

Rolling resistance on concrete pavements in The Netherlands

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Abstract

In an effort to reduce fuel consumption and CO₂, a measurement program initiated by Rijkswaterstaat and province Gelderland was conducted in 2013 to investigate the variation in rolling resistance of passenger cars tyres on different asphalt road surface types on the Dutch main roads (highways and provincial roads). Complementary to the rolling resistance measurements also texture measurements were performed. In addition to this program rolling resistance and texture measurements have been performed on some concrete road sections for the Cement&BetonCentrum. In total 8 concrete road sections were selected and measured. The measurements were a joint effort by M+P and TU-Gdansk. All the concrete road sections were measured on April 2013. The rolling resistance and texture were measured simultaneously. A temperature correction based on the tyre wall side temperature was applied to all rolling resistance coefficients. Two types of concrete road surfaces were measured: brushed concrete (1 road section) and exposed aggregate concrete (7 road sections of different ages: from 8 to 22 years old pavements!). The difference in average rolling resistance coefficient between brushed concrete and exposed aggregate concrete is 0.9 ± 0.4 kg/t (or 10 ± 4 %). This is a significant difference.

Introduction

In an effort to reduce fuel consumption and CO₂, a measurement program initiated by Rijkswaterstaat and Province Gelderland was conducted to investigate the variation in rolling resistance of passenger cars tyres on different asphalt road surface types on the Dutch main roads (highways and provincial roads). Complementary to the rolling resistance measurements also texture measurements were performed.

In addition to this program rolling resistance and texture measurements have also been performed on some concrete road sections for the Cement&BetonCentrum. In total 8 concrete (brushed and exposed aggregate) road sections were selected and measured.

The most important questions to be answered were:

- What is the influence of different concrete road surfaces on the rolling resistance?
- What is the relation between rolling resistance and texture for concrete road surfaces?
- Is it possible to estimate the rolling resistance based on measured texture parameters?
- Comparison of the rolling resistance between concrete and asphalt road surfaces.

The scope of this project is limited to the effect of texture variation on rolling resistance of only passenger cars. This means that possible effects of deflection or unevenness (IRI) of the

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road surfaces are not taken into account. For the Dutch main roads and highways, it is known that the texture effect is the dominant effect for the rolling noise of passenger cars.

Measurement program

The rolling resistance and texture measurements were conducted on 8 road sections with brushed (1 road section) and exposed aggregate (7 road sections) concrete. Before the measurements were performed, the road sections were inspected. The details of the measured road sections are given in Table 1.

Table 1 Selected road section for measurement

No	location	year of construction	concrete surface	km
1	N285 Moerdijk, Provinciale Rondweg	2005	brushed	2.9 – 3.3
2	N285 Zevenbergen, Provinciale Rondweg	2006	exposed	4.0 – 4.5
3			aggregate	4.9 – 5.5
4	N285 Zevenbergen, De Langeweg	2006	exposed	7.3 – 7.7
5			aggregate	8.0 – 10.0
6	N285 Wagenberg, De Brandestraat	1992	exposed	13.3 – 15.8
7			aggregate	16.2 – 16.8
8	N285 Wagenberg, Wagenbergsebaan	1992	exposed aggregate	17.4 – 18.3

All road sections were measured in one driving direction. This was except for road section no. 4 the east direction. Section no. 4 was measured in west direction. Both rolling resistance and texture measurements were performed. The total length of the road sections was almost 8 km. The road sections were constructed between 1992 and 2006. The measurements were conducted on April 17th, 2013

Measurement equipment

Rolling resistance measurement system

The rolling resistance measurements were performed with rolling resistance trailer of the TU Gdansk. The TU Gdansk rolling resistance trailer is a three-wheel trailer (see 0). The two front wheels are bearing wheels. The rear wheel is the measurement wheel. The measuring wheel is attached to the trailer frame by a swivel arm (see 0). The angle of the swivel arm provides an indication of the rolling resistance force on the measuring wheel. In recent years, improvements have been made to the trailer to further limit the effects of interference on measurements.



