Making roads energy efficient by reducing rolling resistance

1. Introduction

The Province of Zuid-Holland encourages the development of innovations to make the provincial road network more energy efficient. This is one way the province can contribute to reducing energy consumption and CO_2 emissions in accordance with the Dutch energy agreement.
To this end, the Province of Zuid-Holland, Strukton Civiel and TNO have conducted joint research on road surfacing that reduces rolling resistance and hence reduces fuel consumption and CO_2 emissions.

This document sets out the objective of the research, as well as the methods used and the research results (both in the laboratory and the field). It also looks ahead at the impact the results could have and how the construction of such energy-saving road surfacing could best be put out to tender by road authorities.

2. Objective, method and intended result of the research

The research had three objectives:

- To establish the technical feasibility of an energy-saving asphalt road surface with low rolling resistance
- To develop a reliable method for measuring rolling resistance in the laboratory (validated in practice)
- To draft a functional design specification for the construction of energy-saving asphalt road surfacing as part of a tender process

The intended result of the research was the development of a road surface with demonstrably improved rolling resistance (being a Proof of Concept (PoC) that meets all required road surface properties such as skid resistance, noise reduction and service life) plus a measurement methodology and functional design specification.

The research method was as follows:
(1) A literature study to identify the most important parameters for the development of road surfacing with low rolling resistance.
(2) The development and installation of a laboratory setup to measure the rolling resistance of asphalt mixtures and assess the quality of optimized asphalt mixtures.
(3) The optimization of existing asphalt mixtures.
(4) The construction of a test road surface using the best-performing optimized mixture (determined in the laboratory) and the validation of the laboratory results.

The result of this research is an asphalt road surface with demonstrably reduced resistance between the vehicle tyre and the road surface (rolling resistance) that hence has a positive effect on the energy and fuel consumption of vehicles. A laboratory methodology has also been developed to measure the rolling resistance of road surfacing. This was used to draw up a preliminary functional design specification for energy-saving asphalt road surfacing.

3. Method and key research results

Literature study

A literature study was used to establish which road-surfacing properties have an influence on rolling resistance and to what extent. This resulted in a number of material and surface properties of asphalt roads that can be optimized to change the rolling resistance of a standard asphalt road surface. The study revealed that the texture or Mean Profile Depth (MPD) of the road surface is one of the most important contributors to rolling resistance. Other properties that play a role are the evenness of the surface and, to a lesser extent, the rigidity of the entire road construction. The results of this literature study were used as a starting point for the optimization process, with a focus on the mixture of materials used in existing asphalt surfaces. The use of existing and proven materials and mixtures as a starting point minimized the risk of the surface failing to meet other road requirements (such as skid resistance, noise reduction and service life).

Laboratory methodology

A measurement methodology was developed to optimize rolling resistance at the laboratory scale. The rolling resistance test trailer and measurement principle developed by Gdańsk University of Technology were used as a starting point for this laboratory methodology. This test trailer is the standard for all national rolling resistance measurements (see Figure 1).

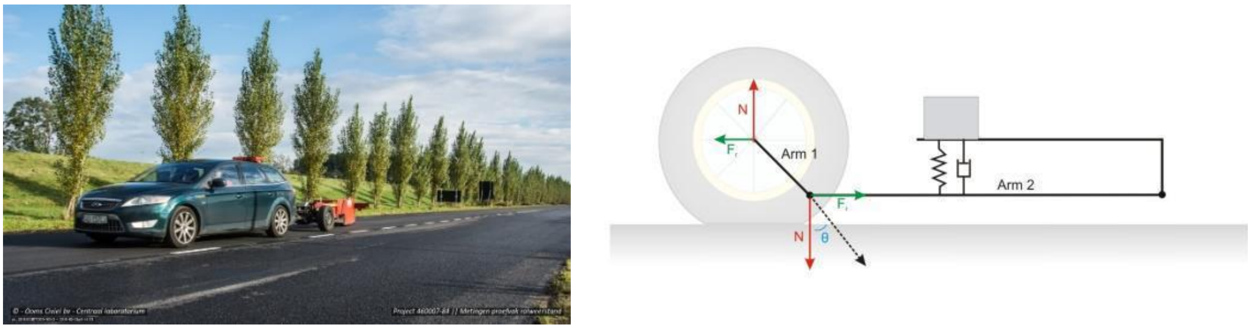

Figure 1: Gdańsk University of Technology test trailer and measurement principle

The measurement principle was implemented in the SR-ITD® (Skid Resistance & Smart Ravelling & Sophisticated Rolling - Interface Testing Device, see Figure 2). Alongside skid resistance and ravelling resistance, this device can now also test the rolling resistance of a road surface. The SR-ITD® measures the torque span required to roll a tyre over a plate covered with a certain type of road surface. This is then compared with a number of reference road surfaces. The test procedure is explained in more detail in Appendix 1. This is a non-destructive measurement method, so the test plate can be used again for skid resistance and/or ravelling resistance.

