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Road surface texture and rolling noise

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Measurements of road surface texture (2 D) were carried out on a great number of pavements in Norway during the period 2006 – 2008. This work was part of the R&D project "Environmentally friendly pavements" run by the Norwegian Public Roads Administration. On a selection of 37 asphalt pavements (dense type, age 1 year or more) and 8 newly laid pavements several investigations were carried out. The main purpose was to increase knowledge concerning: 1) Texture in dense road surfaces and its influence in general, 2) Investigate – if possible – the relation between texture and rolling noise (by the cpx method), possibly also some connection between texture and pavement parameters, 3) The development of texture in time, especially during the first 2 years of operation, 4) Examples of texture data for common Norwegian dense pavements. The investigation had some considerable restrictions. It was limited to one car tyre (the reference tyre A), rolling noise (mostly) at one speed, 50 km/h. Further, no porous pavements were included. The parameters of the pavements (for instance concerning the binder, chipping size, resistance to wear, additions, etc.) were collected. The texture data included the texture spectrum, and a number of texture related parameters (for instance MPD, G-factor). The noise levels, texture data and pavement parameters formed a basis for statistical treatment. A simple regression analysis showed that cpx-noise can be modelled with reasonable accuracy based on measured texture data. In some cases the analysis indicated a connection between texture data and pavement parameters. The development in texture from new-laid pavements showed a relatively consistent pattern. The texture spectrum changes markedly during the first year of operation. This change tends to increase the noise.

1 Introduction

Rolling noise from single vehicles gives important contributions to the overall road traffic noise. The rolling noise depends clearly on the characteristics of the road surface, i.e. the texture. But what texture parameters are vital for understanding the texture influence, and how do we measure them? Is there a link between the design parameters of the asphalt pavement (the sieve curve, binder, additives etc.) and the resulting texture, or is the texture determined solely by other mechanisms? In the Nordic countries the roads are exposed to studded tires in the winter season. This gives pavement wear that probably influences on the road surface texture as well. In the R&D project "Environmentally friendly pavements" run in Norway, a base of relevant data for 37 dense pavements was established. Included here are texture measurements (2 D) and noise measurements (close proximity method, cpx) for the same wheel track, over the same road section length. In order to investigate the relationship between noise and texture, simple statistical analyses were used. The results were reported in [1]. In this paper some of the main results are shown and discussed.

2 Data collection

2.1 Texture

The profile height of the road surface along a line in the wheel track was measured by a laser profilometer. The laser equipment used by the Norwegian Public Roads Administration (NPRA) was an Optocator Type 2008-180/390-A, from Selcom AB. The measuring range is 180 mm. The measuring frequency is 32 KHz. The texture profiles (i.e the profile samples) were analyzed to give texture levels in 1/3-octave bands with center wavelengths in the range 2 – 630 mm. The texture levels $L_{tx,\lambda}$ in 1/3-octave bands with center wavelength λ, is:

$$L_{tx,\lambda} = 20 \cdot \log(\frac{a_\lambda}{a_{ref}}) \tag{1}$$

where a_λ is the rms (root mean square) value in the λ-band, a_{ref} is the reference value of 1μm (10^{-6} m). Texture levels are calculated in 1/3-octave wavelength bands, but can also be given in 1/1-octave bands.

From the texture profiles several parameters were produced, i.e:

- MPD, mean profile depth, mm
- G-factor, a shape factor for the road surface, %. High values represent a reasonable smooth "terrain with cracks". Low values represent a "terrain with deep valleys and peaky mountains"
- RMS, the root mean square value of the profile signal, for a certain profile length.

The tool for these calculations was a relatively simple software based on fft-calculations, that was developed along with the project as a research tool, and not as a professional software package. The calculations are implemented in broad accordance with the standards and Technical Specification under ISO 13473, [2,3].

2.2 Rolling noise, L_{cpx}

The rolling noise was measured according to the close proximity method. Microphones were positioned close to both wheels in a sound proofed compartment where only the rolling noise (tyre/road noise) shall contribute. The trailer was pulled by a car at speeds in the range 50 – 80 km/h. In this investigation the noise levels from the old reference "A-tyre" (Avon/Cooper ZV1 185/65 R15) was used. The measurement was carried out when the wheel was running in the right or left wheel track. Often several runs were used to increase the accuracy. A closer description of this method, the measurements and the results are given in [4].