Figure 1: The TU Gdansk measurement trailer for measuring rolling resistance on road surfaces. The detailed photo provides a view of the measuring wheel over which a wind deflector is placed during measurement.

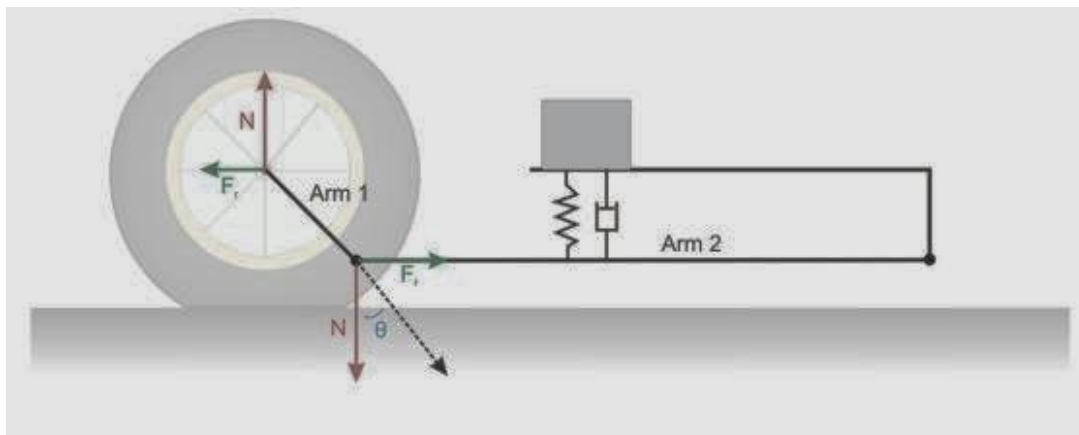


Figure 2: Schematic representation of the measurement principal based on the measurement of an angle that is proportional to the rolling resistance force

The rolling resistance measurements were conducted with the SRTT (Standard Reference Test Tyre). All measurements were done with a vehicle speed of 80 km/h. It is assumed that the vehicle speed doesn't significantly influence the rolling resistance. Due to the instrument principles the measurements are not sensitive for wind influences. For more information about the rolling resistance measurement system see [2]

Texture measurement system

The M+P texture measurement system consists of a laser with a data acquisition system. The system is not bound to a fixed vehicle or set-up. Measurements can be made both when stationary and mobile (80 km/h). For this project we used the mobile system. This system

meets the requirements of ISO 13473-3 0 class D for vertical resolution (i.e. better than 0,03 mm) and class E for wavelength range (i.e. larger than 200 mm). From the texture measurements various parameters can be calculated. In this project we used MPD, RMS and Skewness as defined in [3]



Figure 3: The laser texture meter mounted on the rolling resistance trailer in order to perform mobile measurements

Boundary conditions for measurements

Weather

To perform texture and rolling resistance measurements several boundary conditions concerning the weather are applicable. These boundary conditions are for the rolling resistance measurements more tightly than for the texture measurements. This means that if the weather boundary conditions for the rolling resistance measurements are fulfilled, texture measurements can also be performed.

Weather boundary conditions for performing rolling resistance measurements are:

- Air temperature of at least +5 °C;
- No rain;
- Road surface has to be dry. Some spots with moisture are no problem.

Road sections

To perform rolling resistance measurements there are also some boundary conditions to the road section it serves. These boundary conditions are:

- Road sections without a curve;
- Flat road section, no descending or ascending;
- Possibility to drive outside the wheel track. The rolling resistance is due to the construction of the trailer measured between the wheel tracks. Therefore there should be the possibility on a road section to drive slightly shifted to the right.

Measurement uncertainties

Uncertainty analysis

An investigation was made to estimate the total measurement uncertainty. The total uncertainty is estimated on the basis on the contributions of its subcomponents and the insights from the measurements, e.g. variance, repeatability, reproducibility, effect of temperature etc.

In the following paragraphs the influence of some parameters is given.

