Tyre/road noise testing on various road surfaces - report from the NordTyre project

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A Nordic project, NordTyre, was started in 2011, and the main purpose of the project is to establish scientific evidence of the tyre/road noise contribution to road traffic noise emissions in the Nordic countries. As the first delivery to this project, SINTEF was engaged to write a State-of-the-Art report on tyre/road noise testing on various road surfaces, including the ISO 10844 test surface. The report is based on a literature study, mainly focus on publications from the period 2005-2011. Results from on measurements of car tyres on typically rough-textured pavements found in the Nordic countries like Norway, Sweden and Finland, as well as more smooth surfaces found in Denmark are presented. One of the main findings is that the spread in noise levels on such rough-textured surfaces is much less than on an ISO surface. The noise ranking of tyres can also be considerably different. This indicates a reduced efficiency of tightening the noise limits for tyres on these types of surfaces and the introduction of the tyre labelling system in Europe. The paper presents the main results from the study, as well as proposals for further work in the NordTyre project.

1 INTRODUCTION

Traffic noise in the Nordic countries is an important topic and there is a general concern with the steadily increasing traffic volume and its effect on the traffic noise and noise annoyance. Tyre/road noise is the main contributor to the general traffic noise level under most conditions. It is only for speeds below 30 km/h for light vehicles and below 50 km/h for heavy vehicles that power train related sources are dominating, in addition to high acceleration driving phases.

It is well known that the acoustical quality of the road surface is the dominating part of the tyre/road noise contribution. However, for the time being, it is only the tyres that are regulated by maximum permissible noise levels. The tyre noise regulation requires measurements on an

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ISO surface, initially developed to minimize the tyre/road noise contribution to the noise from an accelerating road vehicle (type approval noise testing of road vehicles). The ISO surface is basically a smooth textured dense asphalt concrete surface with 8 mm maximum chipping size. The ISO surface was initially standardized in 1994, but recently revised and updated[1].

As part of the strategy to reduce the noise annoyance from road traffic noise, a Nordic project, NordTyre, was initiated in 2011. A State-of-the-Art report on tyre/road noise testing on various road surfaces has been presented by SINTEF as the first delivery of this project[2]. This paper presents the main results from the study.

2 NORDTYRE PROJECT LAY-OUT

The main objective of the NordTyre projects is two-fold:

- To establish a platform based on scientific evidence on the tyre/road noise contribution to traffic noise emission from roads in the Nordic countries. Furthermore, to clarify which combinations of tyres and pavements that will yield the lowest noise emission levels throughout their lifetime, including the environment along roads and highways. The findings will be a basis for qualified decision making concerning actions to mitigate traffic noise in the Nordic countries.
- To clarify the noise emission from tyres, including Nordic winter tyres (classes C1, C2 and C3) and its possible correlation with rolling resistance, wet grip, snow grip and ice grip. Those results can be used in a future revision of the tyre labelling system and the tyre noise regulations (see chapter 3). The labelling system may then be supplemented with labels of snow and ice grip.

The NordTyre project is defined in 4 parts:
Part 1: Status on noise emission from "new" tyres rolling on representative pavements (tyres not yet used for normal driving, but may have been used for testing in earlier projects)
Part 2: Relations between noise, wet grip snow grip and ice grip
Part 3: Truck tyres
Part 4: Combined effects of tyre aging and pavement ageing

Part 1 and 2 of the project can be carried out, independently of whether or not Part 3 and 4 will be realized. The potential benefit of Part 4 will be assessed based on the results from Part 1.

3 TYRE REGULATIONS – NOISE, ROLLING RESISTANCE AND WET GRIP

The present limits for noise from tyres are specified in the EU directive 2001/43/EC[3]. In 2009, a new set of noise limits was introduced in Regulation (EC) No.661/2009[4]. This regulation includes requirements for wet grip and rolling resistance. In addition, the classification of the different tyre categories was changed somewhat from the directive of 2001. The new noise limits are introduced from 2012-11-01 for C1/C2 tyres and 2016-11-01 for C3 tyres. From 2012-11-01 a new regulation on the labelling of tyres with respect to their fuel efficiency (rolling resistance), wet grip and noise becomes effective; Regulation (EC) No.1222/2009[5].

