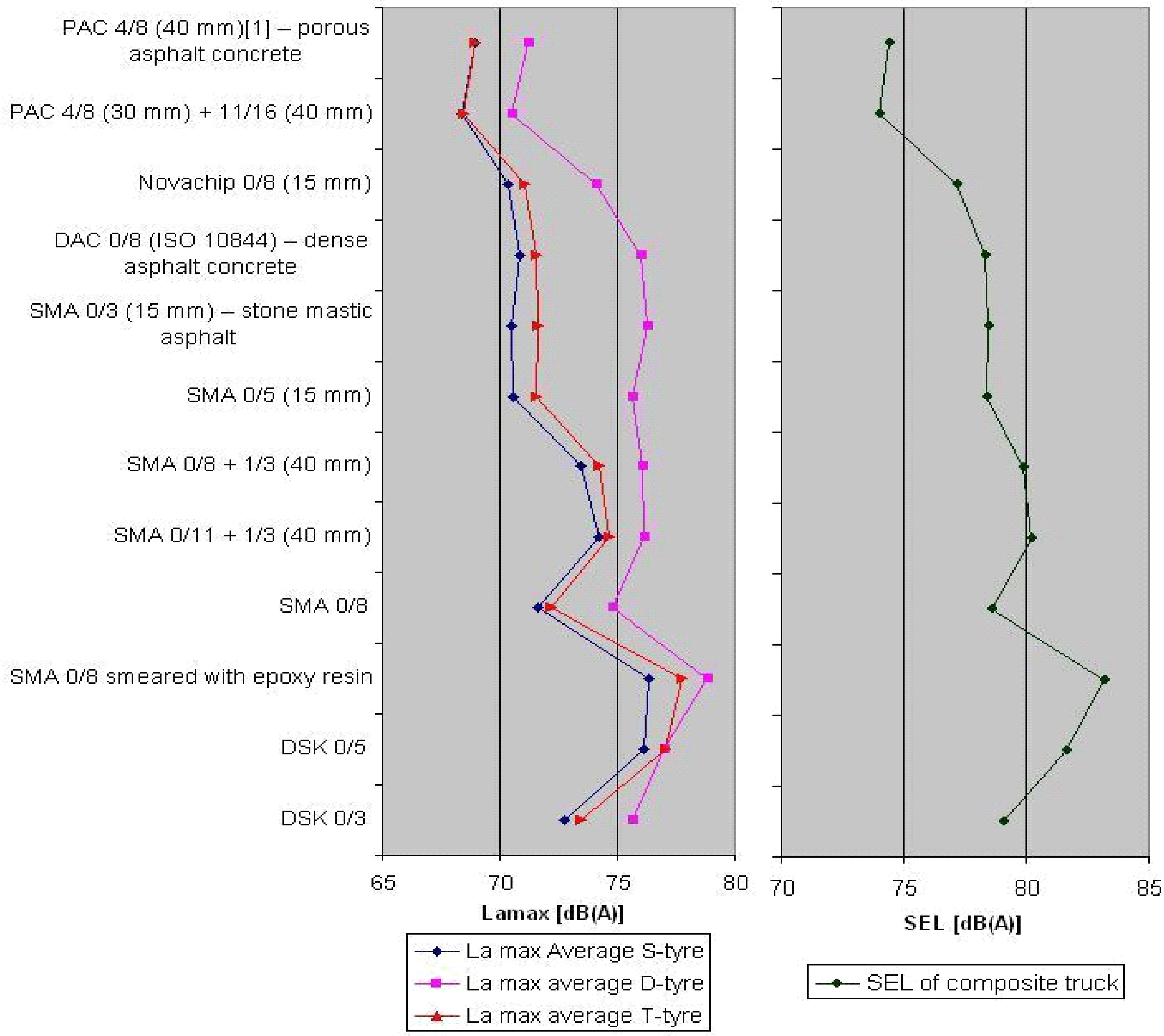

Figure 6: results of averaged levels of the tyres at 70 km/h at the test surfaces: left: rolling noise levels ($L_{A,max}$) of the three types of HDV tyres at the test surfaces; right: total Sound Exposure Level of a vehicle, composed of two steering tyres, four traction tyres and four trailer tyres.

spectral distributions

The effect of two relevant road surface parameters was studied by comparing four SMA type of surfaces that only differed with respect to stone grading (and consequently texture level) and by comparing four surfaces that exhibit similar texture profiles, but differed with respect to acoustic absorption. Since texture and absorption effects exhibit strong frequency dependency, the comparison was made in 1/3 octave bands. Results were based on the SEL level at 70 km/h of the composite vehicle.

