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REPORT

Measurements of tyre/road noise from passenger car tyres according to the EU-directive 2001/43/EC, on a number of different road surfaces.

Truls Berge

SINTEF ICT

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SINTEF REPORT

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ABSTRACT

The report presents measurements of passenger car tyres measured in 2003 and 2004. In 2003 preliminary measurements on 6 tyres on 9 different road surfaces were performed.
In 2004, the measurements were done in 2 parts:
1) 7 car tyres were measured on two test tracks in the Netherlands: ISO-surface and a two layer porous asphalt (2LPA)
2) 13 car tyres were measured on two typical road surfaces in Norway: SMA 0/11 and SMA 0/14.

The results show that the noise levels on the two SMA-surfaces on average are **7.5 dB(A) higher** than on the ISO-surface and **12.5 dB(A) higher** than on the 2LPA.

On the same surface, there is a difference of **3-5 dB(A)** between the quietest and the noisiest tyre. The difference is less on a rough surface (SMA), than on a smooth.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Acoustics	Akustikk
GROUP 2	Noise	Støy
SELECTED BY AUTHOR	Passenger car tyres	Personbildekk
	Texture	Tekstur

Preface

This project was partly financed by the Norwegian Public Road Administration, Vehicle Division, and partly under the Norwegian Research Council Program "Environmental Noise".

M+P Noise and Vibration Consultants, the Netherlands, has been engaged to perform all noise measurement in 2004, in cooperation with SINTEF.

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Senior scientist Svein Å. Storeheier has been responsible for all texture analysis. Senior engineer Asjørn Ustad has been responsible for the noise measurements performed by SINTEF in 2003, and assisted during the measurements in 2004.

Texture measurements have been performed by the Norwegian Public Road Administration in Norway and by M+P in the Netherlands.

Research scientist Truls Berge has been the project leader.

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1 Introduction

The aim of the project was to compare the noise ranking of typical passenger car tyres on an ISO-test surface [1], with the ranking on other road surfaces, with different construction features (stone size, texture, etc).

In the European Union tyre noise directive (2001/43/EC [2]), the noise levels are measured on an ISO-test track. If the noise ranking of tyres in this type of road surface is different from the ranking on road surfaces typically used in Norway, this would reduce the efficiency of reducing the noise limits according to this limit. Therefore, it was important to measure a range of normally used passenger car tyres on a range of road surfaces normally used in Norway.

2 Measuring method

The measurements were performed according to the method described in the EU-directive 2001/43/EC. This method describes the measurement of tyres mounted on a vehicle that drives by a microphone (7.5 m distance from the centreline of the track and 1.2 m height) in a coast-by situation (engine switched off).
The vehicle speed shall vary from 70 to 90 km/h, and based on the regression line (L_{AmaxF} vs speed); the maximum A-weighted sound level is calculated at the reference speed of 80 km/h. At least 4 measurements shall be below 80 and 4 above 80 km/h.

The calculated sound level is finally temperature corrected to the reference temperature of 20°C, based on the formula given in the directive.

In addition, the following measurements have been performed:

- Measurements at lower speeds (around 50 km/h)
- Measurements at a microphone height of 5.0 m (2004 measurements only)
- Interior noise measurements (on some of the cars used), with the microphone position according to ISO 5128 [3].

3 Measurements in 2003

In 2003, a preliminary testing program was performed, mainly to obtain experience with the measuring method, measurement equipment, and to perform measurements on a limited number of tyres. However, the test location made it possible to measure on a wide range of road surfaces, with quite different texture and chipping size.

3.1 Measurement locations

The measurements were performed at 2 locations:

- On the Ottar K. Kollerud Test Track at Oslo Airport, Gardermoen
- On a county road (Fv.530) just outside Oslo Airport, Gardermoen.

The Kollerud Test Track is located inside the airport, and is normally used for testing of friction and texture. The track is built up of 8 sections of different road surfaces, each 100 m long and 5 m wide.

Figure 3.1 shows a layout of the Kollerud Test Track and figure 3.2 a picture from part of the test track.

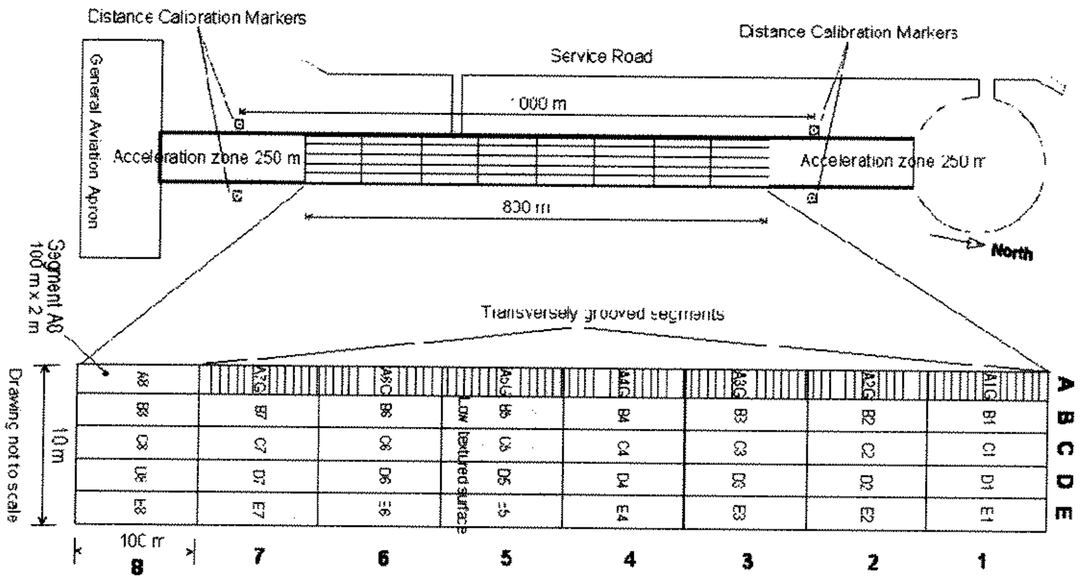


Figure 3.1 Layout of the Kollerud Test Track at Oslo Airport, Gardermoen.

Figure 3.2 Measurements on the Kollerud Test Track.

The 8 different road sections had different texture and different recipes (stone size, etc). 7 of the surfaces are dense asphalt concrete (DAC)-surfaces and one surface is a special porous friction course, see table 3.1.

In addition to the Kollerud Test Track, measurements were also performed (in both directions) at a normal trafficked road outside the airport. The road has a dense asphalt concrete surface 0/16 and was constructed in 1996. The road has a low traffic volume (< 5000 ADT) and a speed limit of 80 km/h.

Figure 3.3 shows the measurement location at Fv.530 and figure 3.4 shows the 2 locations on a map.

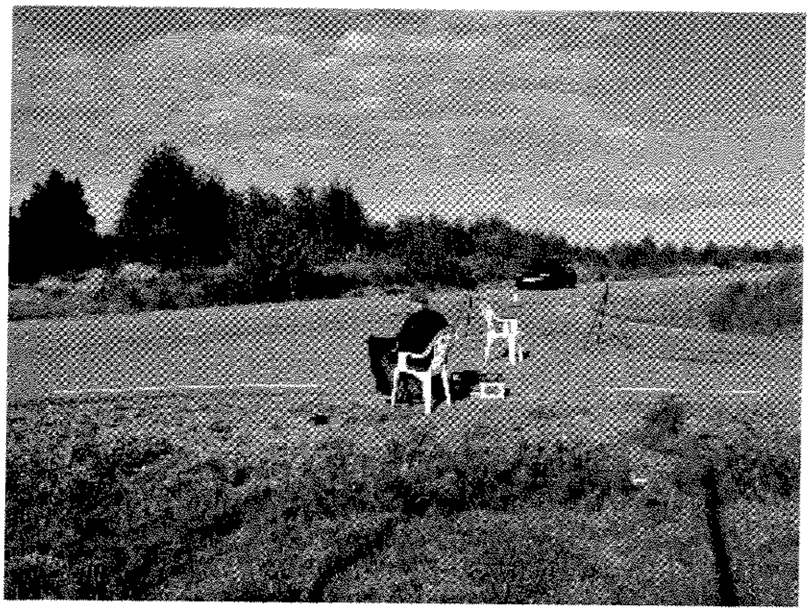


Figure 3.3 Measurement location at Fv.530.

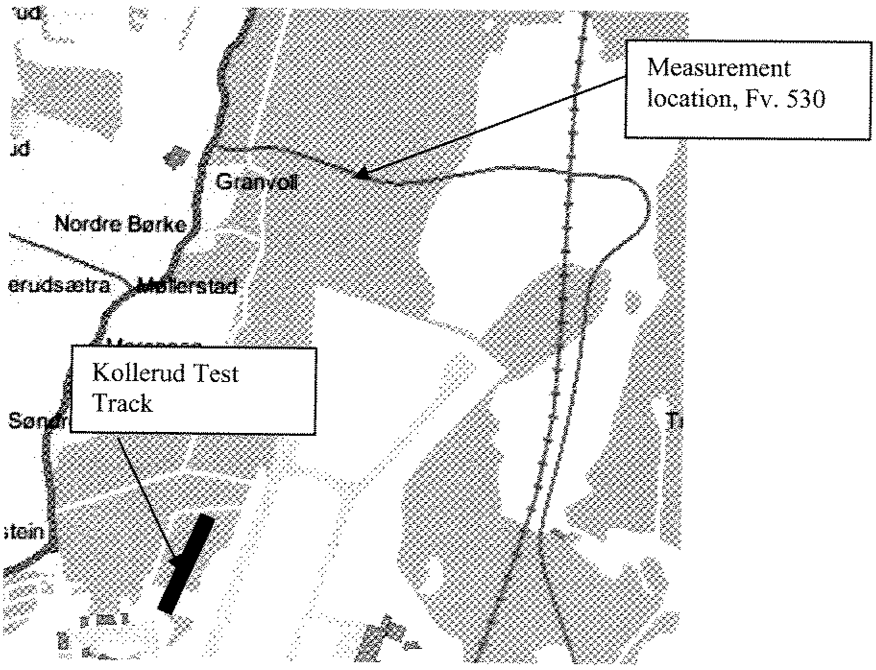


Figure 3.4 Location of the 2 test areas.

In table 3.1 we have listed the 9 road surfaces with measured Mean Profile Depths (MPD). Surfaces 1-8 are on the Kollerud Test Track. Surface 9 is the Fv.530.

Table 3.1 Road surfaces and MPD-values.

Road surface no	Type	MPD-value mm
1	DAC 0/11	1.05
2	DAC 0/11	0.90
3	DAC 0/11	0.82
4	DAC 0/8	0.72
5	DAC 0/4	0.40
6	SMA 0/11	1.05
7	SMA 0/16	1.70
8	PFC[1] 0/11	1.44
9	DAC 0/16	0.66

1) Porous Friction Course

3.2 Tyres and vehicles

Table 3.2 shows data for the vehicles used for the measurements: The additional weight was added to meet the load requirements for the tyres, during the test program.

