The ranking of rolling noise from passenger car tyres - a comparison between measurements and modelling results

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Tyres are type approved with regard to rolling noise on an ISO-test track, according to the EU-directive 2001/43/EC. The test track is basically a rather smooth road surface with maximum chipping size of 8 mm. However, most surfaces normally used on roads, especially in the northern European countries, are rougher surfaces, typically Stone Mastic Asphalt (SMA) with 11 to 16 mm stones.
A project has been initiated to compare the noise levels of a selection of highly used after market summer tyres (in Norway). Noise measurements of 12 tyres have been performed on a selection of new and old SMA-road surfaces. The 3D texture of the same road surfaces has been measured with laser profile equipment. In addition, the point mobility and other design features of the tyres have been measured to be used as input data to the *SPERoN* tyre/road noise model. Then, comparison will be made between measurements and modelling results. Preliminary results from the noise measurements show a difference of 2.5-3 dB(A) on SMA-surfaces, between the tyres. The project is a co-operative between SINTEF (Norway), Müller-BBM (Germany), and Chalmers University (Sweden).

1 Introduction

Normally tyre/road noise is a dominating source of traffic noise for constant speed driving from 30 km/h and upwards (light vehicles). The use of more silent tyres on light vehicles/passenger cars can therefore be an effective tool to reduce the overall traffic noise. Presently, noise from tyres is regulated in the EU-directive 2001/43/EC and measurements are performed on a smooth road surface (ISO 10844 - a type of a dense asphalt concrete (DAC) with maximum chipping size of 8 mm). Such a surface is normally not used on roads in Norway, except for certain test sections. Typical road surfaces in Norway are DAC of 16 mm or Stone Mastic Asphalt (SMA) of 11 to 16 mm.

The important issue raised in this project is to investigate the distribution of noise levels from tyres on typical road surfaces used in Norway. By a combination of measurement results and modelling results, the ranking of noise levels on normally used road surfaces and ISO-surface is investigated. The main question is whether a reduction of noise limits according to the EU-directive will give an equivalent reduction in rolling noise levels on typical surfaces in Norway, which has a rougher texture due to studded tyres and winter conditions.

2 Tyre selection

A total of 12 summer tyres were chosen to fulfil the following requirements:

- be representative for the after market tyres in Norway
- cover a range from low performance/cheap tyres to high performance/expensive tyres
- cover the most used tyre sizes in Norway

After market tyres in this context is defined as replacement tyres, when the original equipment tyres on the new car have been worn out.

In agreement with the organisation of the tyre importers in Norway, the 12 tyres have been separated into 3 categories:

1. Low performance (LP)
2. Medium performance (MP)
3. High performance (HP)

Table 1 show the technical details of the 12 tyres and the category.

Tyre No	Category	Dimensions	Load/speed index	Production week/year
1	MP	175/70 R14	84T	1207
2	LP	175/70 R14	84T	0307
3	MP	185/65 R15	88T	1607
4	MP	185/65 R15	88T	4705
5	HP	195/65 R15	91H	0206
6	HP	195/65 R15	91V	0307
7	HP	205/55 R16	91W	1407
8	HP	205/55 R16	94H	3407
9	HP	215/55 R16	93H	0206
10	HP	215/55 R16	97H	1007
11	MP	195/65 R15	91T	0706
12	MP	185/65 R15	92H	1604

Table 1 Tyre specifications

Tyre 12 is a special designed low noise tyre, which was not included in the modelling part of the project. The tyre is no longer available on the market.

3 Road surfaces

The tyres have been measured on 7 road surfaces, as listed in table 2.

Surface no.	Surface type	Production year
1	SMA11	2005
2	SMA11	2006
2B	SMA11	2007
3	SMA16	1999
4	SMA11 1%[1)]	2005
5	SMA11 3%[1)]	2005
6	DAC16	1992

1) 1 and 3% rubber added to the bitumen

Table 2 Road surface types

Except for Surface 2B, measurements of 3D texture profiles have been performed in 2006, using a laser profile meter.
Initial test measurements were done in 2006 with a single tyre (tyre no 11) and at that time Surface 2 was only about 2 month old and not exposed to studded tyres and winter conditions. To have a similar surface for the measurements

in 2007, Surface 2B was included, as a new, relatively smooth SMA11-surface. The texture characteristics of Surface 2B are then similar to Surface 2, when this surface was new. This was checked by texture measurements of both surfaces, using standard 2D laser profile equipment. Surface 2B replaces then Surface 2 in the modelling part of the project.