2.3 Roads and pavement data

During the project a number of pavements were investigated regarding noise and texture. It turned out that for this investigation 37 pavements were available. The pavements were all dense asphalt, with maximum chipping size in the range 4 – 16 mm. A small number were constructed as thin layers. Noise levels had been measured at 50 km/h for all of these pavements. The length of the road test sections were approximately 100 – 300 m long. The age of the pavements in this investigation was 1 – 6 years. A number of newly laid pavements were also available, but not included in this investigation.

Relevant data for the pavements were collected. They comprised 3 groups. Among the *traffic* data were: traffic load (number of vehicles passing pr. day) and accumulated traffic load (the total number of vehicles that had passed at the time of the noise- and texture measurements), posted speed, the fraction of the vehicles using studded tyres.

Data relevant for the *pavements* were: age, surface weight (Kg/m^2), maximum chipping size Dmax (mm), grading (sieve) curve, parameters of wear.

Data relevant for the *noise and texture* measurements: L_{cpx} (A-weighted rolling noise level (dB), frequency spectrum in 1/3- or 1/1-octave frequency bands, texture levels L_{tx} in 1/3- or 1/1-octave wavelength bands.

2.4 Limitations

L_{cpx} -levels for only one car tyre were included. Noise levels from another tyre could have given slightly different noise results. The noise levels included were measured at a speed of 50 km/h, it was too few results at 80 km/h. The texture measurements had to be carried out with the existing laser equipment within NPRA, although its performance was not optimal for this task. As a consequence, electronic noise often interfered with the texture levels for wavelengths of 4 mm and lower.

3 Texture validation

Several validation tasks regarding the texture levels were carried out: 1) A hardware/software application based on structured light and video photography, was used to create high resolution 3D "terrain" of road surfaces. Sampling this "terrain" along a longitudinal line in the wheel track gave profile heights that could be analyzed as an alternative "texture" recording. 2) A texture measurement test rig was borrowed from M+P in the Nederlands, for testing the texture on a number of pavements with a totally independent method (hardware and software).

The validation tasks went well. In both 1) and 2) the results from the alternative methods compared well with the calculated results, considering a certain difference in measurement conditions. Some details are given in [5].

4 Main results

4.1 Typical texture levels and texture parameters

Figure 1 shows typical texture levels measured on AC (asphalt concrete) and SMA (stone mastic asphalt) pavements, on the test sections on county road 715 (Trolla, Trondheim). The maximum chipping size is in the range 6 – 11 mm. The age of the pavements is 1 year including one winter season. The texture levels show a broad peak in the wavelength range of 16 – 25 mm. The texture levels are strongly dependent on the maximum chipping size. The figure clearly shows that for the given test sections the SMA pavements have greater texture levels than AC pavements, at the same maximum chipping size.

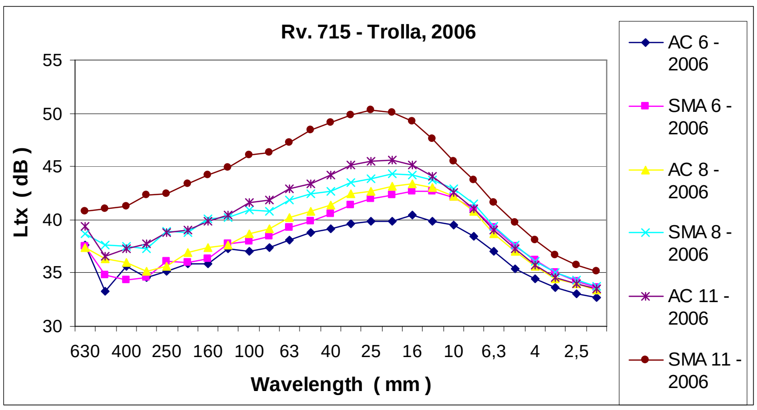

Figure 1 Examples of typical texture spectra

Table 1 shows values for some texture parameters for the pavements shown in Figure 1. The texture levels are given in 1/1-octave band. The table shows that the G-factor has low values. This may indicate that much of the stone material in the pavement surface is already relatively exposed. As indicated above, the SMA pavements have greater texture levels (Ltx80*, Ltx5*) than the AC pavements, at the same maximum chipping size. This is also the case for MPD values, *but not* for the noise levels Lcpx,A.