Tyre pressure

It is known that the tyre pressure can have an influence on the measured rolling resistance coefficient. The measurement principle used by TU-Gdansk uses an intervention level for tyre pressure. During the warm-up time the tyre pressure is constantly monitored. When the tyre temperature is constant, the tyre pressure is adjusted to 2.10 bar. If the tyre pressure gets lower than 2.05 bar or higher than 2.15 bar, the tyre pressure is adjusted to the reference tyre pressure of 2.10 bar.

Using this procedure the variations in rolling resistance coefficient due to tyre pressure variations are typically very small. Therefore no correction was applied for tyre pressure influences.

Temperature

In other studies [2] effects of air temperature were found ranging from 0.06 to 0.12 kg/t per °C. For example in the report of the MIRIAM round robin test in Nantes [4] as indicated that based on literature, an effect of temperature variation of 4 - 9 % could be expected due to 5 degrees air temperature variation.

For Rijkswaterstaat and the Province Gelderland measurement program [1] a few road sections were measured multiple times to determine the impact of temperature changes on the rolling resistance. For each measurement run three temperature values were recorded: air temperature, road surface temperature and tyre wall side temperature. It was found that the tyre wall side temperature had the highest correlation with the measured rolling resistance values. Therefore it was decided to apply a tyre wall side temperature correction on all rolling resistance data and to use as tyre wall side reference temperature a temperature of 25 °C. This resulted in the following correction which was applied to all the data:

$$RRC_{T,gecorr} = RRC - (0,17 \pm 0,02) * (25 - T_{band})$$

To be able to compare the results of the concrete road surfaces with the asphalt road surfaces of the Rijkswaterstaat and province Gelderland measurement program, this correction was also applied to all rolling resistance values in this project.

Because all measurements on concrete road surfaces were measured with approximately the same tyre temperature (30 °C) the correction is approximately +0.85 kg/t for all concrete road sections.

Data overview

Rolling resistance per concrete road section

In figure 4 the rolling resistance coefficients (in kg/t) are given for the concrete road sections. The error bars indicate

± 3 % of the rolling resistance coefficient (see paragraph 3.4). Furthermore the results have been corrected for the tyre wall side temperature according to paragraph 3.3. The road section numbers correspond with table 1.

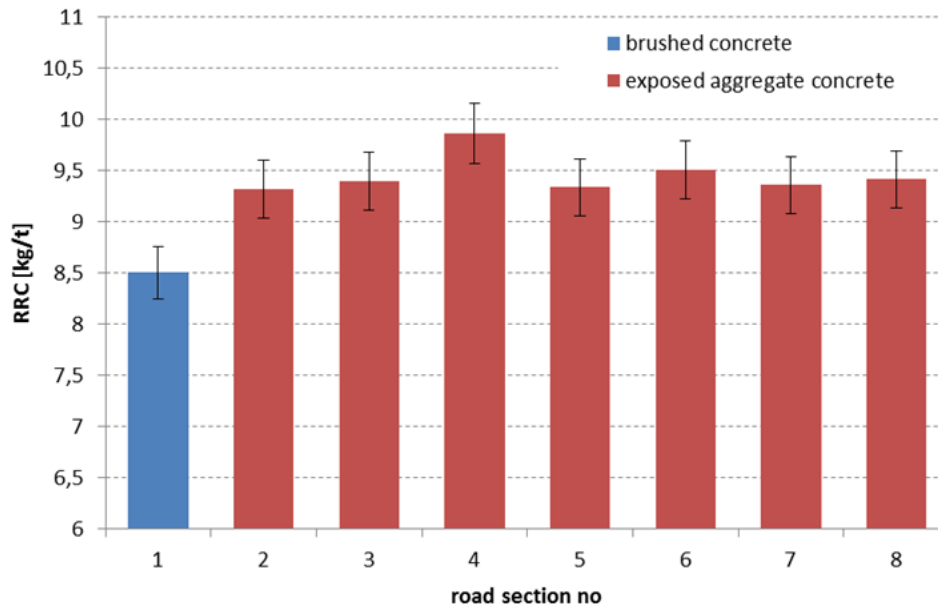


Figure 4: Rolling resistance coefficients (corrected for tyre wall side temperature) for the concrete road sections. The error bars indicate ± 3 % of the rolling resistance coefficient.