The rolling resistance and wet grip are classified in categories A-G, while the noise emission level is given as a symbol, together with the measured exterior noise level according to ECE Reg.117[6]. Figure 1 shows an example of a labelling sticker on a tyre, as presented to a customer. Depending on tyre width, the new noise limits for Class C1 tyres will vary between 70 to 74 dB(A) (72-76 dB(A) in the present regulation).

4 LITERATURE REVIEW – GENERAL CONSIDERATIONS

In 2006, FEHRL published two comprehensive studies[7,8] on tyre/road noise, based on available data up to this year. The studies focused on tyre/road noise measured on ISO surface, possibilities for further reduction of the tyre noise limits, rolling resistance and a cost/benefit analysis. In order to not repeat the main conclusions from these reports, the literature review in the NordTyre project primarily focused on available reports/papers in the period 2005-2011. In addition to measured noise levels on ISO surface, reports on noise data from measurements on normally trafficked roads and other types of test track pavements are all part of the review in the State-of-the-Art report. Articles of a more theoretical type as e.g. on the generation mechanisms of tyre/road noise have not been included in the review.

4.1 Tyre/road noise levels on ISO surface

The FEHRL reports present a collection of tyre noise data measured on different ISO tracks during the period 2000-2005. They showed a span of about 6 dB (from 69 to 75 dB(A)) for C1 tyres. For C2 and C3 tyres, very few data were available at that time. Since the FEHRL reports were published, more data of tyre noise levels on ISO tracks have been collected. The most comprehensive is "the Dutch fact sheet" of 2008[9]. This is a compilation of noise levels of 1250 tyres (1048 C1 tyres). The sources of the data were primarily the FEHRL data, data from the tyre industry itself (ETRTO) and Dutch type approval data (Lelystad). The Netherlands presented these data to the EU Commission in order to promote more stringent noise limits.

In figures 2 and 3, a cumulative distribution of noise data of the most frequently used tyre dimensions for passenger cars (at least in the Nordic countries); C1B and C1C (tyre widths between 195 mm and 245 mm) are shown. The spread in noise levels is rather large, 10 dB for C1B and 8 dB for C1C tyres. However, one should notice that this is a set of noise data from many different ISO test track locations. The spread between different ISO test tracks can be up to 4-5 dB[10]. The new noise limits for these classes of passenger car tyres will be 71 dB(A) from November 2012. Even if these data are based on measurements 5 to 12 years ago, already 40 to 55 % of the tyres seem to fulfill the coming noise limit.

In 2010, the Netherlands issued a new list of type testing levels for tyres (http://kiesdenieuweband.nl/). All the measurements of these tyres have been made on the ISO track at Lelystad in the Netherlands. The data set of 376 tyres consists of summer and winter tyres for cars (C1A, C1B and C1C), and summer tyres for vans (C2).

This is the first data set that enables a comparison of 3 different performance characteristics of a tyre; wet grip, rolling resistance and noise levels. According to the tyre industry[11], it is at the moment impossible to label a tyre with an A in both the wet grip and rolling resistance categories, and at the same time meet the new noise limit. There seems to be a trade off between wet grip and rolling resistance Figure 4 shows a distribution of wet grip and rolling resistance data for 101 summer tyres of classes C1A (≤ 185 mm), C1B (> 185 ≤ 215 mm) and C1C (> 215 ≤ 245 mm).

In the figure, the green area marks tyres meeting future EU regulations for the requirements for A, B and C labels for wet grip and rolling resistance. The yellow area is for tyres meeting the EU standards for label E-F for wet grip and E-G for rolling resistance. In the green area, the

individual requirements for wet grip categories A, B and C are shown. The figure shows some important results:

- There is no significant correlation (negative or positive) between wet grip and rolling resistance.
- No tyres meet label category A or B for the rolling resistance (RRC ≤ 7.7 ‰).
- There are presently no tyres meeting label category A for wet grip and at the same time label category A, B or C for rolling resistance.
- 9 tyres meet label category B for wet grip (about 10 %) and label category C for rolling resistance.

The relationship between wet grip and noise is shown in figure 5 for 101 tyres of class C1B. The areas for label A, B and C for wet grip (and at the same time meeting the new noise limit) are shown in the figure. Again, some important conclusions can be made:

- There is no significant correlation (negative or positive) between wet grip and noise emission levels.
- Only two tyres meet the requirements for class A for wet grip: one tyre with a noise level of 69 dB(A) (and class E for rolling resistance), and one tyre with a noise level of 71 dB(A) (and class E for rolling resistance).
- One tyre meets class B for wet grip and 69 dB(A) for noise (2 dB below the limit).
- 7 tyres meet class B for wet grip and 70 dB(A) for noise (1 dB below the limit).