4 Texture measurements

The texture measurements were performed with a 3D laser profilometer hired from M+P in the Netherlands, see figure 1.

The laser rig measures the texture profiles in a horizontal length of 1.5 m. In the vertical plane, the laser was adjusted to measure a profile every 10 mm. A total of 20 profile traces were measured at each road section, giving a 3D map of the texture over an area of 1.5 x 0.2 m.

The scan resolution was set to 5 samples/mm.

At each road surface, the texture was measured in the right wheel track, at 3 sections approximately 10 m apart.

Fig.1 3D Texture measurement rig

5 Noise measurements

The measurements have been done according to the CPX-method (ISO/CD 11819-2). This is a method where the tyres are mounted on a trailer, towed by a vehicle. On the trailer, 2 microphones on each side of the trailer are mounted in an angle of 45° to the perpendicular axes of the centre of the tyre and at a distance of 0.2 m from the tyre sidewall. The height is 0.1 m above the ground.

Normally, this method is used for measurements of the road surface influence to the road traffic noise, using standardised tyres. However, it is also useful for comparing rolling noise levels of tyres under equal conditions.

The measurements were performed as paired measurements using the CPX-trailer of the Norwegian Public Roads Administration, see figure 2.

Fig.2 CPX-trailer used for measurements

Paired measurements mean that tyres 1 and 2, 3 and 4, 5 and 6, etc, were measured at the same time with one tyre at each side of the trailer.

Before the measurement, all tyres were run-in at a minimum distance of 100 km. The inflation pressure was adjusted to 170 kPa before mounting on the trailer.

With the CPX-trailer, a minimum of 2 runs at each road surface were performed at the two speeds of 50 and 80 km/h. An exception of this was at Surface 6, where measurements were done only at 50 km/h, due to a posted speed limit of 60 km/h.

The 3D texture profiles were measured over a distance of approx. 25 m. However, the noise measurements were done over a distance of approx. 300 m, covering the area of the texture measurements.

The measurement results are given as an average equivalent continuous A-weighted level, L_{AFast} for the 2 microphones, for the total measured distance, as a result of average levels of each 20 m of the measured distance.

All measurement results are temperature corrected to + 20 °C, using a correction factor of -0.05 dB/°C.

6 Measurement results

6.1 CPX-measurements

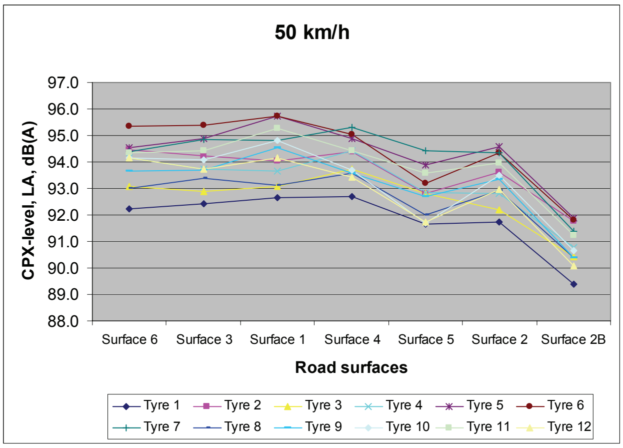
In figures 3 and 4 the results for 50 and 80 km/h are shown.

The surface to the left is the oldest surface, while the surface to the right is the newest surface. Surface 2B is the newest and smoothest surface, not exposed to studded tyres/winter conditions.

The results show some basic trends:

- The ranking of the tyres seems to be more or less the same on all the surfaces, especially at 80 km/h: The "noisiest" tyres have the highest levels, independent of the road surface.

- The spread of the levels are **2-3 dB(A)** on all road surfaces.
- There is a difference of **5-6 dB(A)** between the most "quiet" tyre on the quietest road surface and the "noisiest" tyre on the noisiest road surface.