Table 1 Texture parameters

Pavement	No.	MPD	G-factor	Ltx80*	Ltx5*	Lcpx,A
AC6	1	0.8	32.2	42.3	40.6	90.6
AC8	2	1.04	40.9	44.1	42.1	90.9
AC11	3	1.1	46.3	46.9	42.3	92.4
SMA6	4	0.9	52.3	43.4	42.6	90.9
SMA8	5	1.11	50.4	46.0	42.7	91.3
SMA11	6	1.46	59.1	51.4	44.8	92.2

*1/1-octave wavelength band

4.2 Correlation between noise- and texture levels

Figure 2 shows a correlation contour plot resulting from correlation between texture levels (in 1/3-octave wavelengths) and noise levels (in 1/3-octave frequency bands), over the 37 pavements. The correlation is shown as positive or negative R-values, with a corresponding colored scale. The results seem to be quite obvious: noise levels at acoustic frequencies below approximately 1000 Hz, and texture levels at wavelengths between 40 and 600 mm (red area), show strong positive correlation. This means that if the texture levels increases, so do the noise levels. In the blue area the effect is quite opposite. If the texture levels increase, the noise levels decrease.

These results depend on the specific car tyre that is used for the noise measurements, and the pavements which are tested.

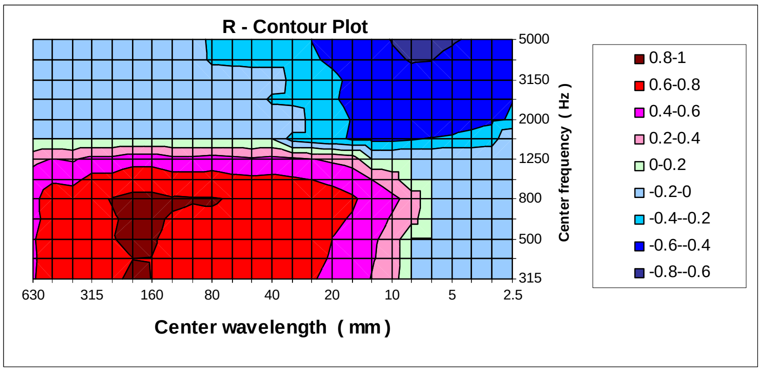

Figure 2 Correlation contour plot

4.3 Linear regression analysis

Linear regression analysis was carried out on the data from 37 road test sections. The noise level measured by the cpx-method, $L_{cpx,A}$, was the dependent variable. Several parameters were tested as the independent variable. The analysis was carried out with one and two independent variables. In the case of *one independent variable*, the best correlations with the noise levels were obtained for the texture parameters Ltx80, Ltx160, DL and Dmax. DL is the unweighted difference (Ltx80 – Ltx5). Dmax is the maximum chipping size. All texture levels here denote 1/1-octave wavelength bands. Best correlation with the noise levels was obtained with the parameter DL (explained variance $R^2 = 0.64$).

The use of DL as one of the variables was motivated by the measure ERNL (Estimated Road Noisiness Level) as described by Ulf Sandberg in [6]. This measure bases on a *weighted* difference between Ltx80 and Ltx5. The ERNL was established to show the *influence of the road surface texture*, and not give typical noise emission values. The DL-variable was adopted within this analysis as a slight alternative to Sandbergs formulation.

A rough model of the noise level based on this statistical analysis with DL as the independent variable, can be estimated from equation (2):

$$L_{cpx,A} = 91.85 + 0.293 \cdot DL \qquad (2)$$

Here DL is (Ltx80 – Ltx5), in 1/1-octave wavelength bands. The explained variance is 0.64, standard error of estimate is 0.68 dB.

With these results in mind, the next step was to investigate the correlation with the noise levels when *two independent variables* were included. The results from this new regression analysis giving best correlation with the noise levels, revealed the following combinations: Ltx80 & Dmax ($R^2 = 0.59$), DL & Dmax ($R^2 = 0.75$), (Ltx160 – Ltx8) & Dmax ($R^2 = 0.73$). The parameter combinations given here were further combined with all the relevant pavement parameters in turn, but no new combination showed up as more significant.