In figure 6, the relationship between rolling resistance and noise emission for the 101 tyres of class C1B are shown. As previous stated, there are no tyres labeled A or B for rolling resistance. For the label C, there are 11 tyres (about 10 % of the total data set) meeting this requirements for rolling resistance ($7.8 < RRC \leq 9.0$) and at the same time meet the new noise limit.

For the wider tyres (class C1C), there are only 3 tyres (of a total of 55 tyres) labelled C for rolling resistance and a noise level of 71 dB(A).

Based on this data set, it seems that it is the requirements for tyres to be labelled in category A (or even B) for rolling resistance that put the strongest pressure on the tyre industry. In figure 7, the cumulative distribution of the noise levels of the 101 class C1B tyres from the Dutch list of 2010 are compared with the FEHRL data from 2006 for the same tyre class. There is obviously a shift to more quiet tyres, and already nearly 80 % meet the new limit of 71 dB(A). This indicates a potential for further reduction of the tyre noise limit in the future.

4.2 Tyre/road noise on other road surfaces

In the NordTyre project, it has been important to investigate how tyres behave on other surfaces than the ISO surface. If the noise ranking of tyres on normally used road surfaces in the Nordic countries differ much from the ranking on the ISO surface, this would seriously reduce the efficiency of the tyre noise regulation. In a previous project reported at Internoise2011 in Osaka[12], this author presented measurements of passenger car tyres on different road surfaces at the Kloosterzande test track in the Netherlands, including the ISO surface. The analysis showed that the correlation with ISO surface (slope and regression coefficient) very much depends on the type of pavement. Higher correlation was found for surfaces with maximum chipping sizes of 4-6 mm.

However, these were measurement on non-trafficked test pavements. For the Nordic situation, and especially for Finland, Sweden and Norway, where studded tyres are used during

the winter season, it is important to study the noise ranking on pavement types our region. In 2011, SINTEF conducted a measurement program with 10 passenger car tyres, all tyres that previously have been measured at the ISO surface at Kloosterzande. The tyres were measured using the CPX trailer of the Norwegian Public Roads Administration (built by M+P in 2005). A total of 19 different pavements were tested. 5 pavements were new, in the meaning that they had not yet been exposed to winter conditions and studded tyres. All the pavement types were dense asphalt concrete (DAC) surfaces (including SMA-types) with maximum chipping sizes from 6 to 16 mm. In Norway, the most commonly used pavement type on the highway network is SMA 0/11.

In figure 7, the measured noise levels (LAcpx, dB(A)) are shown for DAC/SMA 0/11 pavements more than one year old (exposed to winter conditions) compared to the results on the ISO surface at Kloosterzande, Clearly, there is no correlation between the ranking on the ISO surface and the other pavements. A similar comparison was made between results on newly laid DAC 0/8/SMA 0/11 pavement types and on the ISO surface, as shown in figure 8. Again, the correlation is weak, however somewhat better than for the older pavements in figure 7. This is confirmed by the analysis of the slope and correlation coefficient, r, as shown in table 1 (older surfaces – figure 7) and table 2 (new surfaces – figure 8).

The disparity between the tyre noise behaviour on normally used road pavements (exposed to winter conditions) and the behaviour on the ISO surfaces is alarming. It would certainly reduce the efficiency of the tyre noise regulation with more stringent noise limits. In addition, the noise labelling of the tyres may be very misleading for some of the road types commonly used in the Nordic countries. In Denmark, where studded tyres are not used during the winter season, the situation may be different from the other Nordic countries.

Some measurements results of passenger car tyres (C1) in Sweden in 2007[13], indicate some better correlation between results on ISO surface and DAC type of surfaces, than found in the Norwegian project of 2011.

5 PROPOSALS FOR FURTHER WORK

Since the results from the measurement campaign in Norway in 2011 were based on a limited number of tyres (10), it has been proposed to start a new measurement program within the NordTyre project in 2012. Approximately 32-34 passenger car tyres (including summer, winter (non-studded) and all-season tyres) have been selected to be measured on a wide range of pavement types in Denmark, Sweden and Norway. The measurements will be made with the Danish CPX trailer of DRI in Denmark/Sweden and by SINTEF and the Norwegian CPX trailer in Norway. In addition, the tyres will be measured on the drum facilities of TUG in Poland (noise measurements on a replica of ISO surface, as well as rolling resistance measurement). The main focus will be on the ranking of the tyres on the different pavement types compared to the ISO data (labelled and/or measured levels).