Table 3.2 Test vehicle information

Vehicle	Model year	Mileage, km	Net weight kg	Max. weight kg	Additional weight kg
Peugeot 206 SW (Stationwagon)	2002	ca. 3000	1073	1563	490
VW Passat 2.0 (Sedan)	2002	ca. 22 000	1340	1900	560

The tyres used for testing are shown in table 3.3.

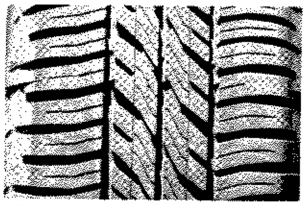
Table 3.3 Tyre information

Peugeot 206 SW:				
Manufacturer	Type	Dimensions	Mileage km	Production week/year
A.Goodyear	GT3	175/65 R14T	100	09/03
B.Michelin	Energy X	175/65 R14H	100	02/03
C.Continental	ContiPremiumContact	195/55 R15H	ca. 1500	18/02
VW Passat:				
D.Bridgestone	Turanza ER30	205/55 R16W	ca.15 000	15/02
E.Firestone	Firehawk 680	195/65 R16V	100	27/03
F.Michelin	Pilot Primacy XSE	205/55 R16V	100	09/03

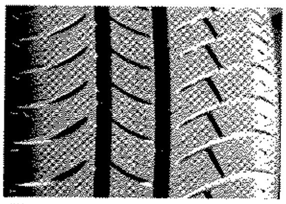
As table 3.3 shows, tyre C and tyre D are the original equipped tyres of the two test vehicles. Tread depth of the Conti-tyres were approx. 5-6 mm, and 4-5 mm for the Bridgestone tyres.

Figure 3.5 show the tread pattern of the 6 tyres.

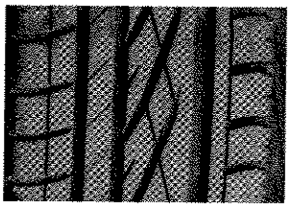
Tyres measured with Peugeot 206:



Tyre A:
Goodyear GT3

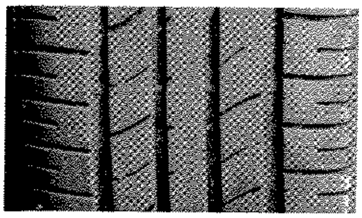


Tyre B:
Michelin Energy X

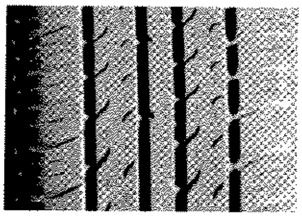


Tyre C:
ContiPremiumContact

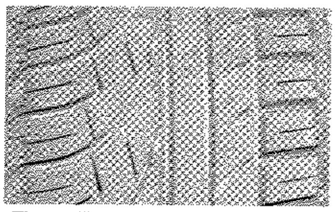
Tyres measured with VW Passat:



Tyre D
Bridgestone Turanza ER30



Tyre E:
Firestone Firehawk 680



Tyre F:
Michelin Pilot Primacy XSE

Figure 3.5 Tread patterns of the tested tyres.

Tyre pressure during the tests:
Peugeot : 1.8 kPa
VW Passat: 2.1 kPa

3.3 Measurement equipment:
Sound levels: Norsonic 121 Environmental Noise Analyser
Vehicle speed: VBOX II DGPS (GPS-system)

3.4 Measurement results
Tables 3.4 and 3.5 show the results for L_{AmaxF} at 50 and 80 km/h.
All values are temperature corrected to 20°C. There is no rounding or reduction of levels due to measurement uncertainty (as required in the EU-directive for type approval).

Road surface no	Surface type	L_{Amax}, dB(A) at 50 km/h					
		Goodyear GT3	Michelin Energy X	Continental Premium Contact	Bridgestone Turanza ER30	Firestone Firehawk 680	Michelin Pilot Primacy
		Tyre A	Tyre B	Tyre C	Tyre D	Tyre E	Tyre F
1	DAC11	66.3	67.2	68.9	69.2	67.5	67.5
2	DAC11	67.1	67.3	69.2	69.5	67.5	67.8
3	DAC11	67.6	67.8	69.7	70.2	68.1	68.3
4	DAC8	66.7	66.3	68.7	69.1	67.0	67.3
5	DAC4	65.5	-	67.7	66.8	65.8	66.0
6	SMA11	67.2	-	70.4	71.0	69.0	69.3
7	SMA16	69.0	-	72,7	73.8	71.5	71.7
8	PFC11	63.2	-	65.8	65.9	64.2	64.0
9	DAC16	68.4	69.9	71.5	72.7	70.4	70.7

Table 3.4 Measurement results at 50 km/h

Road surface no	Surface type	L_{Amax}, dB(A) at 80 km/h					
		Goodyear GT3	Michelin Energy X	Continental Premium Contact	Bridgestone Turanza ER30	Firestone Firehawk 680	Michelin Pilot Primacy
		Tyre A	Tyre B	Tyre C	Tyre D	Tyre E	Tyre F
1	DAC11	72.7	73.9	75.7	75.9	73.4	74.1
2	DAC11	73.6	74.2	76.1	76.3	73.9	74.6
3	DAC11	74.5	75.0	76.8	77.2	74.4	75.4
4	DAC8	73.1	74.0	75.9	75.6	73.1	74.0
5	DAC4	71.9	-	74.7	74.1	71.9	72.9
6	SMA11	74.4	-	77.6	78.1	75.2	76.3
7	SMA16	77.0	-	80.3	81.2	78.2	79.7
8	PFC11	69.5	-	69.5	72.2	70.3	70.6
9	DAC16	74.7	76.7	78.5	80.3	77.3	78.3

Table 3.5 Measurement results at 80 km/h

A complete presentation of all the results from these 9 road surfaces are given in [4].

4 Measurements in 2004

The measurements on tyres in 2004 were performed during two separate projects:

1) Measurements in the Netherlands on 2 road surfaces (closed test tracks)
2) Measurements on 2 normal trafficked road surfaces in Norway.

Both these projects were done in cooperation with M+P Noise and Vibration Consultancy, the Netherlands. M+P was responsible for all measurement equipment, test vehicles (in the Netherlands), loading, tyre pressure, etc. Furthermore, M+P has been responsible for all processing and reporting of measurement results.

SINTEF has assisted M+P during the measurements, both in the Netherlands and in Norway. SINTEF has also been responsible for all measurements inside the vehicles.

4.1 Measurements in the Netherlands

4 of the tyres measured in 2003 (Tyres A, B, E and F in figure 3.5) were available to be included in the measurement program in 2004. In addition to these tyres, 3 new set of tyres were included in the measurement program for 2004.

The measurements were performed at the RDW Test Track at Lelystad [5]. Figure 4.1 shows an overview of the test track. At this test track, there are two road surfaces that were used for the measurements:

- ISO 10844 (Dense Asphalt Concrete 0/8 mm)
- A two layer porous asphalt surface (2LPA), with top layer 2/6 mm and bottom layer 11/16mm.

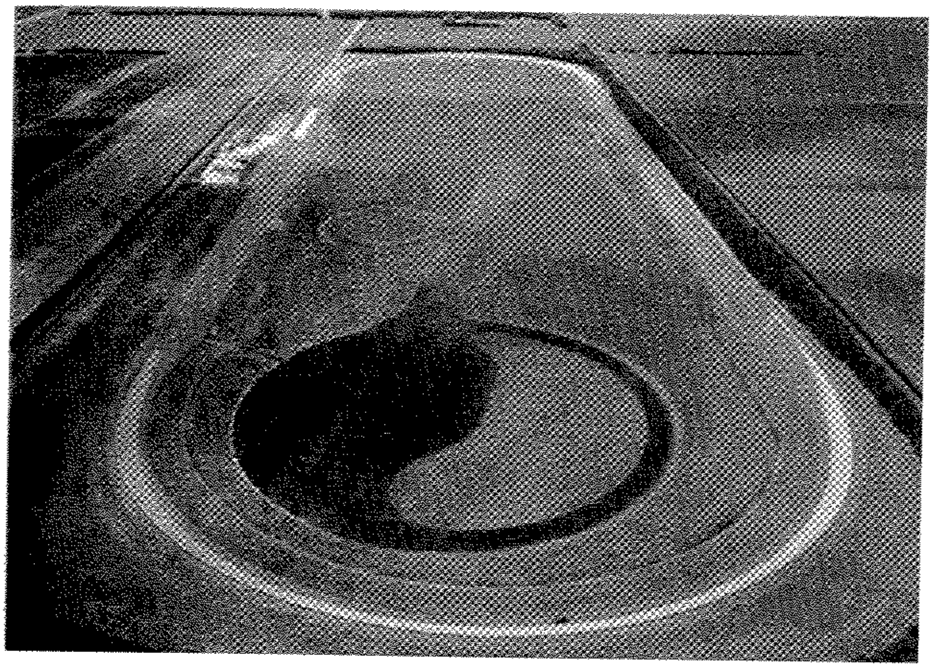
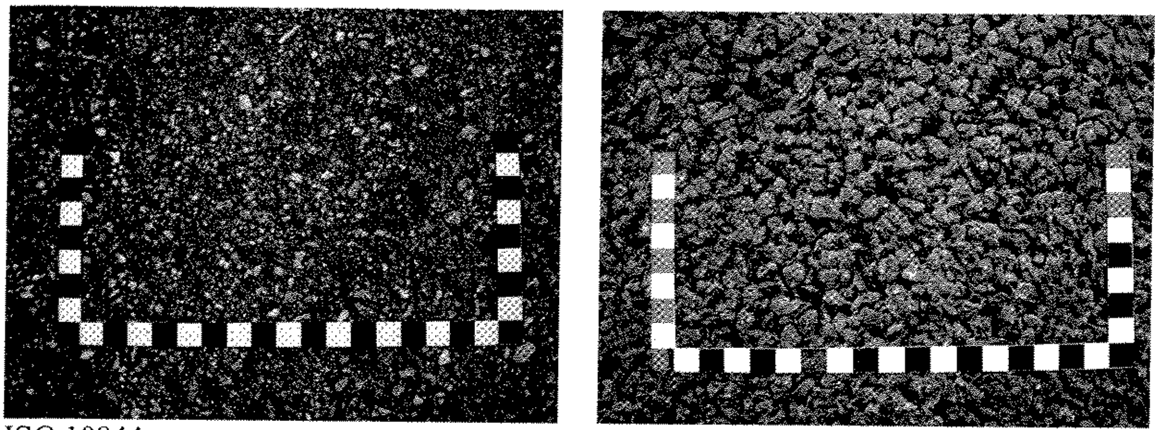


Figure 4.1 The RDW test track at Lelystad

Figure 4.2 shows an overview of the 2 test tracks and figure 4.3 details of the surfaces.

Figure 4.2 The two test tracks at RDW.
ISO 10844 is closest to the camera.