A model estimate of the noise level based on this statistical analysis can be given:

$$L_{cpx,A} = 90.54 + 0.158 \cdot D_{\max} + 0.206 \cdot DL \qquad (3)$$

Here DL is (Ltx80 – Ltx5), in 1/1-octave wavelength bands, D_{max} is the maximum chipping size. Figure 3 shows data-points for the measurement results (Y), and the corresponding model results (X). Explained variance in the model is 0.75, standard error of estimate is 0.57 dB.

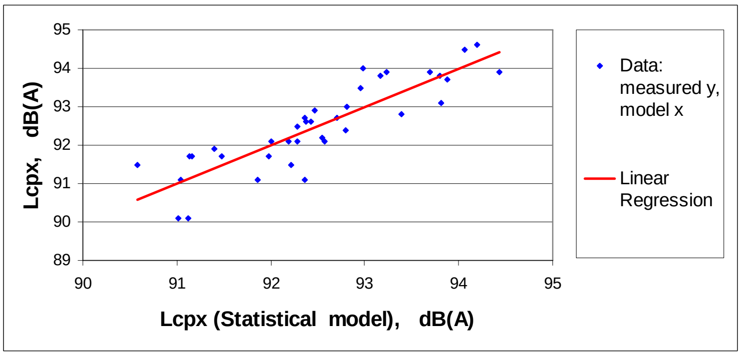

Figure 3 Measured and modeled L_{cpx}

4.4 Some possibilities

The texture parameters Ltx80 and Ltx5 are important for the modeling of $L_{cpx,A}$ as shown in equation (2) and (3) above.

The parameters are obtained from texture measurement. If one want to study the possibilities of getting less rolling noise (from the specific car tyre that was used in this investigation), further analysis on Ltx80 and Ltx5 should be made.

In principle a multi regression analysis should be carried out with all relevant parameters within the traffic data and the pavements data, se section 2.3 above. A preceding factor analysis would probably help to line up the most relevant parameters. If it turns out that Ltx80 and/or Ltx5 depend on some of these data, this would be a help for the pavement designer concerning future pavements. No attempts have been done here to carry out this kind of analysis.

However, in general every effort should be made to understand what affects the Ltx80 or Ltx5 parameters.

5 Texture development

The project has revealed that the texture spectra change markedly during the first year of operation. This is thought to result from the wear of studded tyres. Texture measurements have been carried out on newly laid pavements and on the same pavements after one year. At least for SMA pavements the change shown in figure 4 seem to be fairly representative.

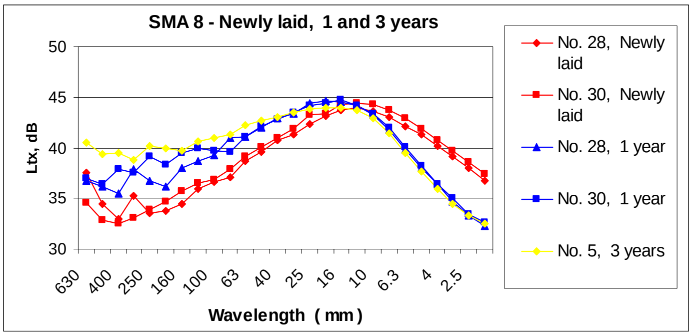

Figure 4 Development in texture spectra

As can be seen, there is a pronounced change in the spectra. The change acts like a “tilting” , thereby changing the DL variable unfavourably. The change shown for the 3 year old pavement, accounts for approximately 2.5 dB(A) increase in noise level.

(A certain reservation should be made for the texture spectrum of newly laid pavements, at short wavelengths).

References

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[3] ISO /TS 13473-4 Technical Specification: “Characterization of pavement texture by use of surface profiles – Part 4: Spectral analysis of surface profiles”.

[4] T. Berge, F. Haukland, A. Ustad: “Environmentally friendly pavements: Results from noise measurements 2005 – 2008” (in Norwegian). SINTEF Report A9720, 2009-02-26.

[5] S. Å. Storeheier: “Environmentally friendly pavements: Measurement and analysis of texture data from road pavements. Premises and validation” (in Norwegian), SINTEF Report A10839, May 2009.

[6] U. Sandberg, J. A. Ejsmont: “Tyre/road noise reference book”, (chpt. 7.5.2.3). Informex Ejsmont & Sandberg Handelsbolag, First edition 2002.