6 FUTURE TRENDS FOR TYRES

The literature review also included some papers on future trends for tyres, which may influence the general traffic noise situation in urban areas. The trend up till now, especially for passenger cars, has been steadily increasing tyre widths, and speed index, as the top speed of the cars has increased. This may force the tyre manufacturers to design tyres to meet performance requirements rarely, if ever, used in the lifetime of the vehicle. Except for certain motorway sections in Germany, the maximum allowed speed in most European countries is 130 km/h. In

Norway, even lower, 100 km/h. The situation world-wide is quite similar in most other regions. Still, tyres fitted on the most frequent used cars must meet a top speed of 180-240 km/h. According to the tyre manufacturers, this clearly makes it difficult to lower the noise levels of the present fleet of tyres with more than, say 1-2 dB.

However, there is a growing interest in the development of new types of tyres designed to be fitted on electric/hydrogen vehicles and some hybrid types. Many of these vehicles will have a limited top speed of around 140-160 km/h. As an example, the new Opel Ampera (Chevrolet Volt in the U.S.) has a speed limitation of 160 km/h. This makes it possible to completely redesign tyres for such vehicles.

In the European project "Green City Car", one of the goals is to reduce the total noise of the vehicle with 10 dB, having identical weight and energy consumption as normal today. All the major tyre companies are now working on different solutions to meet this goal as well as reduced rolling resistance. Continental has just released a tyre, Conti.e.Contact with dimensions 195/55 R20, designed only for electric vehicles. Michelin has a similar concept for a prototype tyre ("Tall and Narrow") with a potential for significant noise reduction.

It may that in the future, the widespread use of "zero-emission" vehicles in urban areas can give a considerable reduction in reduced road traffic noise, as both power train noise and tyre/road noise can be significantly reduced.

7 CONCLUSIONS

The introduction of a new labelling system in Europe from 2012, is a positive step to promote tyres that have a potential to reduce CO_2 emissions, reduce traffic noise (tyre/road noise) and at the same time provide necessary safety properties (wet grip, etc.). The labelling of tyres may improve the awareness of the vehicle owners on these environmental issues.

Concerning noise labelling of tyres, there are several challenges. From a Nordic perspective, the most important are:

- Due to significant differences between the ISO surface and the types of surfaces frequently used in some of the Nordic countries (like Norway, Finland and Sweden), the noise ranking of the tyres could be different on real roads than what the labelled values indicate.
- The smooth ISO surface emphasizes the importance of the tread pattern of tyres, which is not so relevant on rough-textured surfaces, as found in the Nordic countries that use studded winter tyres.
- The use of the smooth ISO surface can lead to sub-optimisation of tyre noise performance, which is not reflected on other types of road surfaces.
- The labelled noise value is based on measurement on a single ISO track. Due to track-to-track variations of up to 4-5 dB, the uncertainty of the labelled value is rather high for consumer information. The newly adopted improvements of the ISO 10844 standard can reduce this spread in the future.

Based on the literature review, the following conclusions can be made, concerning tyre/road noise levels on different kind of surfaces, commonly used in the Nordic countries:

- On ISO surfaces, based on type testing data, there is a spread in noise levels from passenger tyres (C1) of 10 dB (from 66 to 76 dB(A)). This spread includes the fact that it covers tyres of widths below 185 mm to above 275 mm, and also measurement data from

different ISO tracks. The influence of the ISO track variation may be a more significant than the variation due to tyre width.