ISO 10844

Two Layer Porous Asphalt

Figure 4.3 Test surfaces at RDW, Lelystad

4.2 Tyres and test vehicles

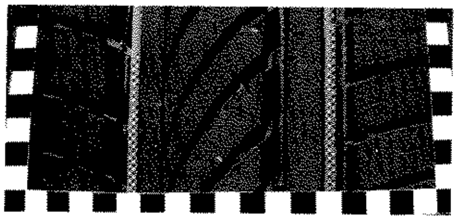
Table 4.1 shows the tyres tested at RDW.

Table 4.1 Tyres tested at the RDW test tracks

Tyre no.	Type	Dimensions, load and speed index
1	Goodyear GT3	175/65 R14 82H
2	Michelin Energy X	175/65 R14 82H
3	Nokian NRHi	205/55 R16 94H
4	Yokohama C-Drive	205/55 R16 94V
5	Goodyear Eagle F1	205/55 R16 91W
6	Michelin Pilot Primacy XSE	205/55 R16 91V
7	Firestone Firehawk 680	195/65 R15 91V

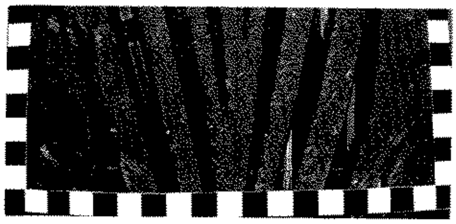
Tyres 1, 2, 6 and 7 are identical to the tyres A, B, F and E in table 3.3 and figure 3.5.

Figure 4.4 shows the tread pattern of the 3 additional tyres (tyre 3, 4 and 5).



Tyre 3. Nokian NRHi

Tyre 4. Yokohama C-Drive



Tyre 5. Goodyear Eagle F1

Figure 4.4 Tread pattern

Tyres 1 and 2 were measured with a Citroen Berlingo, while tyres 3 to 7 were tested with a VW Passat Variant, se figure 4.5.

Figure 4.5 Test vehicles

4.3 Test program

The following test program was performed:

- Measurements according to 2001/43/EC
- Additional measurements at speeds in the range of 50-70 km/h
- Additional microphone height of 5.0 m
- Interior noise levels at 80 km/h (VW Passat only)

4.4 Measurement results

4.4.1 Results at 80 km/h

Table 4.2 shows the results at 80 km/h. All the values are temperature corrected (no rounding or -1 dB(A) correction).

Table 4.2 Measurement results on two test tracks at RDW/Lelystad, 80 km/h.

Tyre no.	Type	ISO 10844 dB(A)	2LPA dB(A)
1	Goodyear GT3	72.0	68.6
2	Michelin Energy X	73.7	70.8
3	Nokian NRHi	72.5	68.2
4	Yokohama C-drive	73.6	68.3
5	Goodyear Eagle F1	70.8	66.0
6	Michelin Pilot Primacy XSE	73.9	69.8
7	Firestone Firehawk 680	72.9	69.2

In table 4.3 we compare the measurement results on the ISO-surface with the limits in the EU-directive. The measured values have been temperature corrected, rounded down to the nearest dB and subtracted 1 dB for measurement uncertainty.

Table 4.3 Measurement results according to 2001/43/EC, compared to the limits.

Tyre no.	Type	Noise limit EU, dB(A)	ISO 10844 dB(A)
1	Goodyear GT3	74	71
2	Michelin Energy X	74	72
3	Nokian NRHi	75	71
4	Yokohama C-drive	75	72
5	Goodyear Eagle F1	75	69
6	Michelin Pilot Primacy XSE	75	72
7	Firestone Firehawk 680	75	71

As table 4.3 shows, the measured noise levels are from 2 to 6 dB(A) below the limits.

4.4.2 Results at 50 km/h

In table 4.4 the results at 50 km/h are shown.

Table 4.4 Measurement results on two test tracks at RDW/Lelystad, 50 km/h.

Tyre no.	Type	ISO 10844 dB(A)	2LPA dB(A)
1	Goodyear GT3	65.4	61.1
2	Michelin Energy X	66.4	63.8
3	Nokian NRHi	65.5	61.4
4	Yokohama C-drive	67.1	62.6
5	Goodyear Eagle F1	65.0	60.3
6	Michelin Pilot Primacy XSE	67.1	63.1
7	Firestone Firehawk 680	66.3	63.5

Comparing tables 4.2 and 4.4 shows that the ranking of tyres is almost the same at 80 km/h and at 50 km/h. Tyre 5 is the quietest at both speeds on both surfaces. On the ISO-test track tyres 2 and 6 are the noisiest tyres at both speeds. At 80 km/h, the difference between the quietest tyre and the noisiest is 3.1 dB(A) on the ISO-surface and 4.8 dB(A) on the 2LPA. At 50 km/h, the same differences are 2.1 dB(A) and 3.5 dB(A) (regardless of tyre sizes).

4.4.3 Additional microphone positions

In addition to the standard microphone height of 1.2 m, the noise levels at 5.0 m were also recorded. At this height, there should be less influence of the surface itself on the propagation path.

Table 4.5 shows the results at 80 km/h on the two test tracks.

Table 4.5 Measurement results on two test tracks at RDW/Lelystad, 80 km/h. Microphone height 5.0 m.

Tyre no.	Type	ISO 10844 dB(A)	2LPA dB(A)
1	Goodyear GT3	69.6	67.3
2	Michelin Energy X	71.6	69.3
3	Nokian NRHi	70.3	67.2
4	Yokohama C-drive	71.3	67.1
5	Goodyear Eagle F1	68.6	65.1
6	Michelin Pilot Primacy XSE	71.2	68.3
7	Firestone Firehawk 680	70.3	67.5

Comparing the results in table 4.5 and table 4.2 shows that on the ISO-surface, the difference between microphone height 1.2 m and 5.0 m is in the range 2.1 to 2.7 dB(A), while on the 2LPA-surface the difference is only in the range of 0.9 to 1.7 dB(A).

5 Measurements on two SMA-surfaces in Norway

In this part of the investigation, we wanted to compare the ranking of tyres on two typical SMA-surfaces in Norway, with the ranking on the ISO-surface and on the 2LPA-surface in the Netherlands. In addition to the 7 tyres tested here, we measured the noise on 13 of the 26 passenger car tyres that M+P had previously tested on the two test tracks at RDW/Lelystad [6].

The measurements were performed 7-9. June 2004. Detailed results can be found in [7].

5.1 Test tyres

Table 5.1 gives a complete list of all the measured tyres.

Table 5.1 Tyres measured in Norway

Tyre no	Type	Dimensions, load and speed index
1	Goodyear GT3	175/65 R14 82T
2	Michelin Energy X	175/65 R14 82H
3	Semperit Sportlife	175/65 R14 82T
4	Continental EcoContact EP	175/65 R14 82T
5	Michelin Energy XT-1	175/65 R14 82T
6	Pirelli P3000	175/70 R13 82T
7	Pirelli P3000	175/65 R14 92T
8	Firestone Firehawk 680	195/65 R16 91V
9	Michelin Pilot Primacy XSE	205/55 R16 91V
10	Goodyear Eagle F1	205/55 R16 91W
11	Nokian NRHi	205/55 R16 94H
12	Yokohama C-drive	205/55 R16 94V
13	Yokohama AVS dB500	195/65 R15 91H
14	Hankook K406	195/65 R15 91H
15	Goodyear Eagle NCT5	195/60 R15 88H
16	Continental PremiumContact	205/55 R16 91V
17	Bridgestone Turanza ER70	195/60 R15 88H
18	Pirelli P6	195/65 R15 91H
19	Vredestein Sportrac	205/55 R16 91W
20	Michelin Energy XH-1	195/60 R15 88H

Tyres 1, 2, 8, 9, 10, 11 and 12 are tyres that were tested in the Netherlands, see table 4.1.
In appendix 1, photos of the tread pattern for all these tyres are shown.

5.2 Test vehicles

Tyres 1-7 in table 5.1 were measured with a Peugeot 206 SW and tyres 8-20 were measured with a VW Passat Variant, see figure 5.1.

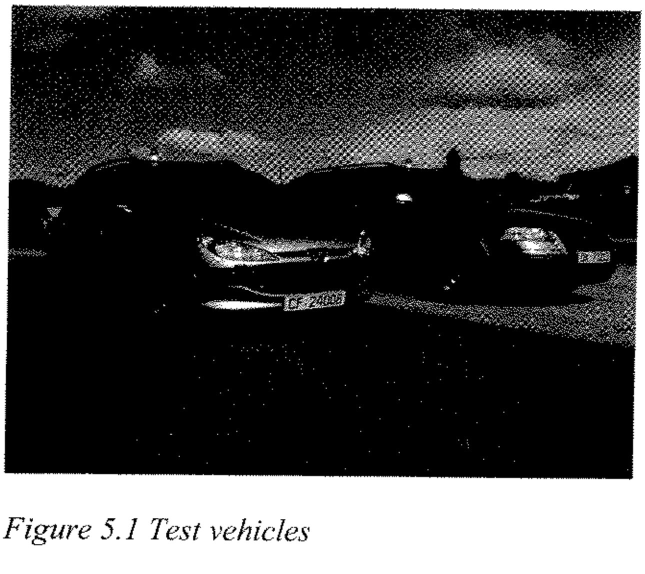


Figure 5.1 Test vehicles

5.3 Road surfaces

The measurements were performed on two SMA-surfaces on Rv.2 near Kongsvinger, see figure 5.2.


SMA 0/11

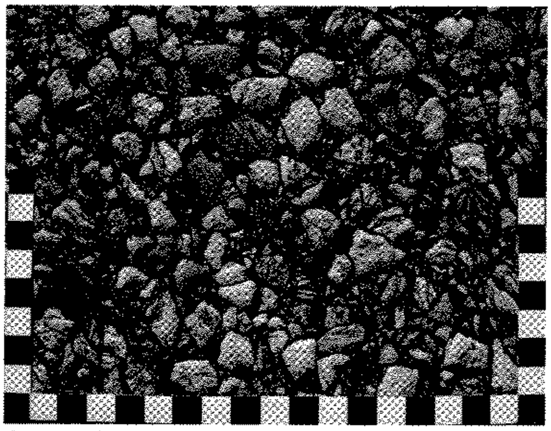
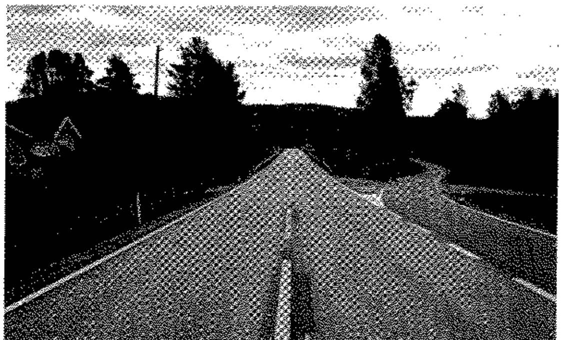

SMA 0/14

Figure 5.2 SMA-surfaces, Rv.2

The SMA 0/11- surface was constructed in October 2003, thus only about 8 months old, and exposed to one winter season.
The SMA 0/14 was constructed in August 1999, thus exposed to 5 winter seasons.