,Fig.3 CPX-levels at 50 km/h

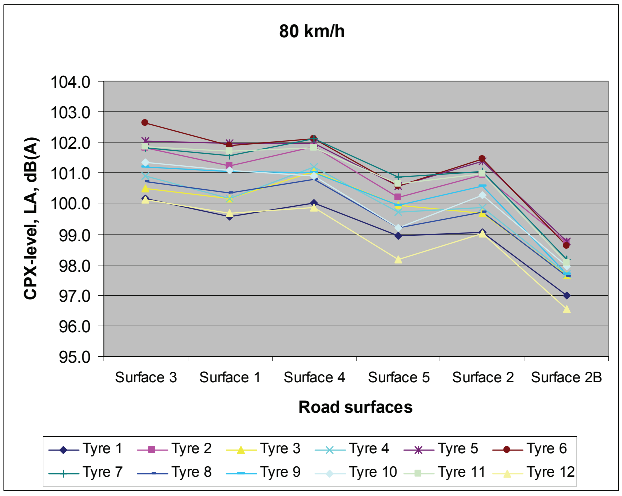


Fig. 4 CPX-levels at 80 km/h

The levels on Surface 5 are lower than on Surface 4. Both surfaces are on the same location (left and right lane northbound on a 4 lane motorway) and produced at the same period. There is a small difference in the added rubber to the bitumen, but this is not the reason for the different noise levels. The major reason is that the traffic load on Surface 4 (right lane) is 90 % of the total traffic, while Surface 5 has only 10 %. This difference clearly influences the wear of the surface, especially during the winter season.

6.2 Noise ranking

Based on the average measured level at 50/80 km/h and the 95% confidence intervals, the tyre have been ranked. The tyre with the lowest level on a certain surface is given the value 1, while the tyre with the highest level is given the value 12. If two or more tyres cannot be separated due to the confidence interval, they are given the same ranking number. In table 3, the overall ranking is shown for both speeds and all road surfaces.

Tyre	Average ranking	Category	Dimensions
1	1.2	MP	175/70 R14
12	2.0	MP	185/65 R15
3	2.5	MP	185/65 R15
8	2.6	HP	205/55 R16
4	3.2	MP	185/65 R15
9	3.6	HP	215/55 R16
10	3.8	HP	215/55 R16
2	4.5	LP	175/70 R14
11	4.8	MP	195/65 R15
7	5.5	HP	205/55 R16
5	6.0	HP	195/65 R15
6	6.1	HP	195/65 R15

Table 3 Noise ranking of the tyres

Based on this table, we can conclude that there seems to be no correlation between the noise levels and the **category** of the tyres (low, medium or high performance)

6.3 Noise vs. tyre width

In figure 5, the correlation between the **width** of the tyres and the measured noise levels at 80 km/h for the roughest surface (Surface 3). The results show, that within the measured tyre sizes, there is a very poor correlation between the width and the noise. The same results was found for the smoothest surface (2B).

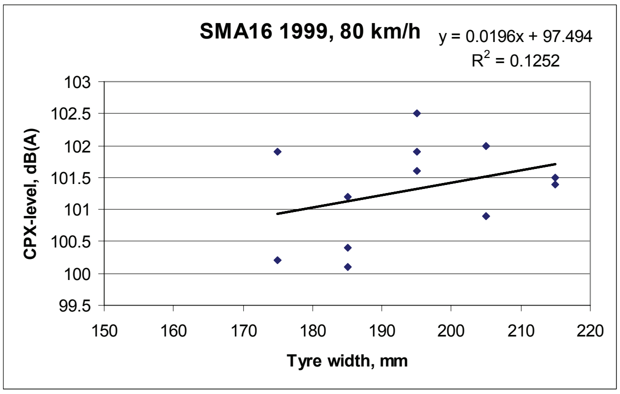


Fig. 5 Surface 3: Noise level vs tyre width

The poor correlation is in line with the findings in recent studies [1].

6.4 CPB measurements

On Surface 5, controlled pass-by (CPB) measurements were performed with 4 sets of Tyre 8, mounted on a VW Passat Sedan 2007-model. The CPB-measurements were performed according to the procedure given in the EU-directive 2001/43/EC. A total of 14 pass-by measurements were performed at speed ranges from 53 to 96 km/h. Based on the regression curve, a level of 79. 7 dB(A) was found at a speed of 80 km/h.

To compare this measurement with the CPX-measurement, the CPX-level was recalculated to a coast-by level at 7.5 m, using a method described in the SILVIA-project [2]. Using the parameters for a dense road surface, a level of 79.0 dB(A) was found, which is quite close to the measured value.

In figure 6, the frequency spectrum from the CPB-measurements at 80 km/h is compared to two CPX-measurements at speeds close to 80 km/h (77 and 84 km/h). The results show similar shape of the spectra.