- For normal C2 tyres, the spread is from 68 to 75 dB(A), for snow tyres from 71 to 77 dB(A).
- For normal C3 tyres, the spread is from 67 to 78 dB(A), for snow/traction tyres from 71 to 80 dB(A).
- Based on CPX measurements on a single ISO track, the spread in levels are somewhat lower, in the range of 6-7 dB for summer tyres for cars.
- Among summer tyres for cars, on typical Norwegian dense pavements, a spread in noise levels of only 2-3 dB has been found. It is likely that the situation is the same in Sweden and Finland. Since vehicles in Denmark are not using studded winter tyres, it is likely that the spread in noise levels from tyres is larger here. The spread in tyre/road noise of roads of the same types (not including new surfaces) in Norway is about the same; 2-3 dB.
- The road influence on the variation in tyre/road noise levels in the Nordic countries is much larger than the tyre influence. A combination of a new good open graded dense asphalt in Denmark (AC6o) with 6 mm maximum chipping size and a low-noise tyre (Michelin Primacy LC) gave a reduction of approximately 13 dB, compared to the noise level on a old SMA 0/16 surface in Norway, with a "noisy" tyre.
- In Norway, a combination of tyres and the most used pavement types, can give around 5 dB variations in noise levels, while a variation of 7-8 dB was found on Danish road surfaces.
- Tyre/road noise seems to be approximately 2-3 dB ***higher*** on the most common Norwegian road surfaces like SMA 0/11, than on similar Danish road surfaces. Similar Swedish road surfaces seem to give 1-1.5 dB ***higher*** noise levels than in Norway. This is probably caused by a significant higher percentage of studded tyres during the winter season in Sweden than in the southern regions/cities in Norway. Since Finland has about the same percentage of studded tyres (~ 85 %) as Sweden, it is assumed that the tyre/road noise levels here are comparable to Sweden (very little comparable measurement data are available).

8 ACKNOWLEDGEMENTS

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Table 1 - Regression analysis of 10 summer tyres for cars, measured on ISO surface and 15 older Norwegian dense surfaces. Slope and correlation coefficient, r.

Road surface	Slope	Correlation coefficient, r
DAC 0/6	0,07	0,17
DAC 0/8	0,17	0,47
DAC 0/8	-0,01	0,36
DAC 0/8	0,005	0,01
DAC 0/8	-0,004	0,01
DAC 0/11	-0,005	0,01
DAC 0/11	0,022	0,06
DAC 0/11	-0,114	0,28
DAC 0/11	-0,008	0,02
DAC 0/16	-0,096	0,22
SMA 0/6	0,1	0,28
SMA 0/8	0,11	0,30
SMA 0/11	0,1	0,26
SMA 0/11	0,113	0,30
SMA 0/16	0,066	0,20

Table 2 - Regression analysis of 10 summer tyres for cars, measured on ISO surface and 6 newly laid Norwegian dense surfaces. Slope and correlation coefficient, r.

Road surface	Slope	Correlation coefficient, r
DAC 0/8	-0,26	0,62
DAC 0/8	0,21	0,35
DAC 0/11	0,18	0,57
DAC 0/11	0,25	0,69
DAC 0/11	0,29	0,60
DAC 0/11	0,28	0,48

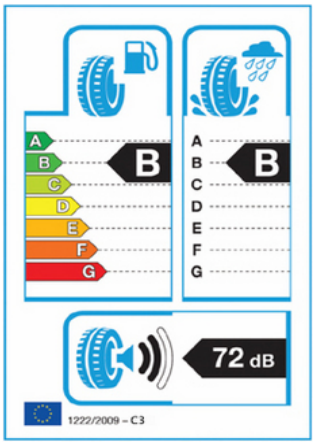

Fig. 1 – EU tyre labelling system.

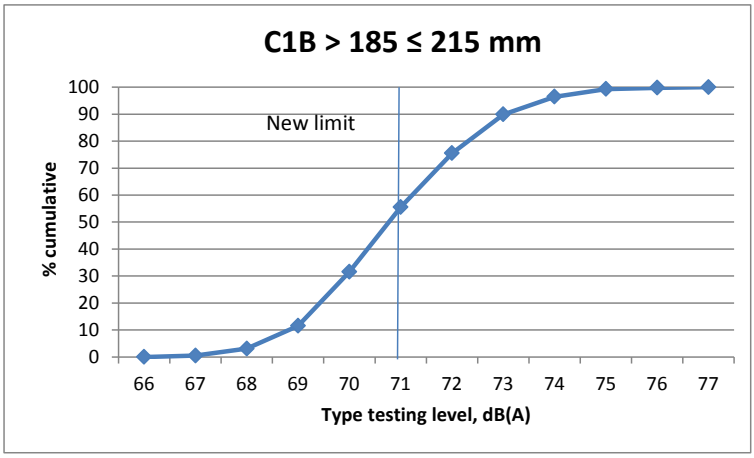

Fig.2 – Cumulative distribution of type testing levels of tyre class C1B and new noise limit.