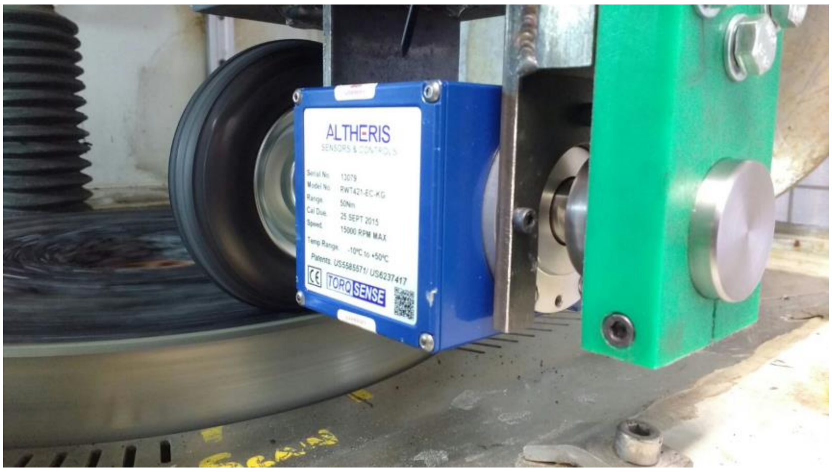

Figure 2: Rolling resistance on an asphalt layer in the laboratory

Optimizing the asphalt mixture

Various asphalt surfaces were optimized in the laboratory for rolling resistance by means of repetitive testing. The results were then compared with the rolling resistance of SMA 11B, a commonly used road surface in the Province of Zuid-Holland. The asphalt surfaces were ranked for rolling resistance based on the laboratory methodology displayed in Table 1. These laboratory results revealed that rolling resistance is reduced by approximately 20-25% in comparison with SMA 11B.

Table 1: Asphalt surface ranking for rolling resistance based on the laboratory methodology

Asphalt road surface	**Relative rolling resistance (SR-ITD® test)**
SMA 11B	100% (reference surface)
AC 16 surf	90%

Ultrathin Surface 5	90%
Porous Thin Surface 5	84%
Thin Surface 8	80%
Optimization #1: DGD 5	78%
Optimization #2: Thin Surface 5	73% → Practical validation: Test sections in the field

Construction and validation of the asphalt mixture in practice

After the surface layers had been optimized using the laboratory methodology, the best-performing surface mixture (optimization #2: Thin Surface 5) and the reference mixture (SMA 11B) were both laid in test sections to validate the laboratory results in the field. In Hoorn, a test section was laid of approx. 200 metres for each road surface (see Figure 3). The test sections were laid using standard road construction machinery. The environmental conditions were carefully monitored during construction (using the ASPARi methodology and equipment supplied by the University of Twente). The construction was demonstrably of consistent high quality.

To validate the rolling resistance of the test section, Gdańsk University of Technology measured the rolling resistance properties using their test trailer. This trailer is used often for road measurements in the Netherlands (Figure 1). The test trailer was also used to measure various road surfaces commonly used in the Netherlands (the surfaces that were also tested in the laboratory).

The key functional properties of the road surface were also tested: safety (skid resistance) and noise reduction (CPX). Tests were also conducted on the mechanical properties of the optimized mixture, being cracking resistance, toughness, water resistance (ITSR) and rutting resistance (f_c).