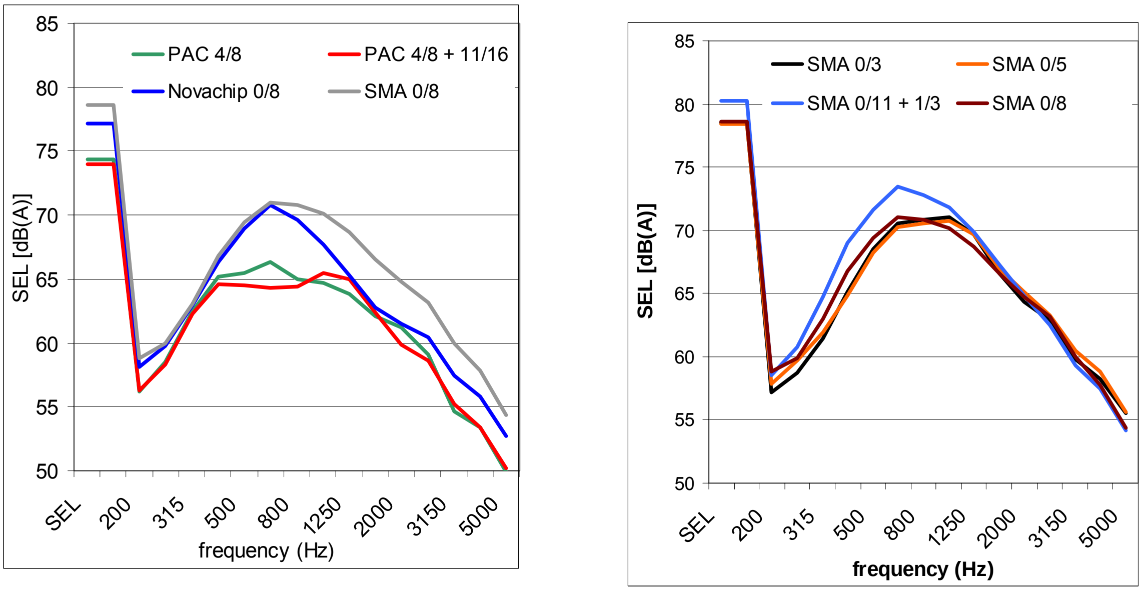

Figure 7 : 1/3 octave SEL spectra of composite vehicle (2S, 4D and 4T tyres), left: variation of acoustic absorption, right: variation of surface texture.

4. DISCUSSION AND CONCLUSIONS

first conclusions

The study has succeeded in its objective to deliver a complete set of data on HDV tyre rolling sound on a sample of representative surfaces, together with the acoustic relevant properties of the test surfaces and the tread profile of the test tyres. The statistical accuracy of the resulting levels at 70 km/h is typically better then 0.3 dB. In a few cases statistical accuracy is worse since the tyre/road sound levels did not follow an $a+b.log(v/v_0)$ relation ship which then resulted in enlarged scatter of data points around the regression function, although repeatability of measurements at the same speed falls within 0.5 dB.

The tyres of the type Drive are in general about 3 dB louder then the Steering and Trailer types. On medium textured surfaces (that includes the porous ones), the difference was smaller and on the smooth surfaces it was larger.

The level difference between an average silent tyre/road combination and an average loud one exceeds 10 dB. The difference between the most silent and the loudest exceeded 20 dB.

The effect of tyre wear, simulated by artificially removing 90% of the tread and comparing the result with the full tread depth tyre, was negligible for the studied Steering and Trailer type, but exceeded 2 dB for the Drive type.

Furthermore our primary analysis has showed that:

1. low noise surfacings are effective for suppressing rolling noise of HDV tyres;
2. texture optimization, found to be effective for passenger car tyres, is less effective in reducing rolling noise of HDV tyres, especially drive axle tyres are insensitive to texture variations;
3. introduction of acoustic absorption results in suppressing rolling sound of the studied types of HDV tyres.

The reduced efficiency of texture optimization beyond a certain texture level was found in earlier studies, in fact a too low texture may even lead to an increase of rolling noise.
Optimization of road surfaces by introducing acoustic absorption is effective. The phenomena is similar to that of passenger cars, although the frequency range of interest is shifted with about two 1/3 octave bands to lower frequencies. This corroborates the impression that thick porous surfaces (such as double layer drainage asphalt) are especially effective for HDV's.
The final report will become available from the IPG web site: www.innovatieprogrammageluid.nl.

further work

In the next phase the data will be input to a further study to model the force interaction of the tyre and the surface and thus to understand texture effects on HDV tyres. This will in first step be done according to the SPERoN approach [1,2]. The availability of the test tyres allows us to determine the dynamic properties of the tyre and enables also a dynamic approach such as the modelling work of Kropp [3].

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