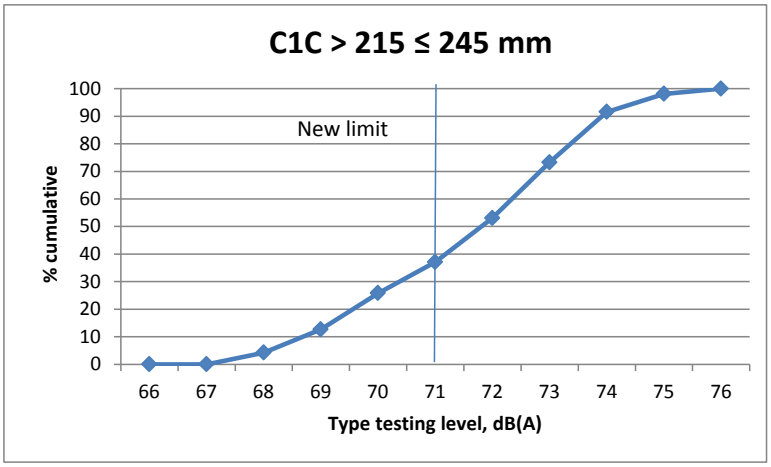

Fig.3 – Cumulative distribution of type testing levels of tyre class C1C and new noise limit.

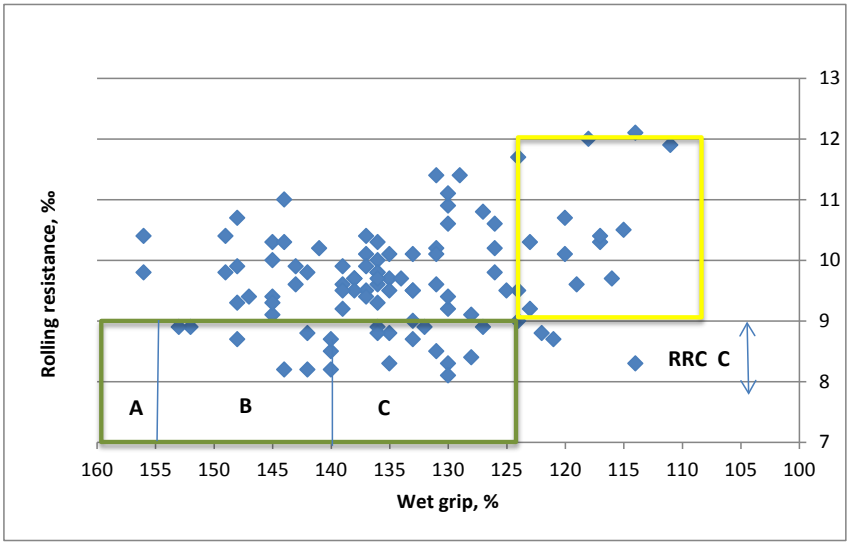

Fig. 4 – Wet grip index and rolling resistance coefficient for car summer tyres (C1A, C1B, C1C). Areas for wet grip labelling of category A, B and C are shown, as well as area for rolling resistance labelling of category C.

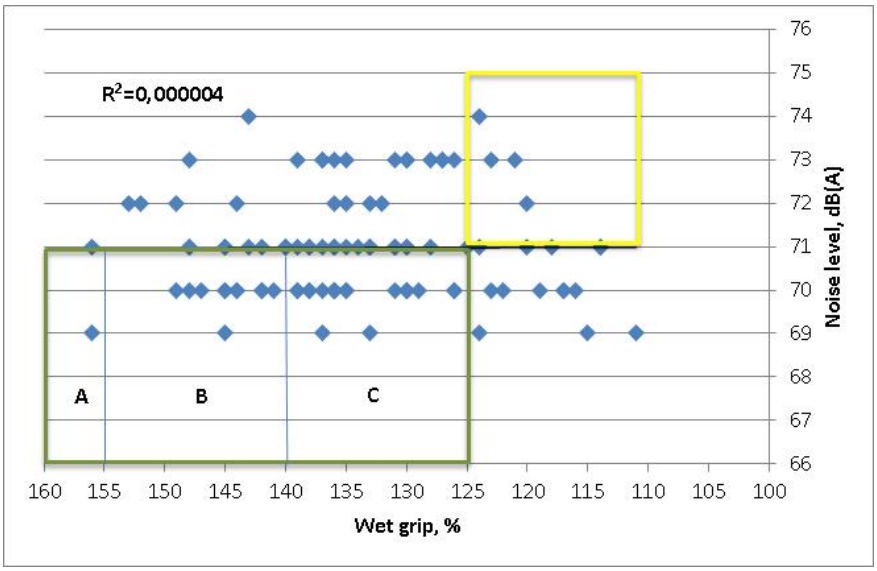

Fig. 5 – Wet grip index and noise emission levels for car summer tyres of class C1B. Areas for wet grip labelling of category A, B and C are shown.