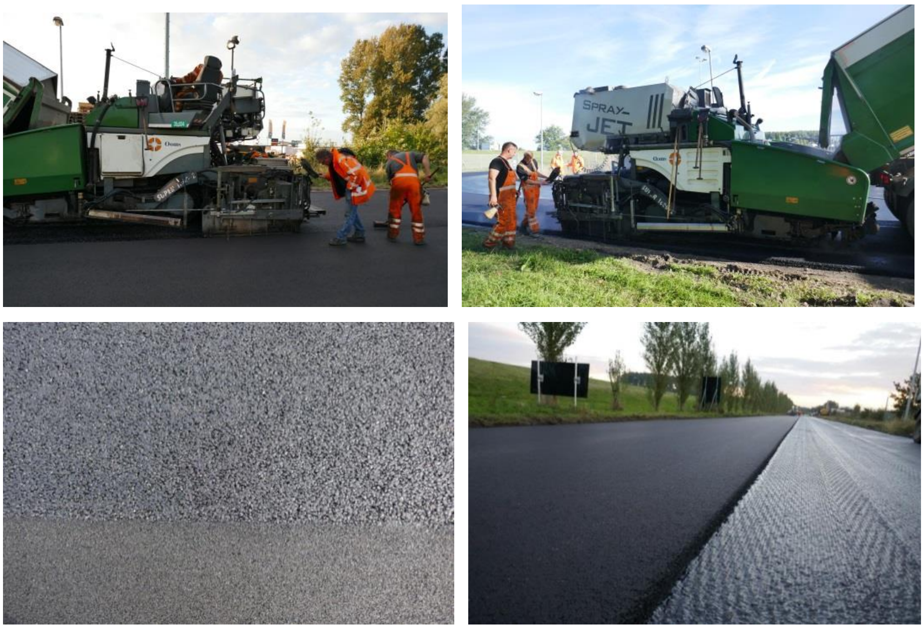

Figure 3: Road sections for field testing

The rankings produced by the rolling resistance measurements in the field were largely the same as those recorded in the laboratory (for some surfaces, the profile produced in the laboratory was different to that in the field, which explains the alternative rankings for these surfaces). This sufficiently validates the predictive capacity of the laboratory methodology.

The chosen asphalt mixture (optimization #2: Thin Surface 5) reduced rolling resistance by 10% in comparison with the reference mixture (SMA 11B).

The comparison with existing roads (SMA 11B) in the Province of Zuid-Holland resulted in as much as 20% less rolling resistance. The optimized asphalt mixture also scored better than the reference mixture for skid resistance (approx. 30% better) and noise reduction (difference of approx. 5.5 dB(A), initial noise). The asphalt mixture also meets the road-evenness criteria according to the RAW standard.

Table 2 provides a qualitative comparison between the optimized asphalt mixture and the standard asphalt mixture (the reference mixture). This table reveals that the optimized mixture has higher scores for skid resistance, noise reduction and rolling resistance and similar scores for service life and costs. The mechanical properties (splitting resistance, toughness, water resistance and rutting resistance) are similar to the reference mixture.

Table 2: Comparison between optimization #2 (Thin Surface 5) and SMA 11B

Property	- -	-	0	+	+ +
Skid resistance/deceleration				X	
Noise reduction					X
Rolling resistance					X
Service life*		▨	X	▨	
Costs per m^2			X		

* The service life was similar to that of the functional laboratory tests, but the service life in the field cannot be estimated with 100% reliability and so a -/0/+ range was applied.

This resulted in a Proof of Concept (PoC) for an asphalt road surface with demonstrably reduced rolling resistance. The tests also demonstrated that other functional properties are retained, no additional investment per square metre is required and that the service life of this optimization is similar to existing road surfaces.

4. Impact of the research results

The impact of the improved road surface on energy consumption and the environment was estimated for the province, road users and Dutch society in general.

A reduction in rolling resistance directly reduces fuel consumption. The amount of the reduction depends on the nature and speed of the traffic. The ratio between rolling resistance reduction and fuel savings is approximately 5:1 for the type of traffic and speeds typical of a provincial road. In other words, every percentage point of rolling resistance reduction results in 0.2% fuel savings. So, the rolling resistance reduction of 10% measured in the field tests results in 2% fuel savings (+/- 0.5%) in comparison with a newly laid SMA 11B road surface.
This represents fuel savings of between 8,000 and 14,000 litres per kilometre per year for every kilometre of provincial road (with an average traffic load of 15,000 vehicles per day). This is equivalent to 22 to 38 tonnes of CO_2 emissions (see Table 3).