Figure 5.3 shows the two measuring locations at Rv.2.


Rv.2, SMA 0/11


Rv.2, SMA 0/14

5.4 Measurement results

5.4.1 Results at 80 km/h

Table 5.2 shows the results at 80 km/h. The levels are only temperature corrected.

Table 5.2 Noise levels at 80 km/h at two SMA-surfaces

Tyre no	Type	Dimensions	SMA 11 dB(A)	SMA14 dB(A)
1	Goodyear GT3	175/65 R14 82T	77.1	78.3
2	Michelin Energy X	175/65 R14 82H	79.6	80.3
3	Semperit Sportlife	175/65 R14 82T	79.7	80.5
4	Continental EcoContact EP	175/65 R14 82T	79.4	79.8
5	Michelin Energy XT-1	175/65 R14 82T	79.3	79.9
6	Pirelli P3000	175/70 R13 82T	78.9	79.6
7	Pirelli P3000	175/65 R14 92T	79.5	80.1
8	Firestone Firehawk 680	195/65 R16 91V	79.2	80.1
9	Michelin Pilot Primacy XSE	205/55 R16 91V	80.5	81.1
10	Goodyear Eagle F1	205/55 R16 91W	78.9	79.6
11	Nokian NRHi	205/55 R16 94H	78.7	79.5
12	Yokohama C-drive	205/55 R16 94V	80.2	81.3
13	Yokohama AVS dB500	195/65 R15 91H	78.0	79.0
14	Hankook K406	195/65 R15 91H	79.1	79.4
15	Goodyear Eagle NCT5	195/60 R15 88H	80.4	80.8
16	Continental PremiumContact	205/55 R16 91V	81.4	81.7
17	Bridgestone Turanza ER70	195/60 R15 88H	80.0	80.6
18	Pirelli P6	195/65 R15 91H	81.0	81.4
19	Vredestein Sportrac	205/55 R16 91W	81.2	81.8
20	Michelin Energy XH-1	195/60 R15 88H	80.9	81.3

If we compare the results between the two SMA-surfaces, we can see that there is a small difference. The tyre noise levels on the SMA 0/11 is on average 0.7 dB(A) less than on the SMA 0/14. The difference vary between 0.2 to 1.2 dB(A).
Baring in mind that the SMA 0/11 is 8 month old and only exposed to one winter season (with approximately 55 % of the vehicles with studded tyres), this may be sufficient to even out the differences on these two surfaces.

If we compare the results between the tyres on one surface only, we can see the following:

- On the SMA 0/11 surface, there is a maximum difference between the loudest (tyre no.16) and the quietest tyre (tyre no.1) of **4.3 dB(A)**, regardless of tyre dimensions.
- On the SMA 0/14 surface, the same difference is **3.5 dB(A)** (tyre 19 and tyre 1).
- On both surfaces, tyre 1 (Goodyear GT3) is the most quiet tyre.

5.4.2 Results at 50 km/h

In table 5.3, the noise levels at 50 km/h are given.

Table 5.3 Noise levels at 50 km/h at two SMA-surfaces

Tyre no	Type	Dimensions	SMA 11 dB(A)	SMA14 dB(A)
1	Goodyear GT3	175/65 R14 82T	70.0	71.3
2	Michelin Energy X	175/65 R14 82H	73.1	73.2
3	Semperit Sportlife	175/65 R14 82T	72.0	73.2
4	Continental EcoContact EP	175/65 R14 82T	72.4	72.4
5	Michelin Energy XT-1	175/65 R14 82T	71.6	72.4
6	Pirelli P3000	175/70 R13 82T	71.5	72.4
7	Pirelli P3000	175/65 R14 92T	71.9	73.0
8	Firestone Firehawk 680	195/65 R16 91V	72.3	72.9
9	Michelin Pilot Primacy XSE	205/55 R16 91V	73.6	74.1
10	Goodyear Eagle F1	205/55 R16 91W	71.5	72.6
11	Nokian NRHi	205/55 R16 94H	71.2	72.0
12	Yokohama C-drive	205/55 R16 94V	72.6	73.9
13	Yokohama AVS dB500	195/65 R15 91H	71.7	72.4
14	Hankook K406	195/65 R15 91H	72.3	72.2
15	Goodyear Eagle NCT5	195/60 R15 88H	72.9	73.7
16	Continental PremiumContact	205/55 R16 91V	74.1	74.4
17	Bridgestone Turanza ER70	195/60 R15 88H	72.7	73.2
18	Pirelli P6	195/65 R15 91H	73.5	74.1
19	Vredestein Sportrac	205/55 R16 91W	73.6	74.8
20	Michelin Energy XH-1	195/60 R15 88H	74.1	74.1

Comparing the results at 50 km/h with the results at 80 km/h (table 5.2), the difference between the tyres with the highest and lowest noise level are approximately the same (4.1 dB(A) on the SMA 0/11 and 3.5 dB(A) on the SMA 0/14). Equally, the ranking of the tyres at 50 km/h is more or less the same as at 80 km/h.
This is important results, as it shows that the potential noise reduction of using more low noise tyres on our road surfaces is the same at 50 km/h (where more people live near trafficked roads) and at 80 km/h.

5.4.3 Additional microphone positions

Table 5.4 shows the noise levels at the microphone height of 5.0 m (80 km/h).

Table 5.4 Noise levels at 80 km/h at two SMA-surfaces, microphone height 5.0 m

Tyre no	Type	Dimensions	SMA 11 dB(A)	SMA14 dB(A)
1	Goodyear GT3	175/65 R14 82T	74.2	75.5
2	Michelin Energy X	175/65 R14 82H	76.9	77.8
3	Semperit Sportlife	175/65 R14 82T	76.8	77.7
4	Continental EcoContact EP	175/65 R14 82T	76.3	77.3
5	Michelin Energy XT-1	175/65 R14 82T	76.4	77.2
6	Pirelli P3000	175/70 R13 82T	76.4	76.8
7	Pirelli P3000	175/65 R14 92T	76.6	77.2
8	Firestone Firehawk 680	195/65 R16 91V	76.9	77.6
9	Michelin Pilot Primacy XSE	205/55 R16 91V	77.8	78.5
10	Goodyear Eagle F1	205/55 R16 91W	76.6	77.4
11	Nokian NRHi	205/55 R16 94H	76.1	77.3
12	Yokohama C-drive	205/55 R16 94V	77.6	78.9
13	Yokohama AVS dB500	195/65 R15 91H	75.6	76.7
14	Hankook K406	195/65 R15 91H	76.1	77.0
15	Goodyear Eagle NCT5	195/60 R15 88H	77.9	78.3
16	Continental PremiumContact	205/55 R16 91V	78.5	79.2
17	Bridgestone Turanza ER70	195/60 R15 88H	77.1	77.8
18	Pirelli P6	195/65 R15 91H	78.4	78.9
19	Vredestein Sportrac	205/55 R16 91W	78.5	79.2
20	Michelin Energy XH-1	195/60 R15 88H	77.9	78.8

On average, the noise levels at 5.0 m is 0.9 lower on the SMA 0/11 surface, than on the SMA 0/14 surface (76.9 dB(A) vs. 77.8 dB(A).
The differences between the max./min levels are approximately the same as at the 1.2 m microphone height (4.3 dB(A) on 0/11 and 3.7 dB(A) on 0/14).

5.5 Comparison with Dutch measurements

As mentioned, 13 of the tyres at previously been measured by M+P in 2002 at the test tracks in Lelystad [6].
Thus we are able to compare results for 20 tyres on 4 different road surfaces:
- ISO 10844
- Two Layer Porous Asphalt
- SMA 0/11
- SMA 0/14

Table 5.5 and figure 5.4 show the results at 80 km/h (1.2 m height) for all 4 road surfaces.

Table 5.5 Noise levels at 80 km/h on 4 road surfaces

Tyre no.	Type	ISO 10844 dB(A)	2LPA dB(A)	SMA 0/11 dB(A)	SMA 0/14 dB(A)
1	Goodyear GT3	72.0	68.6	77.1	78.3
2	Michelin Energy X	73.7	70.8	79.6	80.3
3	Semperit Sportlife	71.2	66.7	79.7	80.5
4	Continental EcoContact EP	72.4	67.7	79.4	79.8
5	Michelin Energy XT-1	72.0	67.4	79.3	79.9
6	Pirelli P3000	72.9	67.5	78.9	79.6
7	Pirelli P3000	72.9	67.6	79.5	80.1
8	Firestone Firehawk 680	72.9	69.2	79.2	80.1
9	Michelin Pilot Primacy XSE	73.9	69.8	80.5	81.1
10	Goodyear Eagle F1	70.8	66.0	78.9	79.6
11	Nokian NRHi	72.5	68.2	78.7	79.5
12	Yokohama C-drive	73.6	68.3	80.2	81.3
13	Yokohama AVS dB500	69.5	65.7	78.0	79.0
14	Hankook K406	70.6	66.0	79.1	79.4
15	Goodyear Eagle NCT5	71.6	67.2	80.4	80.8
16	Continental PremiumContact	71.7	67.4	81.4	81.7
17	Bridgestone Turanza ER70	72.4	66.7	80.0	80.6
18	Pirelli P6	72.9	68.6	81.0	81.4
19	Vredestein Sportrac	72.6	67.1	81.2	81.8
20	Michelin Energy XH-1	72.9	67.6	80.9	81.3
	Mean value	**72.3**	**67.7**	**79.6**	**80.3**

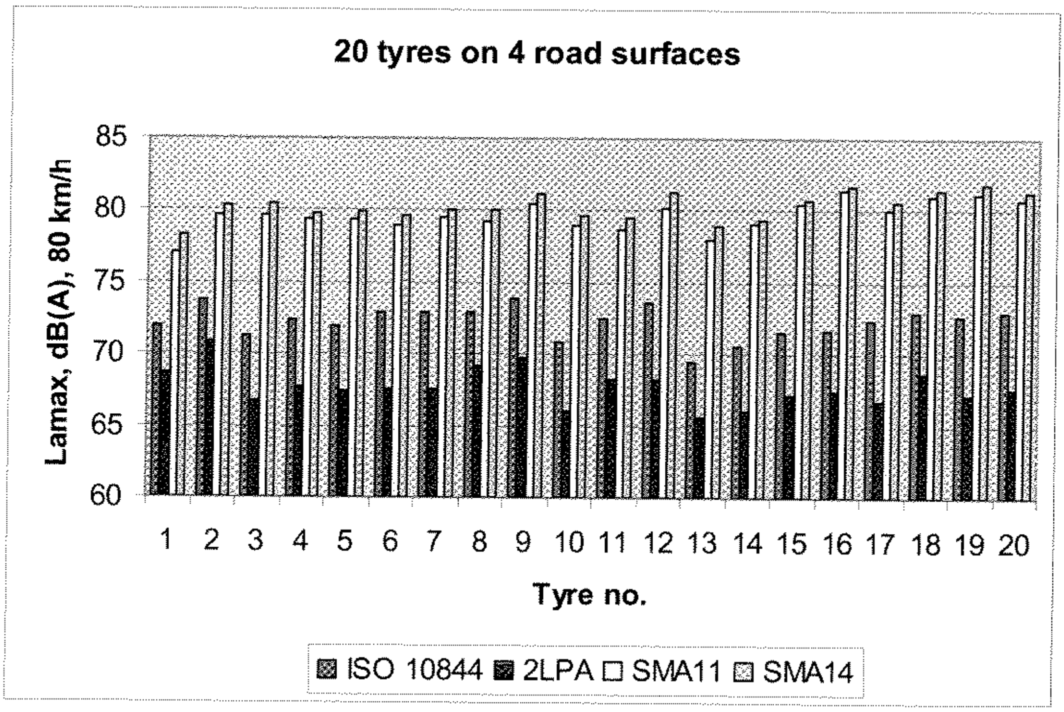


Figure 5.4 Noise levels at 80 km/h.