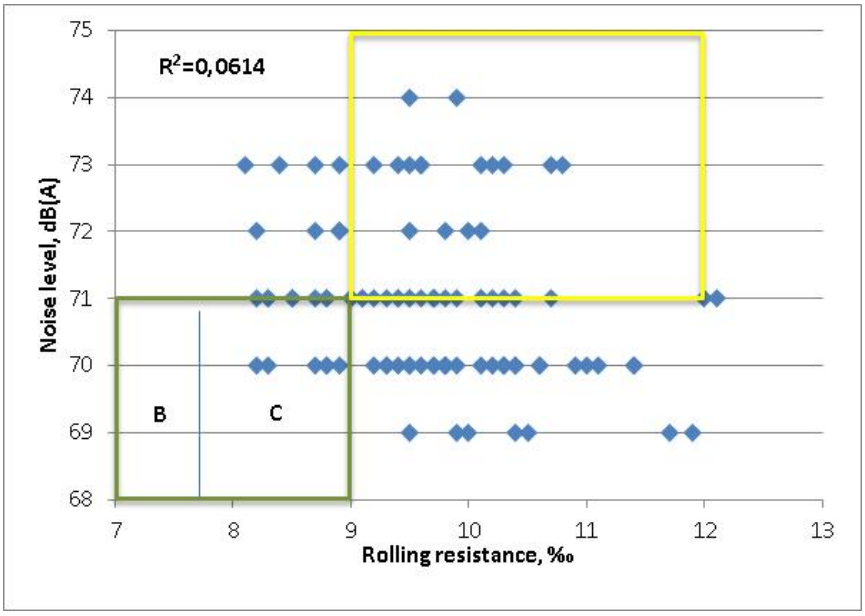

Fig. 6 – Rolling resistance and noise emission levels for car summer tyres of class C1B. Areas for rolling resistance labelling of category B and C are shown.