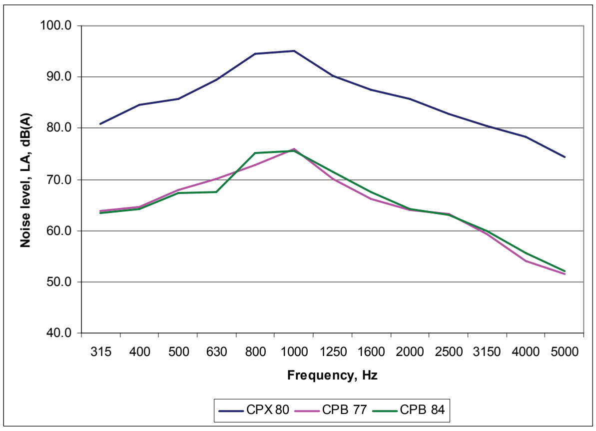


Fig. 6 CPX and CPB-measurements of Tyre 8 on Surface 5

7 Noise modelling

The noise of all tyres has been modelled using the *SPERoN* model, developed by Müller-BBM (Germany) and Chalmers University (Sweden) [3].

SPERoN is a tyre/road interaction model that predicts tyre/road noise, based on input data for the texture of the road and measured parameters of the tyre. The model can be separated into two major parts, a contact model and a tyre/road interaction model. The contact model describes the forces resulting from the interaction within the rolling process of a tyre on the road. The interaction part uses a hybrid approach (combines a physical and statistical model) that describe all relevant mechanisms that play a role in the generation of a tyre/road noise level of a passenger car tyre.

To determine the coast-by levels (7.5 m, 1.2 m height) of all the tyres at 50 and 80 km/h and to an air temperature of + 20°C, the following input parameters were needed:

- Road surface quasi 3D texture data
- Tyre's macroscopic properties derived by means of point mobility measurements
- Tyre's 3D geometry and Shore A hardness measured
- Air flow resistance estimated by means of an empirical model
- Tyre load 325 kg, corresponding to the CPX trailer's axle load of 650 kg.

8 Comparison with measurements

In addition to modelling of the levels on the surfaces in table 2, the levels have also been modelled on the texture of an ISO-surface (from the Sperenberg test field). Thus, we are able to compare measurement and modelling levels on SMA-surfaces, with modelling results on an ISO-surface. Table 4 shows the modelling results on the ISO-track at 80 km/h.

Tyre no.	ISO-level, dB(A)
3	70.7
6	71.6
7	71.7
2	71.8
4	71.9
11	72.1
8	72.3
1	73.6
9	74.7
10	74.9
5	75.9

Table 4 Modelling levels on ISO-track

Comparing the modelled results on the ISO-track with the ranking in table 3, based on measured CPX-levels, shows a quite different ranking on the SMA-surfaces. Tyre 1 is in general the quietest tyre on the SMA-surfaces, while this tyre is ranked only at 8. place on the ISO-surface. For tyre 6, the ranking is opposite; low level on the ISO-surface and high on the SMA's.

To compare the modelling results on the SMA-surfaces, with the measured levels on the same surfaces, all the CPX-levels have been recalculated to coast-by levels at 7.5 m, using the SILVIA-approach (basically reducing the measured CPX-level with 21.2 dB(A)).

In figures 7 and 8, the modelling results are shown for 50 and 80 km/h.