The results can be summarised as follows:

- On average the noise levels on the SMA 0/14 are **12.6 dB(A)** higher than on the 2LPA-surface.
- On average, the noise level on the SMA 0/14 are **7.5 dB(A)** higher then on the ISO-surface.
- Tyre no.19, Vredestein Sportrac has a noise level on the SMA 0/14 that is **14.6 dB(A)** higher than on the 2LPA.
- On the SMA 0/14 surface, the range of levels are 3.5 dB(A) (independent on tyre size), while on the 2LPA, the range is 5.1 dB(A) between the tyre with the highest and lowest level.

From these results, we can conclude that the influence of the road surface itself on the tyre/road noise is higher than the influence of tyre design.

Since the 2LPA is an absorptive road surface, one can expect that this road surface gives lower noise levels than the ISO-surface, which is a dense asphalt concrete surface (0/8 mm). On average the difference is approximately 5 dB(A).
However, that the SMA-surfaces gives 7-8 dB(A) higher levels than the ISO-surfaces is more surprising.

The SMA-surfaces were chosen from practical reasons, and need to be checked if they can be regarded as typical for Norwegian dense road surfaces concerning noise levels, before firm conclusions can be drawn. However, in another current project, CPX-measurements have been performed on these two SMA-surfaces and compared to another 8-9 years old SMA 0/14-surface in the same region, and the results are very similar [8].

5.6 Noise and tyre width

In table 5.6 we have analysed the results on the 4 road surfaces, depending on tyre width. The table shows the maximum difference in noise level at 80 km/h for the 3 different categories of widths.

Table 5.6 Differences in noise levels depending on tyre width

Tyre width, mm	ISO 10844 2001/43/EC, dB(A)	ISO 10844 dB(A)	2LPA dB(A)	SMA 0/11 dB(A)	SMA 0/14 dB(A)
All widths	4.0	4.4	5.1	4.3	3.5
175	2.0	2.5	4.1	2.6	2.2
195	3.0	3.4	3.5	3.4	2.7
205	3.0	3.1	3.8	2.5	2.3

Table 5.6 indicates that there is a difference of **2-4 dB(A)** in noise level between the most quiet tyre and the most noisy tyre (of the 20 tested in this investigation) within the same tyre width. Furthermore, the results indicate that the differences are smaller on rough surfaces, where the differences in tread pattern are of less importance than the tyre dimensions itself. This is also indicated in figures 5.5 to 5.8, where the noise levels as a function of tyre dimensions are shown. On the smooth surfaces, the dimensions (primarily the width) seem less important than the tread pattern.

However, since the number of tyres within each category of tyre width is rather small, one should be careful to draw final conclusions.

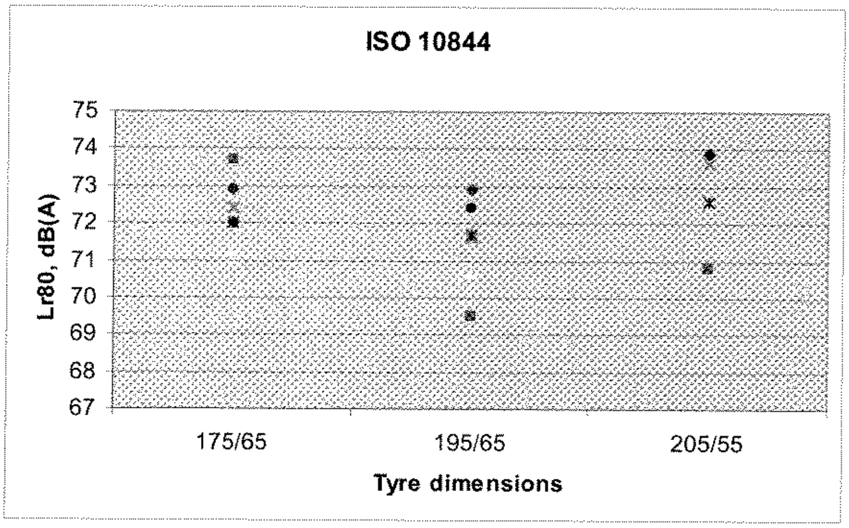


Figure 5.5 Noise levels at 80 km/h on ISO 10844

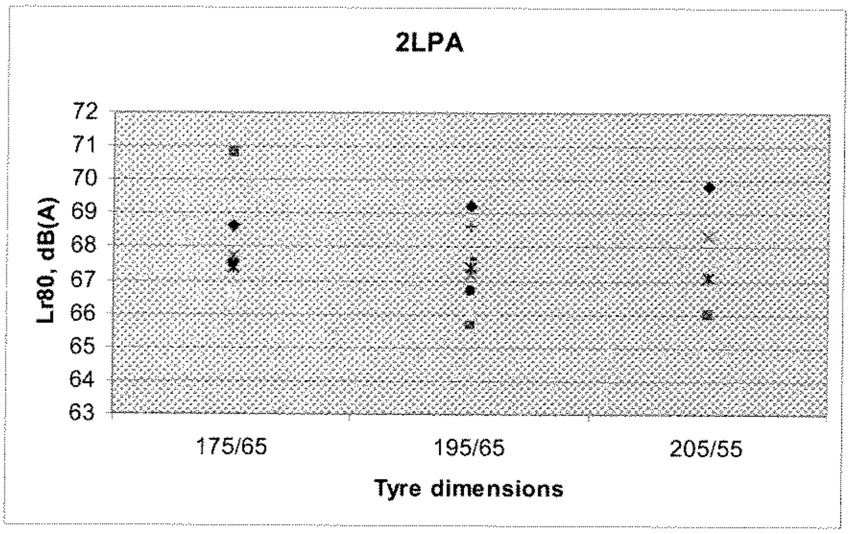


Figure 5.6 Noise levels at 80 km/h on 2LPA

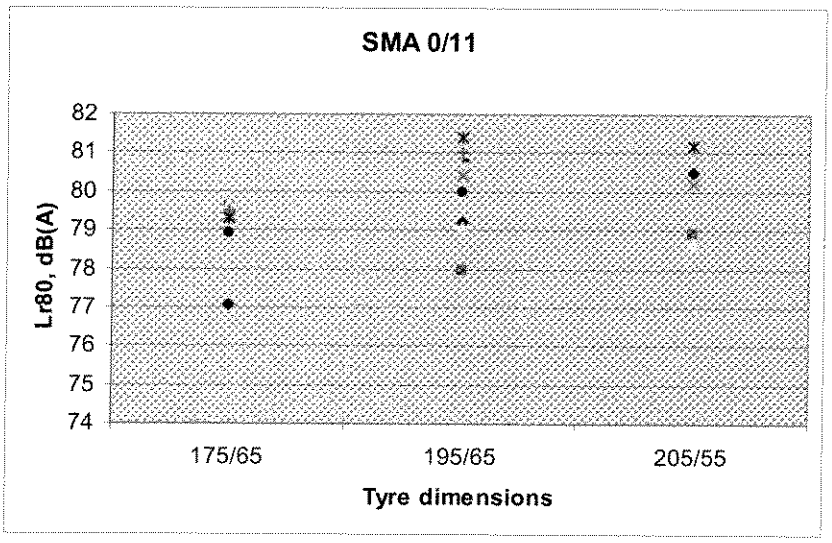


Figure 5.7 Noise levels at 80 km/h on SMA 0/11

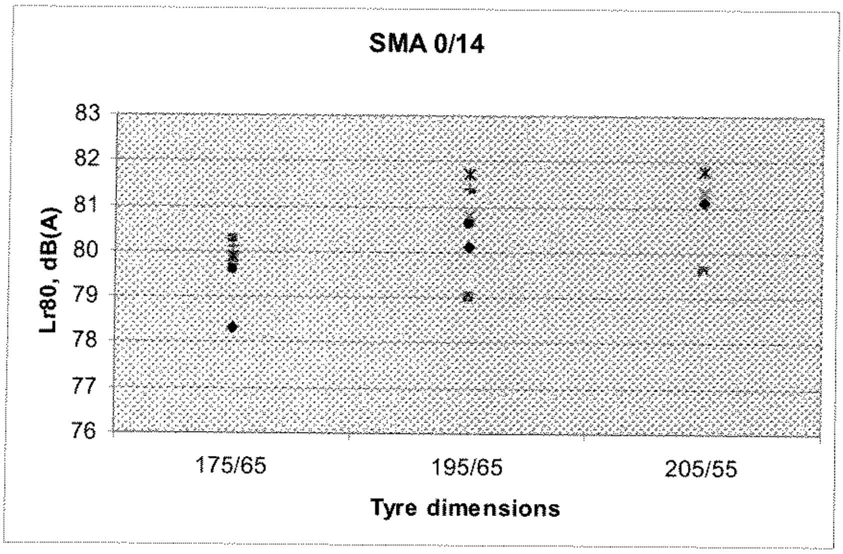


Figure 5.8 Noise levels at 80 km/h on SMA 0/14

5.7 Noise ranking of tyres

One interesting conclusion from the results presented in table 5.4 is that the noise ranking of tyres is different on the two rough SMA-surfaces than on the ISO-surface (and the 2LPA also). The noise ranking is shown in table 5.7, where 1 is the most silent tyre on each surface and 20 is the noisiest (within a maximum difference of 5 dB(A) on the 2LPA).