From figure 4 the following can be concluded:

- The brushed concrete road section has the lowest rolling resistance coefficient of 8.5 kg/t;
- The rolling resistance coefficients for the exposed aggregate concrete road sections show some differences. The largest rolling resistance coefficient is found for road section no. 4 (9.9 kg/t). The difference in rolling resistance coefficient for this road section with respect to the other exposed aggregate road sections is significant.

The difference in average rolling resistance coefficient for brushed concrete and exposed aggregate concrete is 0.9 ± 0.4 kg/t (or 10 ± 4 %) This difference is significant.

Texture per road section

The texture was simultaneously measured with the rolling resistance in the wheel track of the measurement tyre. The MPD-values for each concrete road section are shown in figure 5.

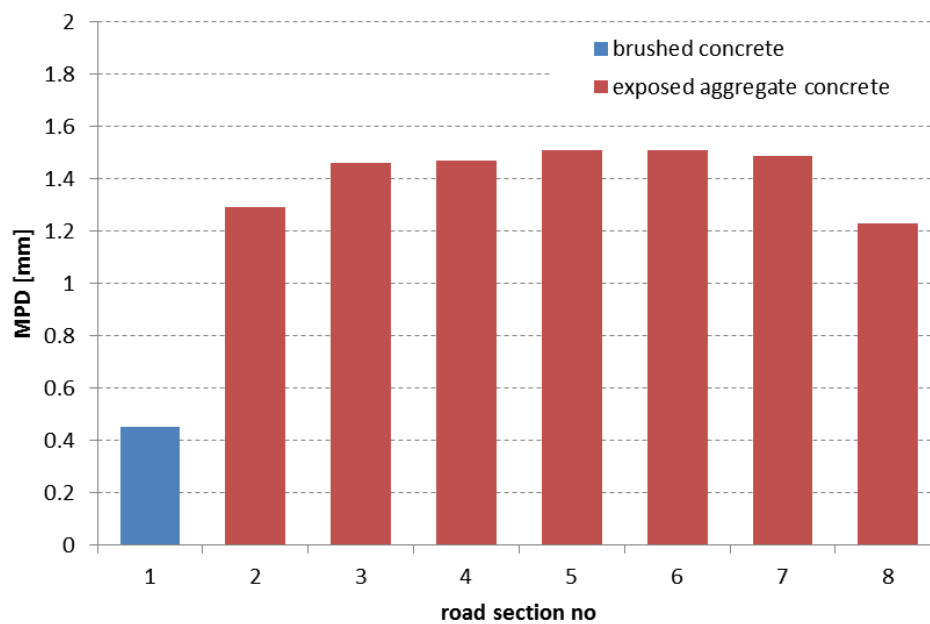


Figure 5: MPD-values for the concrete road sections

From figure 5 the following can be seen:

- The brushed concrete road section has the lowest MPD-value (0.45 mm) which is approximately one-third of the MPD-value of the exposed aggregate road sections;
- The MPD-values of the exposed aggregate road sections show only small differences. These differences cannot be related to the age of the road section.