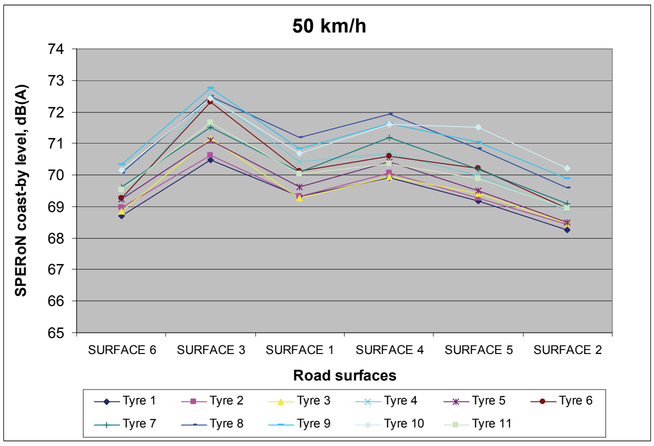


Fig.7 Modelling results at 50 km/h

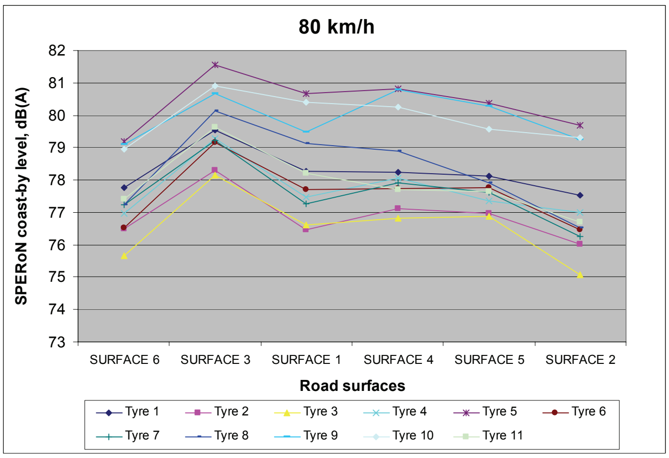


Fig.8 Modelling results at 80 km/h

The results show that the *range* of levels is about the same when comparing modelling and measurement results. A combination of the most quiet tyre and road surface is in the range of 5-6 dB(A) for the speed range 50-80 km/h. The dynamic range in the modelling results is about the same for 50 km/h, about 3 dB(A), while the range is somewhat higher, about 4 dB(A) at 80 km/h. The noise levels on the oldest surface (Surface 6) seem to be underestimated by the model, compared to measurements.

If the results for Surface 6 (DAC16 1992) are excluded, where only measurements at 50 km/h are available, there is an agreement between the model and the measurement results; the ranking of the surfaces is quite similar.

In figure 9 the modelling results (80 km/h) for the roughest surface (Surface 3) are compared with measurement results (recalculated to 7.5 m) and modelled results for the ISO-surface. The comparison shows that the ranking is fairly good between the modelled results on Surface 3 and on the ISO-surface. However, there is a somewhat different ranking between the measured levels and the ISO-levels (see again tyres 6 and 1).

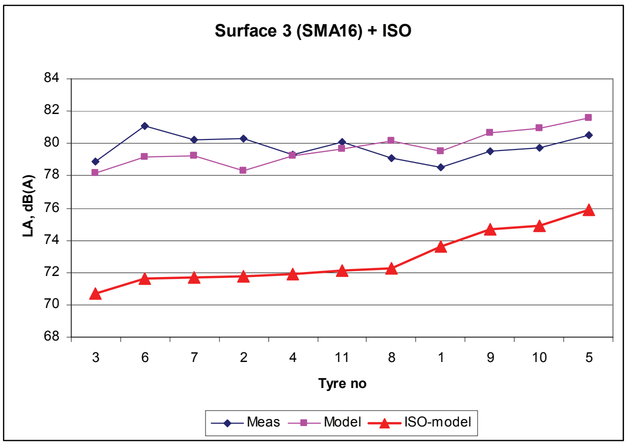


Fig. 9 Comparison between measured and modelled results on Surface 3, and on the ISO-surface.

In figure 10, the same comparison has been made for the smoothest surface, Surface 2/2B, and the ISO-levels.

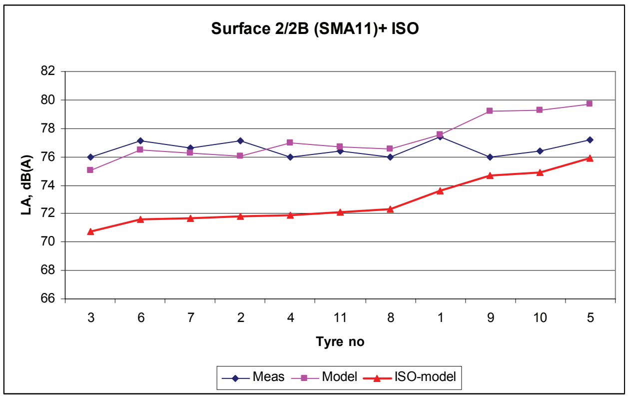


Fig.10 Comparison between measured (Surface 2B) and modelled results (Surface 2) and on the ISO-surface.

On the smoothest surface, there is a better agreement between the modelling and measured levels/ranking of tyres.

9 Conclusions

From this limited investigation, on a selection of widely used after market summer tyres, the following conclusions can be made:

- For this selection of tyres, the noise levels varies in the range of 2-3 dB(A) on normal used SMA-surfaces.
- The combination of a quiet tyre on a quiet road surface indicates a potential reduction of tyre/road noise in the area of 5-6 dB(A).
- No correlation was found correlation between the noise levels and the width of the tyres, nor with the performance class.
- The *SPERoN*-model seems appropriate to rank surfaces concerning tyre/road noise levels
- the dynamics (spread of levels) of the modelling results seems to be in good agreement with measurement results
- The individual noise ranking of tyres seems to be different on the rougher surface than on the smoother, when comparing modelling and measurement results.
- Based on the results of this project, it seems that a reduction of noise levels according to the EU-directive (on an ISO-surface) does not give the same noise reduction on rougher SMA-surfaces, as commonly found in the Nordic countries, where studded tyres are widely used during the winter season.

Acknowledgments

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