Table 3: Cost-benefit analysis: Costs, fuel consumption and CO_2 emissions per kilometre per year

	2% fuel savings			**Bandwidth (1.5 – 2.5%)**
	SMA 11B	**Optimization #2**	**Δ**	**Δ**
Construction costs [€]	same		0	0
Fuel costs for road users [€]	€729,000	€715,000	- €14,000	- €11,000 to - €17,000
Fuel consumption [litres]	516,000	505,000	- 11,000	- 8,000 to - 14,000
CO_2 emissions [tonnes]	1,513	1,483	- 30	- 22 to - 38

This is a considerable reduction in CO_2 emissions per km of new road. In fact, the reduction in CO_2 emissions over a period of 1 to 2 years is greater than the emissions released during the construction of a kilometre of road (materials, production, transport and construction).

5. The tender process and design specifications for road authorities

There is currently insufficient experience to include absolute limit values for rolling resistance in tender documents or design specifications. The establishment of a test location for the systematic collection of rolling resistance data from various sections of road could provide the required information. This could make it possible to collect data on a number of indirect parameters which can be used to include rolling resistance limit values and requirements in the future.
To encourage rolling resistance reductions today, we recommend including the following indirect specifications for new asphalt mixtures to reduce fuel consumption and CO_2 emissions:

- Maximum MPD of 1.2 mm
- Smaller grain sizes (< 11 mm) in porous asphalt mixtures

We recommend establishing the following values to be able to set limit values in the design specifications of future calls for tender:

- Texture (laboratory and field): determine the MPD (and state which methodology is used)
- Rolling resistance (laboratory): determine the rolling resistance in the laboratory using the SR-ITD® (see Appendix 1)
- Rolling resistance (field): determine the rolling resistance in the field using Gdańsk University of Technology's measurement principle and test trailer

6. Follow-up and future

The optimized mixture (PoC) demonstrably leads to substantial reduction of rolling resistance and fuel consumption and hence will potentially lead to energy savings and reduced CO_2 emissions for the provincial road network. This research could be followed up by a demonstration and validation process in which the current PoC is tested on the provincial road network (in a controlled environment). To this end, we recommend constructing a road section of 1 kilometre in length that connects to a new reference road surface (SMA 11B) of likewise 1 kilometre so that all parameters can be systematically tested and monitored in a realistic field situation (in particular the effect on fuel savings).

The actual performance during this follow-up and the additional profile and rolling resistance data measured on newly constructed road surfaces will provide sufficient information to fine-tune the functional specifications of the energy-saving road surface. These data can then be used to establish limit values. This will enable the province to determine how a validated fuel-saving asphalt mixture can be used and assessed in tender processes for new road construction.

Appendix 1: Rolling-resistance test procedure using the SR-ITD®

Determining the relative rolling resistance and profile using the SR-ITD® (Skid Resistance & Smart Ravelling & Sophisticated Rolling - Interface Testing Device).

Test sections:

- asphalt test plates with minimum dimensions of 500 x 500 x 60 mm (compacted according to NEN-EN 12697-33)
- 3 plates per material type

SR-ITD® test procedure:

- determine the MPD (Mean Profile Depth) of the plate (Figure 1)
- determine the rolling resistance (torque span) of the plate (Figures 2 and 3)
  - type of tyre rubber: Blickle soft – VW 125/15R
  - 100 revolutions per minute
  - test duration of one minute
  - load of 20 kg
  - 3 independent measurements per plate

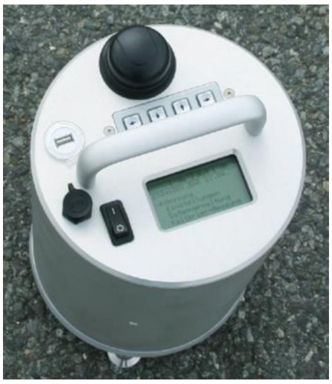

Figure 1: Surface profile

Reports:

- average torque span per measurement
- average MPD per measurement
- relative rolling resistance in comparison to SMA 11B

This is a non-destructive measurement method, so the test plat
and/or ravelling resistance.