The RMS-values for all concrete road section are shown in figure 6

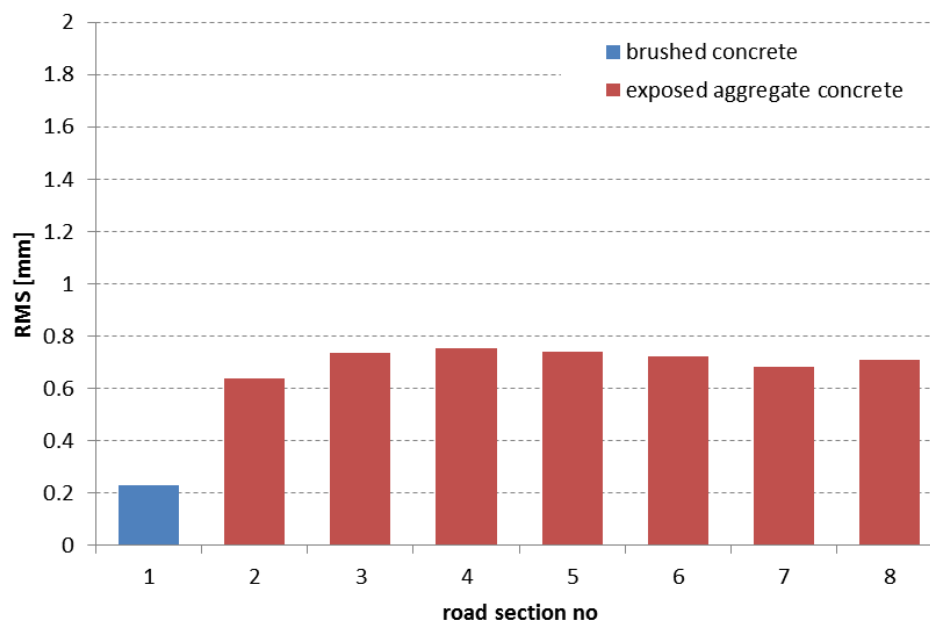


Figure 6: RMS-values for the concrete road sections

The Skewness-values for each concrete road section are shown in figure 7

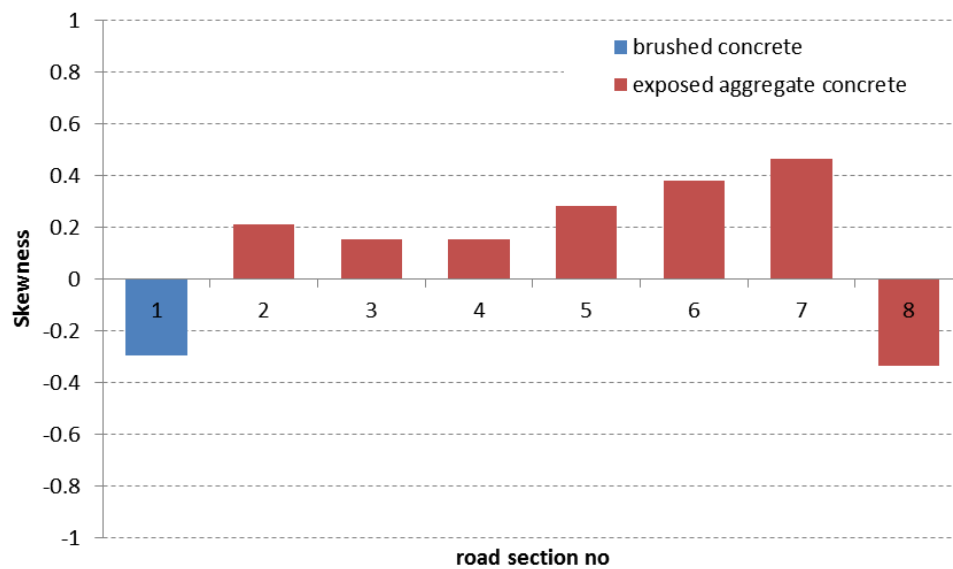


Figure 7: Skewness-values for the concrete road sections

Rolling resistance versus texture

In the conducted measurements program texture measurements were performed simultaneously with the rolling resistance measurements. This chapter will look in more detail to the relation between rolling resistance and texture. This will be done by means of some models based on three texture parameters (MPD, RMS and Skewness). All the used rolling resistance coefficients are corrected for tyre temperature.

The following simple linear models will be investigated:

- $RRC = C_1 \cdot MPD + C_2$
- $RRC = C_1 \cdot RMS + C_2$

The following multiple regression model will be investigated:

- $RRC = C_1 \cdot MPD + C_2 \cdot RMS + C_3 \cdot \text{Skewness} + C_4$
- $RRC = C_1 \cdot MPD + C_2 \cdot \frac{MPD}{RMS} \cdot C_3 + C_4$

In the last formula also the ratio between MPD and RMS is used because the relation between RMS and MPD depends strongly on the orientation direction of the texture.