Table 5.7 Noise ranking or tyres

No	Tyre	Dimensions	ISO 10844	2LPA	SMA11	SMA14
1	Goodyear GT3	175/65 R14T	7	16	1	1
2	Michelin Energy X	175/65 R14T	19	20	11	11
3	Semperite Sportlife	175/65 R14T	12	6	19	20
4	Conti EcoContact EP	175/65 R14T	9	9	9	4
5	Michelin Energy XT-1	175/65 R14T	8	8	8	8
6	Pirelli P3000 Energy	175/70 R13T	13	10	4	5
7	Pirelli P3000 Energy	175/65 R14T	14	11	10	9
8	Firestone Firehawk 680	195/65 R16V	15	18	7	10
9	Micelin Pilot Primacy XSE	205/55 R16V	20	19	16	15
10	Goodyear Eagle F1	205/55 R16W	3	2	5	6
11	Nokian NRHi	205/55 R16H	11	14	3	4
12	Yokohama C-Drive	205/55 R16V	18	15	14	16
13	Yokohama AVS dB500	195/65 R15H	1	1	2	2
14	Hankook K406	195/65 R15H	2	3	6	3
15	Goodyear Eagle NCT5	195/65 R15H	5	7	14	15
16	Conti Premium Contact	195/65 R15H	6	9	20	19
17	Bridgestone Turanza ER70	195/60 R15H	10	4	13	13
18	Pirelli P6	195/65 R15H	16	17	18	18
19	Vredestein Sportrac	205/55 R16W	12	6	19	20
20	Michelin Energy XH-1	195/60 R15H	17	12	17	17

From this table, we can see that tyre 13, the Yokohama AVS dB500 is a silent tyre on all the surfaces, along with tyre 10, Goodyear Eagle F1.
On the other end of the scale, tyre 9, Michelin Pilot Primacy and tyre no 18, Pirelli P6 are both among the noisiest on all 4 surfaces.

For some tyres, like tyre no.1, Goodyear GT3 the ranking is quite different; it is the most quiet on the rough surfaces, while amongst the most noisy on the 2LPA. The same goes for tyre no.11, Nokian NRHi, which is among the quietest tyre on the rough surfaces, but is not so quiet on the smooth surfaces.

Comparing the ranking of tyres, it indicates that reductions of tyre noise limits on an ISO-surface will not necessarily give the same benefit on the rough surfaces included in this investigation.

In figures 5.9 to 5.12 we have shown the correlation between the noise levels (80 km/h) on the different surfaces, which underlines this conclusion.

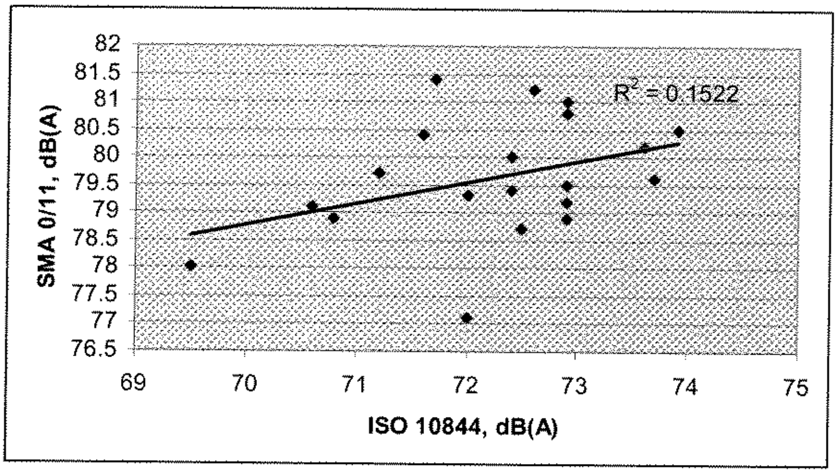


Figure 5.9 Correlation between levels on ISO 10844 and SMA 0/11

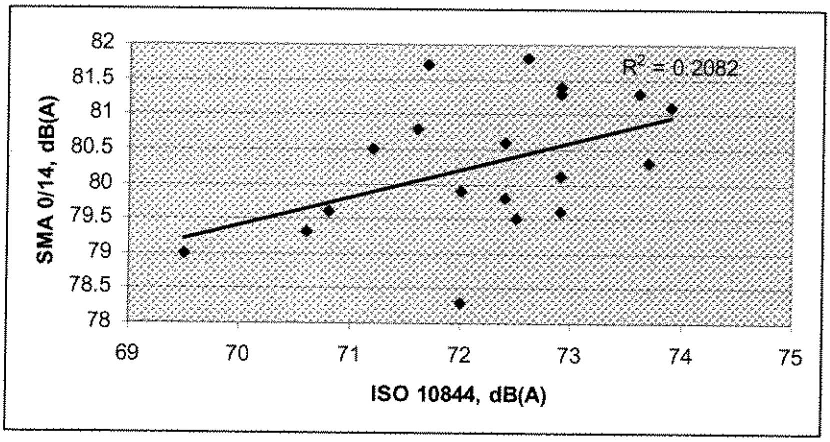


Figure 5.10 Correlation between levels on ISO 10844 and SMA 0/14

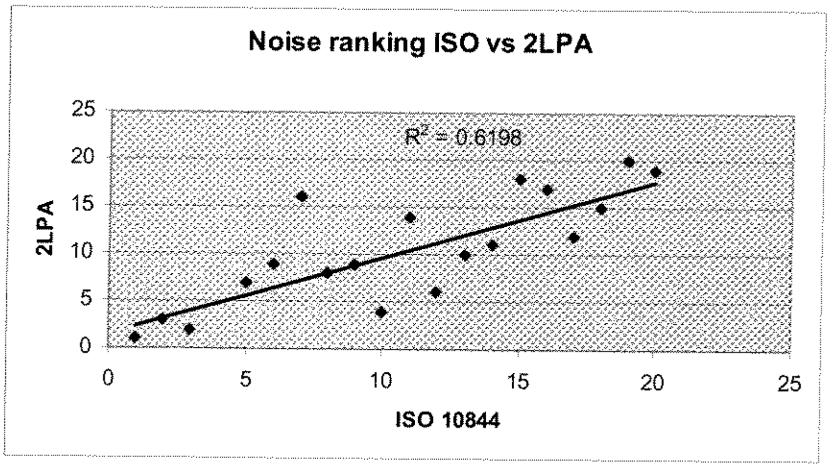


Figure 5.11 Correlation between levels on ISO 10844 and 2LPA

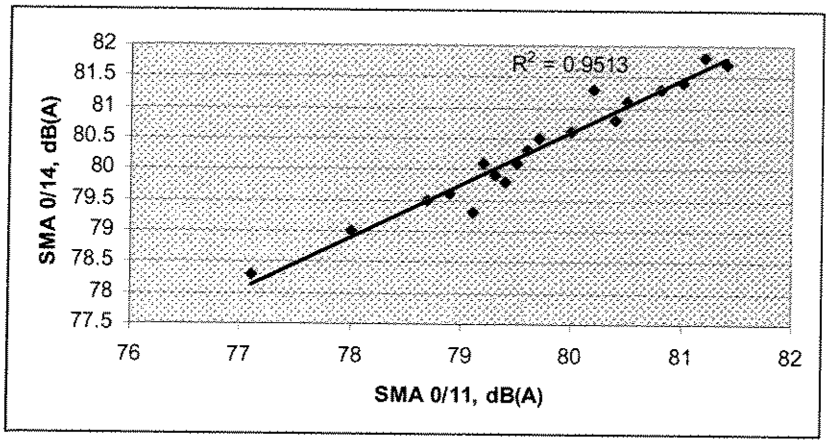


Figure 5.12 Correlation between levels on SMA 0/11 and SMA 0/14

5.8 Frequency spectra

In addition to maximum A-weighted sound levels, the frequency spectra were also available for some of the surfaces.

As an example of these measurements, the 1/3rd octave band spectra for Tyre 1 (Goodyear GT3) are shown in figure 5.13 for the ISO and the SMA0/11 surfaces.

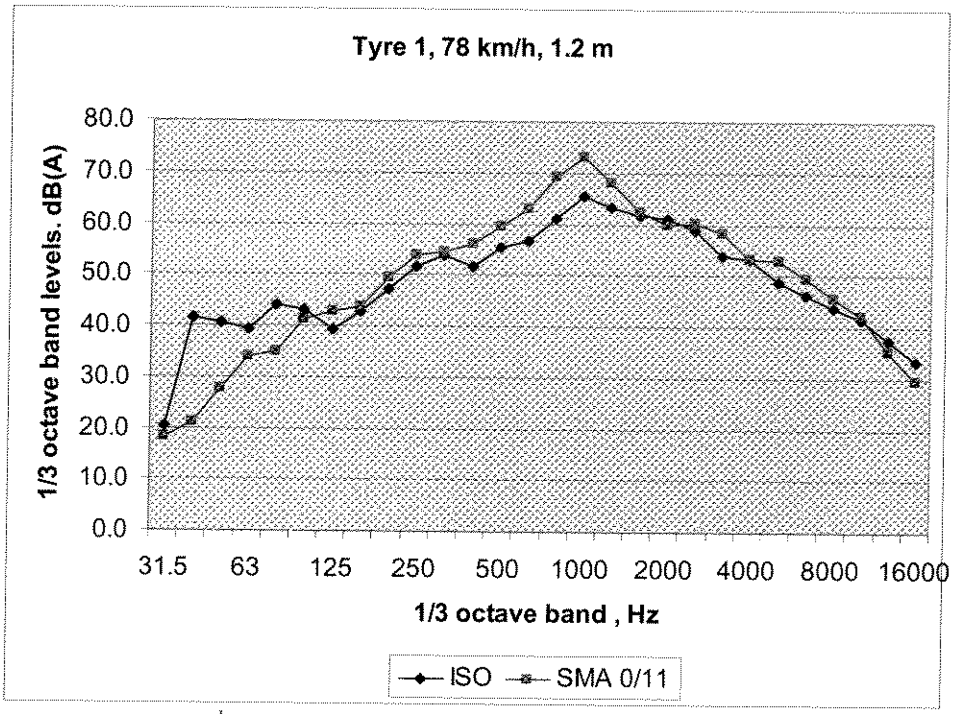


Figure 5.13 1/3rd octave band frequency levels for Tyre 1 at two road surfaces. Speed 78 km/h.

As figure 5.13 shows, the main difference in spectra levels are in the region 300-1200 Hz, which is the most important area for the A-weighted levels.
The differences in the low frequency area are probably caused by differences in wheel body design (the measurements were performed with two different vehicles).

6 Noise inside vehicle

The noise inside two of the test vehicles was also measured. These two vehicles were the VW Passat Variant used for the measurements at Lelystad (see figure 4.5) and the VW Passat Variant used for measurements at the two road surfaces near Kongsvinger in Norway (see figure 5.1). For both vehicles, the noise level was measured at 80 km/h with the microphone position according to ISO 5128 [3]. Figure 6.1 shows the microphone mounted in the Passat used for the measurements in Lelystad.

Figure 6.1 Microphone position according to ISO 5128.

At the two test tracks at RDW, the noise level inside the car was tested for 5 tyres, while at the two road surfaces near Kongsvinger, a total of 13 tyres (including the 5 tyres from RDW) were used for interior noise measurements.

Table 6.1 shows the measured noise levels for all the tyres at the different road surfaces, together with the measured exterior noise levels at the same surfaces. All interior values have been rounded to nearest 0.5 dB(A). Tyre numbering is according to table 5.1.