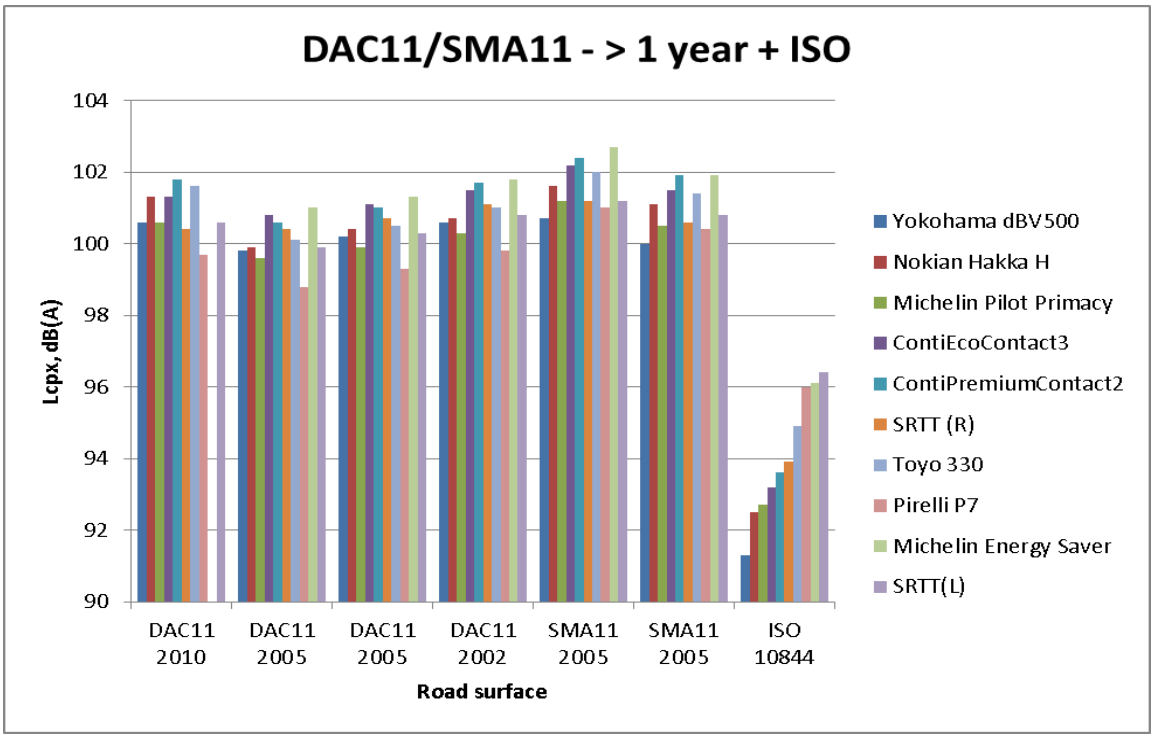

Fig. 7 – Measured CPX levels of 10 summer tyres on Norwegian DAC11/SMA11 surfaces > 1 year old and on ISO surface. Speed: 80 km/h.

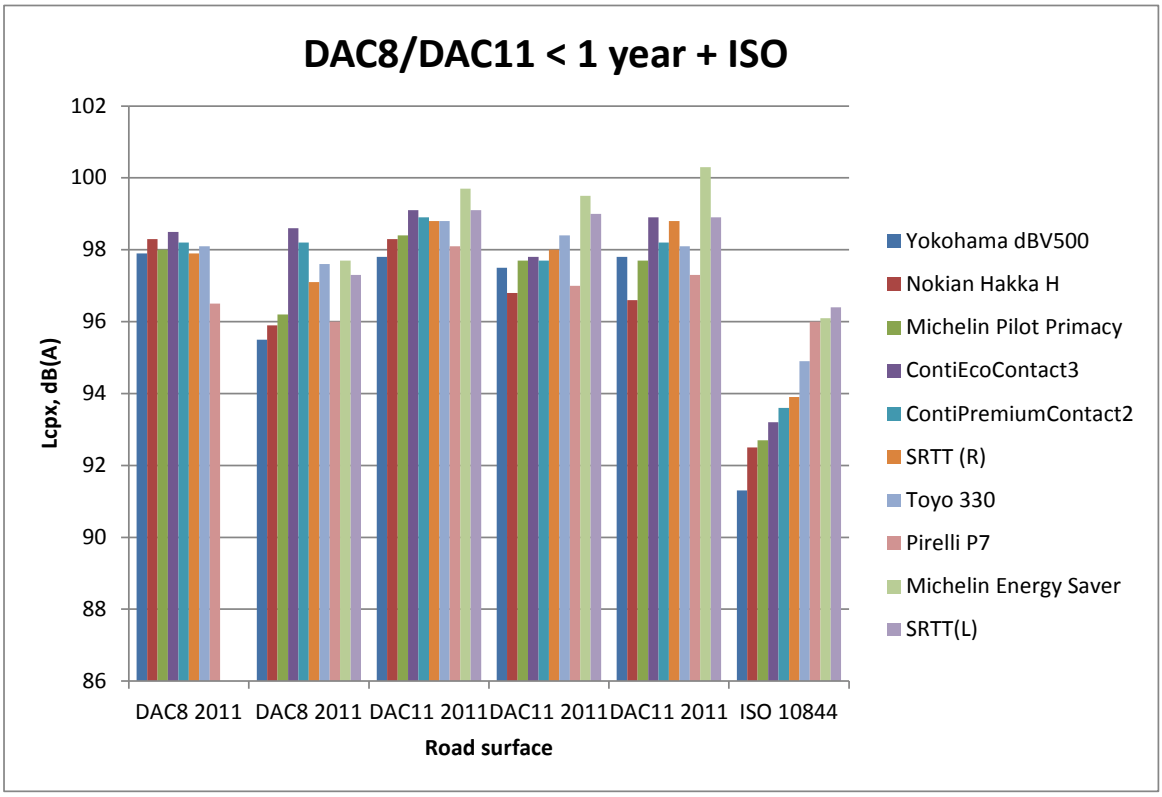

Fig. 8 – Measured CPX levels of 10 summer tyres on Norwegian DAC8/SMA11 surfaces < 1 year old and on ISO surface. Speed: 80 km/h.