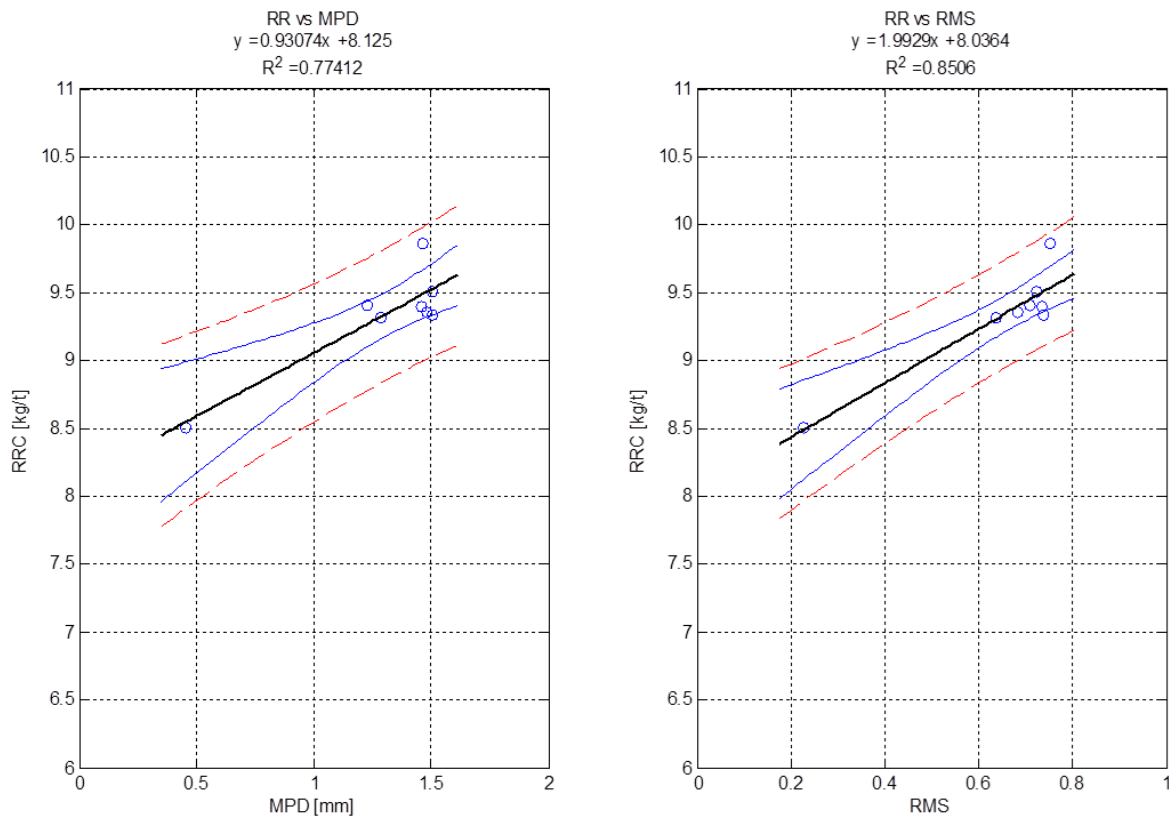


Figure 8: Simple regression analysis of RR ~ MPD and RR ~ RMS

The results of the multi regression are shown in figure 9.