Table 6.1 Exterior and interior noise

Tyre no.	Tyre Type	ISO 10844 Exterior dB(A)	ISO 10844 Interior dB(A)	2LPA Exterior dB(A)	2LPA Interior dB(A)	SMA0/11 Exterior dB(A)	SMA0/11 Interior dB(A)	SMA 0/14 Exterior dB(A)	SMA 0/14 Interior dB(A)
8	Firestone Firehawk 680	72.9	60	69.2	59.5	79.2	65	80.1	66
9	Michelin Pilot Primacy XSE	73.9	60	69.8	59	80.5	66	81.1	66
10	Goodyear Eagle F1	70.8	60	66.0	59	78.9	65	79.6	64.5
11	Nokian NRHi	72.5	60.5	68.2	59.5	78.7	64	79.5	65
12	Yokohama C-Drive	73.6	59	68.3	58	80.2	64	81.3	65.5
13	Yokohama AVS dB500	69.5	-	65.7	-	78.0	64.5	79.0	65.5
14	Hankook K406	70.6	-	66.0	-	79.1	64	79.3	64.5
15	Goodyear Eagle NCT5	71.6	-	67.2	-	80.4	65	80.8	66
16	Conti Premium Contact	71.7	-	67.4	-	81.4	64.5	81.7	66
17	Bridgestone Turanza ER70	72.4	-	66.7	-	80.0	63.5	80.6	64.5
18	Pirelli P6	72.9	-	68.6	-	81.0	65.5	81.4	67
19	Vredestein Sportrac	72.6	-	67.1	-	81.2	65.5	81.8	67
20	Michelin Energy XH-1	72.9	-	67.6	-	80.8	66	81.3	67

Since both the measurements are carried out with the same type of Passat, all the results should be comparable.

Table 6.1 shows that on the smooth surfaces, there is almost identical interior levels, while the exterior noise level varies with approx. 4 dB(A).
However, on the rough surface, SMA 0/14, the variation in interior noise level are in the same magnitude as the exterior level (about 2.5 dB(A)).

Perhaps what is more interesting is to look at the interior noise level of the Passat on a 2LPA-surface with the most silent tyre (interior noise). According to table 6.1 this gives a level of 58 dB(A). Then on the SMA 0/14 road surfaces, using tyres with the highest interior noise level, we have a level of 67 dB(A). This is a difference of **9 dB(A)**, which can be regarded as a very large difference. Possible differences in frequency spectra with different tyres on different road surfaces also are important in such a comparison.

Driving a car on a surface that reduces the interior noise with approximately **6-9 dB(A)** would certainly improve the safety and comfort for driver/passengers of the car.

6.1 Correlation with external vehicle noise

Since the interior noise level is filtered from the source (tyre/road) and very much dependent on the vehicle design and construction, one might not find a good correlation between the exterior and interior noise level. This is confirmed by looking at this correlation in figure 6.2 from the measurements on the SMA 0/11 and figure 6.3 on the SMA 0/14. The correlation is somewhat better on the 0/14 than on the 0/11.

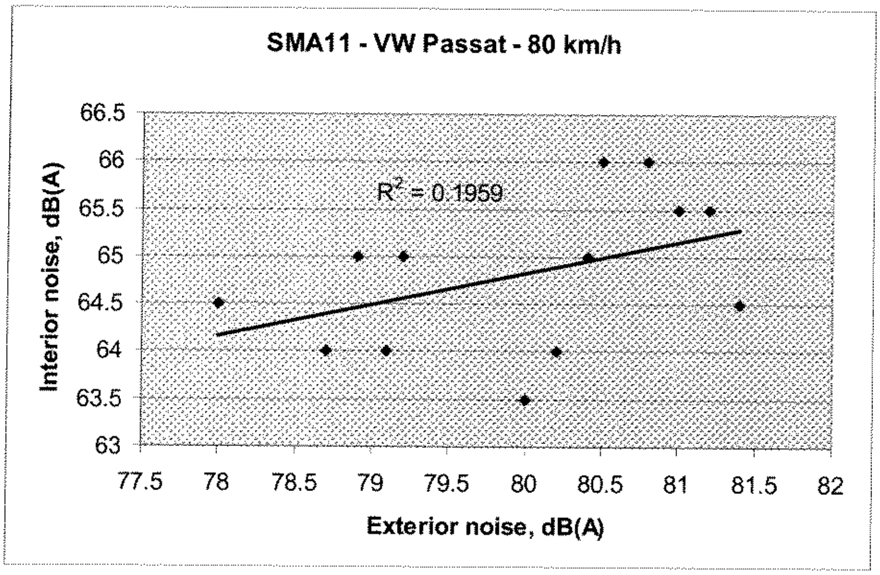


Figure 6.2 Correlation between exterior and interior noise on SMA 0/11.

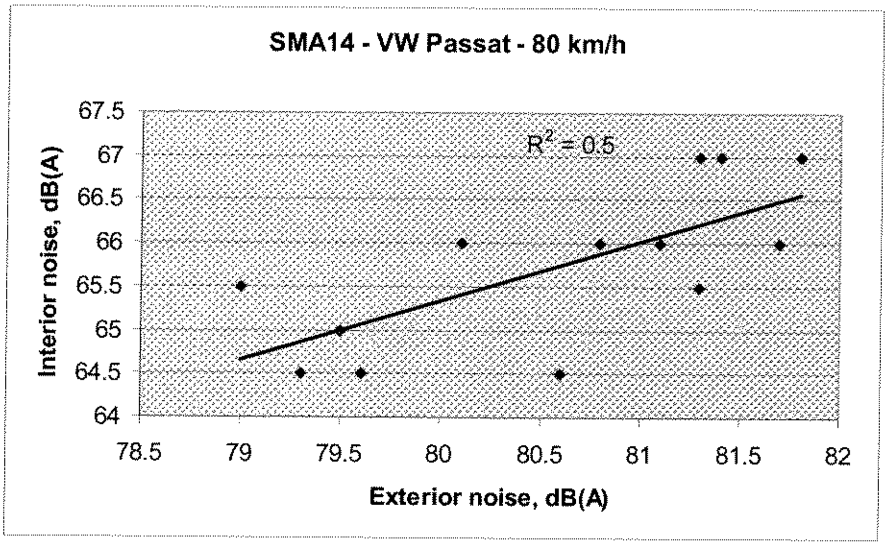


Figure 6.3 Correlation between exterior and interior noise on SMA 0/14.

On our more rough surfaces, there seem to be possible to choose tyres for the Passat that are both moderately silent inside the car (Goodyear Eagle F1, Hankook K406) and have a low exterior noise level (see table 6.1).

7 Texture measurements

To investigate the reasons for the high level differences between the measured noise level on the SMA-surfaces and the ISO-surface, texture measurements were performed on both surfaces. On the ISO-test track, these measurements were performed by M+P (stationary laser profilometer), while the physical measurements on the Norwegian roads were performed by the Public Roads Administration in Norway, with a dynamic laser profilometer. SINTEF ICT carried out the calculation of texture levels and mean profile depth, following the recommendations given in

ISO/CD 13473-4 [9] and ISO 13473-1:1997(E) [10]. A power spectrum was estimated based on discrete Fourier transformation of the profile sample values. The power in spectral lines was summed to form a 1/3-octave band spectrum. The texture spectrum levels were calculated in dB re 10^{-6} m (rms).
The data acquisition for the ISO-surface and the SMA-surfaces differed somewhat. For the ISO-surface the texture spectrum was an average over an area of 1.5m x 0.225 m in the right wheel track, at the position along the track where the maximum sound pressure level was measured. For the SMA-surfaces, the texture spectrum was an average of 6 single measurements taken along a road test section of 20m (approximately within ± 10 m relative to the measurement line for the car tyre noise measurements). Each measurement included 7500 profile samples over 2.7 m at 40 km/h. The vertical resolution was 0.044 mm; the scan resolution was about 2.8 samples /mm.
The resulting texture spectra are shown in Figure 7.1.

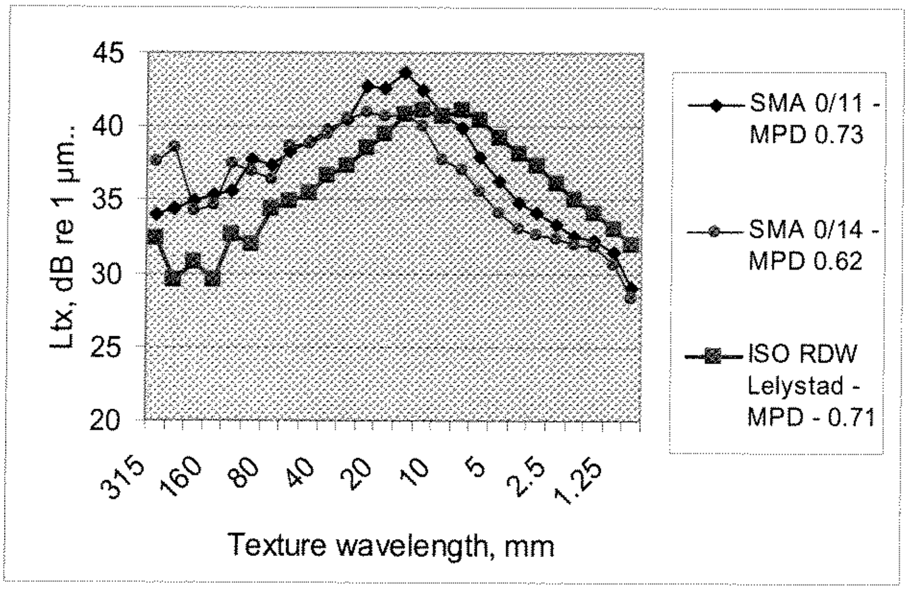


Figure 7.1 Texture spectra for the ISO-surface and SMA0/11- SMA0/14. Mean Profile Depth-values are indicated.

As compared to the ISO-texture spectrum, the maximum levels of both SMA-spectra show a significant shift towards greater wavelengths. This is probably due to the difference in maximum chipping size, as the ISO-surface is mainly a DAC0/8-surface.
The spectra reveal that in the wavelength range 50-80 mm which is considered important to texture induced noise radiation from the tyre, the SMA-surfaces show 3-4 dB **higher** texture levels than on the ISO-surface. In the wavelength range below 8 mm, which is considered important to compressed air release in the tyre-road contact area, the SMA-surfaces show 4-5 dB **lower** texture levels. In both ranges the texture of the SMA-surfaces seems unfavourable compared to the ISO-surface concerning noise.

8 References

[1] ISO 10844:1994 "Acoustics – Specification of test tracks for the purpose of measuring noise emitted by road vehicles".

[2] 2001/43/EC amending Council Directive 92/93/EEC relating to tyres for motor vehicles and their trailers and to their fitting, June 27th 2001.

[3] ISO 5128:1980 "Acoustics – Measurements of noise inside vehicles.