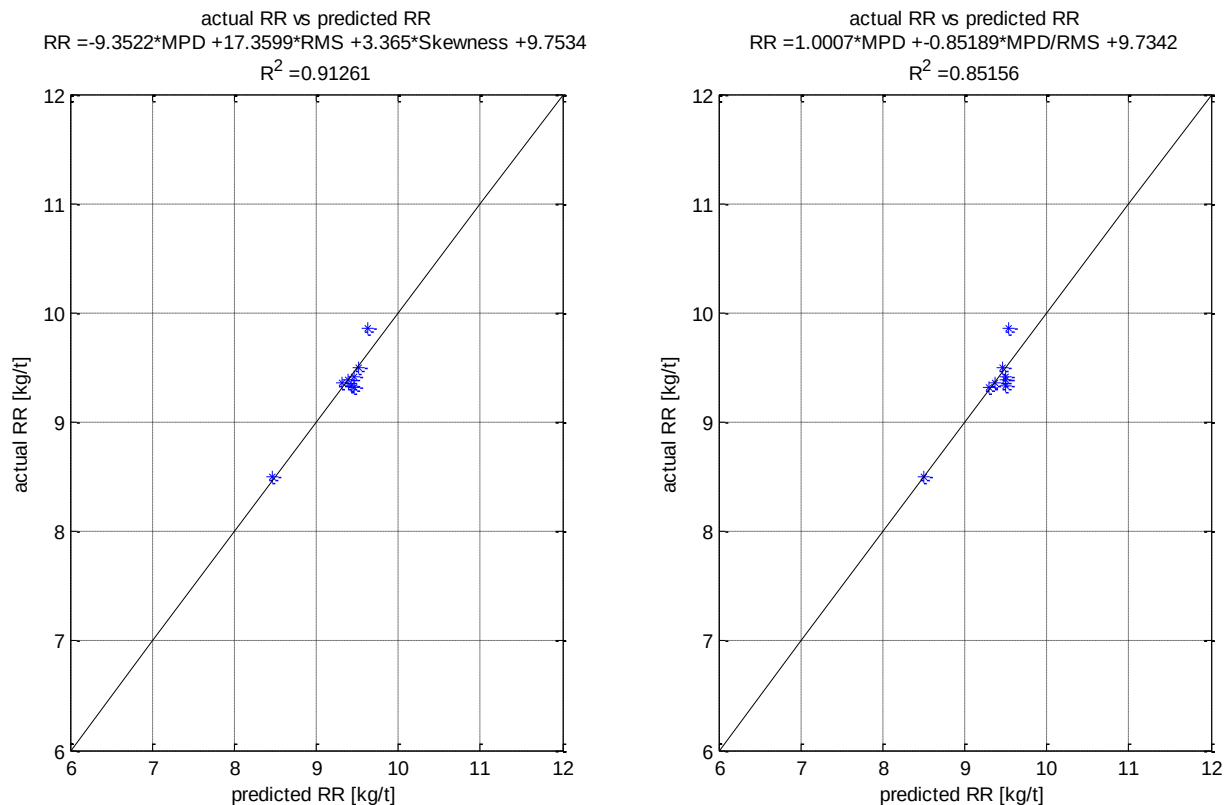


Figure 9: Multiple regression analysis of $RR \sim MPD + RMS + Skewness$ and $RR \sim MPD + MPD/RMS$

Conclusions

Two types of concrete road surfaces were measured: brushed concrete (1 road section) and exposed aggregate concrete (7 road sections). The difference in average rolling resistance coefficient between brushed concrete and exposed aggregate concrete is 0.9 ± 0.4 kg/t (or 10 ± 4 %). This difference is significant.

If comparing the rolling resistance coefficients of the concrete road sections with the results of the asphalt road sections that were measured in the Rijkswaterstaat and province Gelderland project, it shows that the rolling resistance for the brushed concrete road section (8.5 kg/t) is comparable with the rolling resistance for thin surface layer (TSL) or dense asphalt concrete (DAC) road surfaces. The average rolling resistance of the exposed concrete road sections (9.5 kg/t) are comparable with approximately the average rolling resistance for PAC 16 road sections

By combining the rolling resistance and texture data, a number of regression models were evaluated. Using these models the rolling resistance can be estimated using one or more texture parameters (MPD, RMS, Skewness).

The following simple linear regression model was found to have a good fit (adjusted $R^2 = 0.85$) (the 95 % confidence interval is also given):

$$RRC = (1.99 \pm 0.83) \cdot RMS + (8.04 \pm 0.55)$$

The following multiple regression model was found to have a slightly better fit (adjusted $R^2 = 0.91$):

$$RRC = -9.35 \cdot MPD + 17.36 \cdot RMS + 3.37 \cdot Skewness + 9.75$$

Comparison with asphalt road sections

In figure 10 the rolling resistance coefficients are shown for all the asphalt road sections measured in the Rijkswaterstaat and province Gelderland project. All values are corrected for tyre wall side temperature. To compare these results with the results of the concrete road sections, the average rolling resistance coefficients of the exposed concrete road sections (red dashed line) and the brushed concrete road section (blue dashed line) are added to this figure.

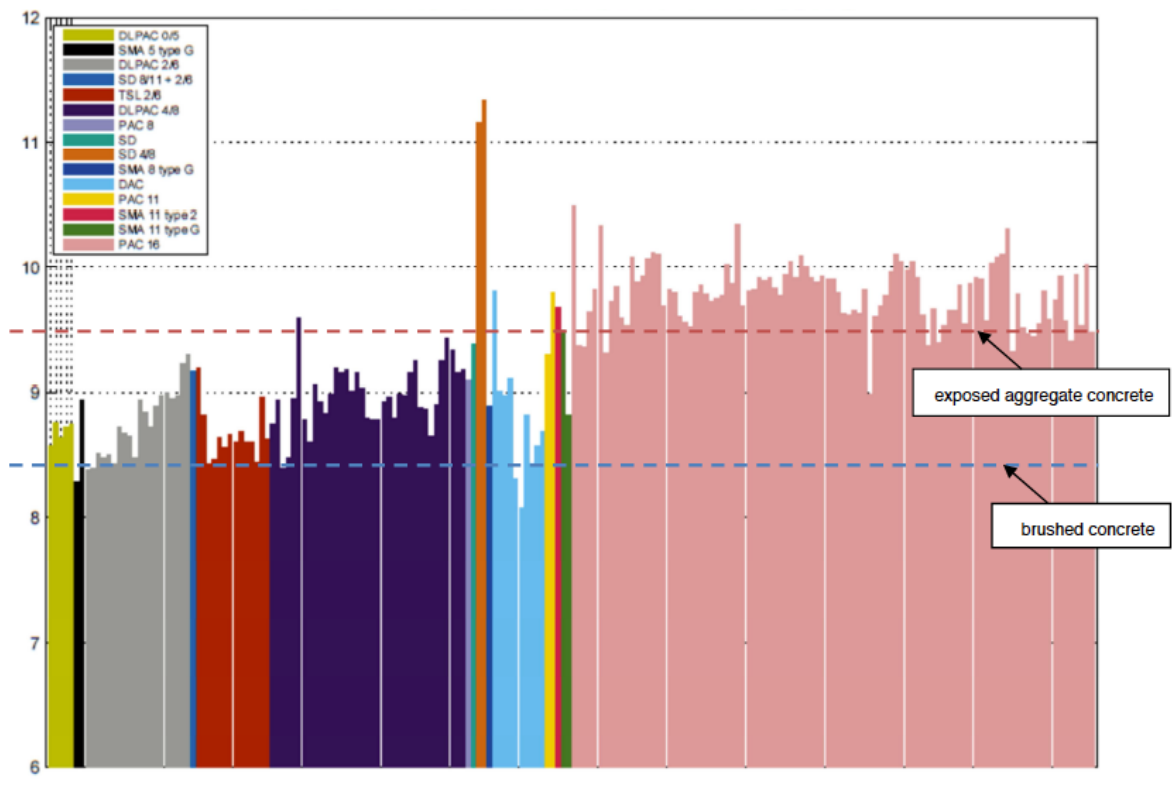


Figure 10: Rolling resistance coefficients (corrected for tyre temperature) found in the Rijkswaterstaat and province Gelderland measurements [1]. The red dashed line indicates the average rolling resistance of the exposed concrete road sections. The blue dashed line indicates the rolling resistance of the brushed concrete road section.

From 0 to 10 the following can be concluded:

- The rolling resistance for the brushed concrete road section (8.5 kg/t) is comparable with the rolling resistance for thin surface layer (TSL) or dense asphalt concrete (DAC) road surfaces.
- The average rolling resistance of the exposed concrete road sections (9.5 kg/t) are comparable with approximately the average rolling resistance for PAC 16 road sections.

REFERENCES

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[4] A. Bergiers et al., “Comparison of Rolling Resistance Measuring Equipment - Pilot Study”; MIRIAM, SP1 Deliverable No. 3, Final version 2011-12-31 <http://miriam-co2.net/>.