[4] T. Berge, A.Ustad: Støymålinger på bildekk, Gardermoen 2003 (Noise measurements on car tyres, Gardermoen 2003) (In Norwegian).SINTEF Report STF90 A04010. 2004-02-05.

[5] A.A.A.Peters: Tyre/road noise measurements of passenger car tyres according to directive 2001/43/EC (Lelystad measurements) M+P.SINTEF report 04.1.1. July 5th 2004.

[6] M.S.Roovers: Tyre/road noise measurements of passenger car tyres according to directive 2001/43/EC. M+P, January 16th 2003.

[7] A.A.A.Peters: Tyre/road noise measurements of passenger car tyres according to directive 2001/43/EC (Kongsvinger measurements) M+P.SINTEF report 04.2.1. August 16th2004.

[8] T.Berge, A.Ustad: Vegdekkers støyegenskaper. Foreløpige resultater fra målinger på norske vegdekker. (Road surfaces and noise properties – preliminary results from measurements on Norwegian roads) (In Norwegian). SINTEF Report STF90 A04006, 2004-01-26.

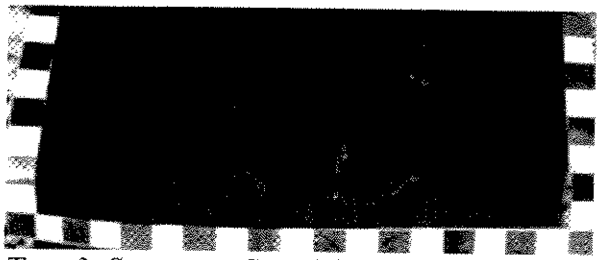
[9] First ISO/CD 13473-4 "Characterization of pavement texture by use of surface profiles – Part 4: Spectral analysis of texture profiles" (Committee Draft by 2004-02-02)"

[10] ISO 13473-1:1997(E): "Characterization of pavement texture by use of surface profiles – Part1: Determination of Mean Profile Depth".

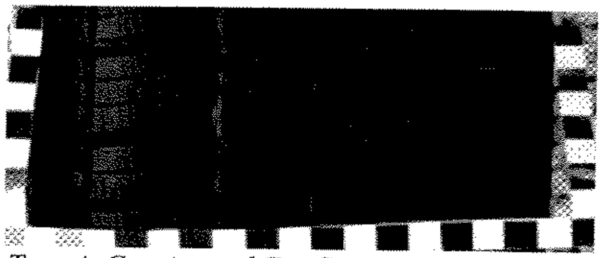
Appendix A. Tread pattern of 20 measured tyres.

Tyre 1. Goodyear GT3
175/65 R14 82T

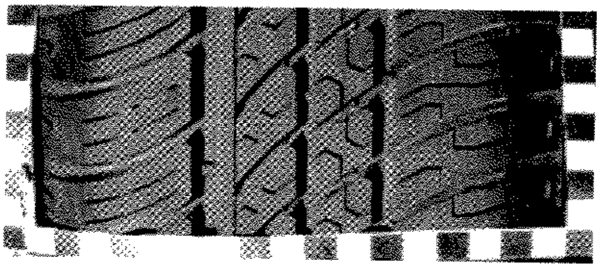
Tyre 2. Michelin Energy X
175/65 R14 82H



Tyre 3. Semperite Sportlife
175/65 R14 82T

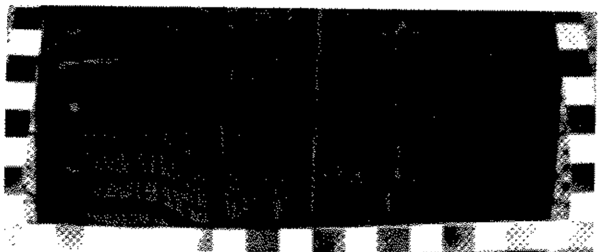


Tyre 4. Continental EcoContact EP
175/65 R14 82T

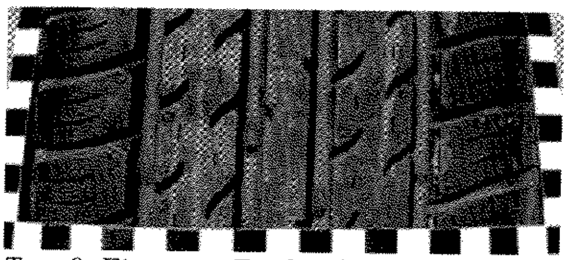


Tyre 5. Michelin Energy XT-1
175/65 R14 82T

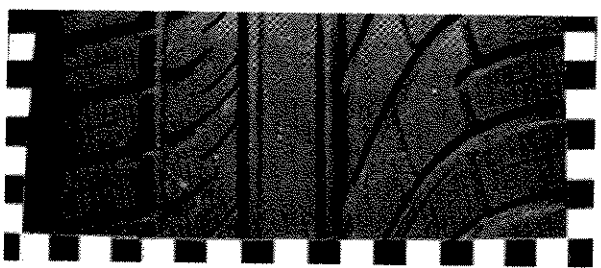
Tyre 6. Pirelli P3000
175/70 R13 82T



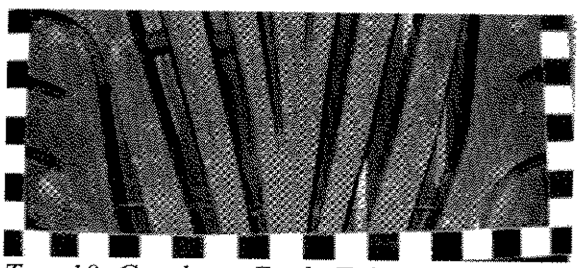
Tyre 7. Pirelli P3000
175/65 R14 92T



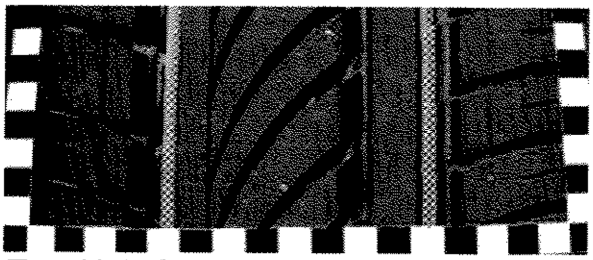
Tyre 8. Firestone Firehawk 680
195/65 R16 91V



Tyre 9. Michelin Pilot Primacy XSE
205/55 R16 91V

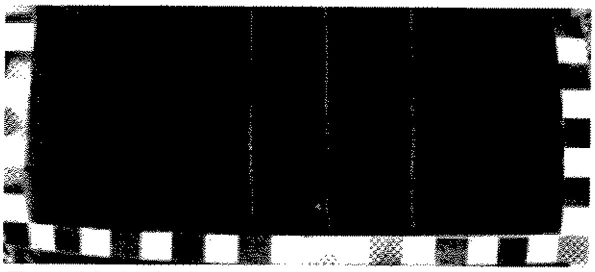


Tyre 10. Goodyear Eagle F-1
205/55 R16 91W

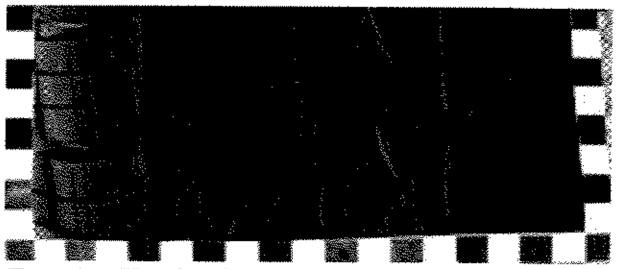


Tyre 11. Nokian NRHi 205/55 R16 94H

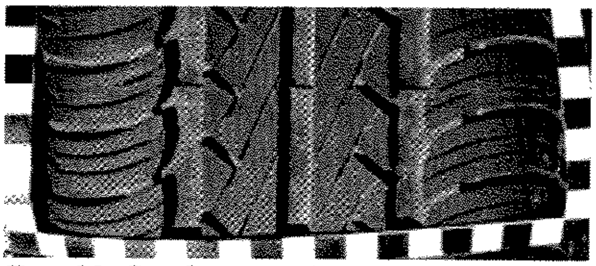
Tyre 12. Yokohama C-Drive 205/55 R16 94V



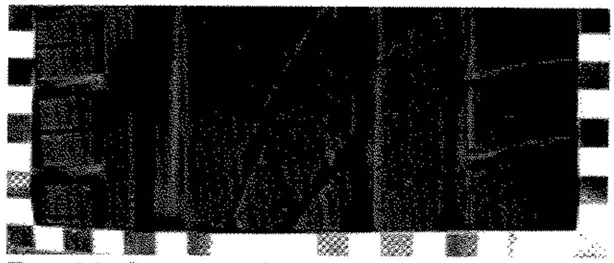
Tyre 13. Yokohama AVS dB500 195/65 R15 91H



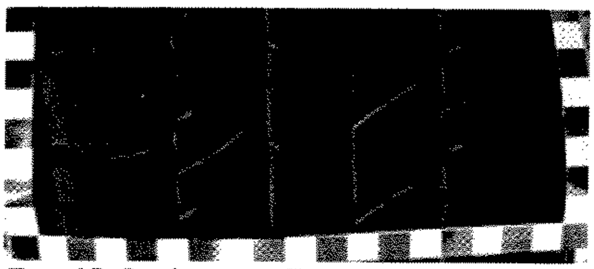
Tyre 14. Hankook K406 195/65 195/65 R15 91H



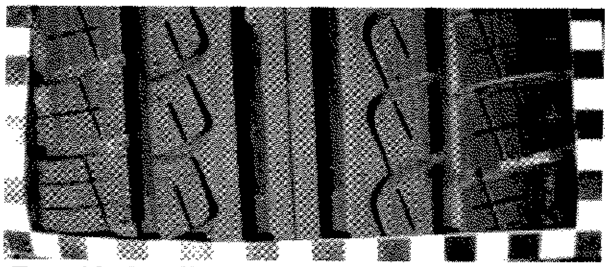
Tyre 15. Goodyear Eagle NCT5 195/60 R15 88H



Tyre 16. Continental PremiumContact 205/55 R16 91V

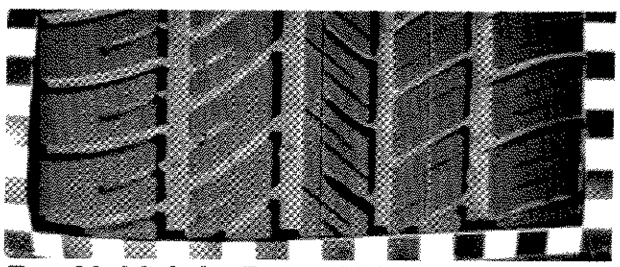


Tyre 17. Bridgestone Turanza ER70 195/60 R15 88H



Tyre 18. Pirelli P6 195/65 R15 91H

Tyre 19. Vredestein Sportrac 205/55 R16 91W



Tyre 20. Michelin Energy XH-1 195/65 R15 88H