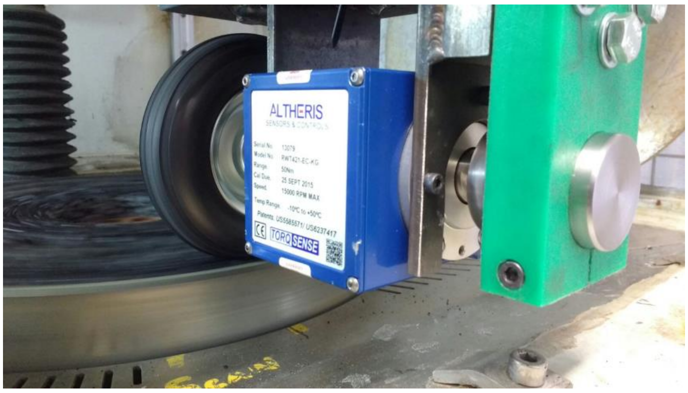

Figure 2: Measuring rolling resistance on an asphalt

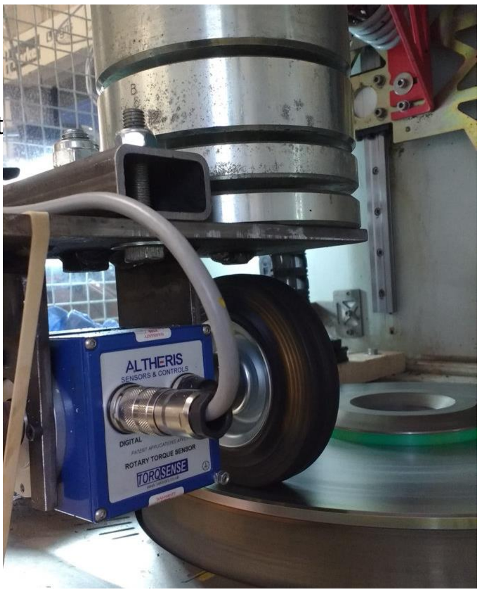

Figure 3: Measuring rolling resistance on a steel plate

Appendix 2: Properties of the energy efficient asphalt surface – Thin Surface 5

Thin Surface 5 is an ultrathin energy-efficient asphalt surface that scores better for rolling resistance, noise reduction and skid resistance than a standard SMA 11B surface.

Properties and advantages of Thin Surface 5 (thickness: 20-25 mm):

- Low rolling resistance: 10-20% lower rolling resistance than the standard SMA 11B surface. This results in fuel savings of between 2 and 4%.
    - Example: Thin Surface 5 results in savings of 11,000 litres of fuel and 30,000 kg of CO_2 in comparison with SMA 11B per kilometre of provincial road (based on 15,000 vehicles per day). The CO_2 emissions caused by production and construction of a new road surface are compensated within 1 to 2 years and the emissions caused by the construction of a completely new road are compensated within 4 to 5 years.
- Initial noise reduction of 6.3 dB(A).
- Skid resistance: 30% more skid resistance than SMA 11B (in both dry and wet conditions).
- Long service life due to high-quality modified bitumen (Sealoflex SFB 5-90(HS)).
- Excellent adhesion to the sublayer through the application of the adhesive layer and the asphalt layer in a single pass using the special Novachip asphalt machine.
- Faster construction (10-15 m/min) means less hindrance for road users and local residents.
- Applications: Mainly suitable for provincial and municipal roads where rolling resistance (service life and fuel consumption) and noise reduction are important factors. Also suitable as overlay for national motorways.

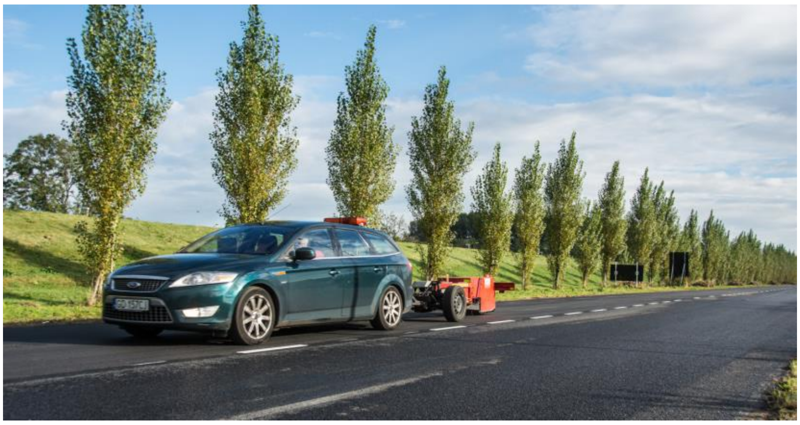

Figure 1: Rolling resistance measurement on the test section in

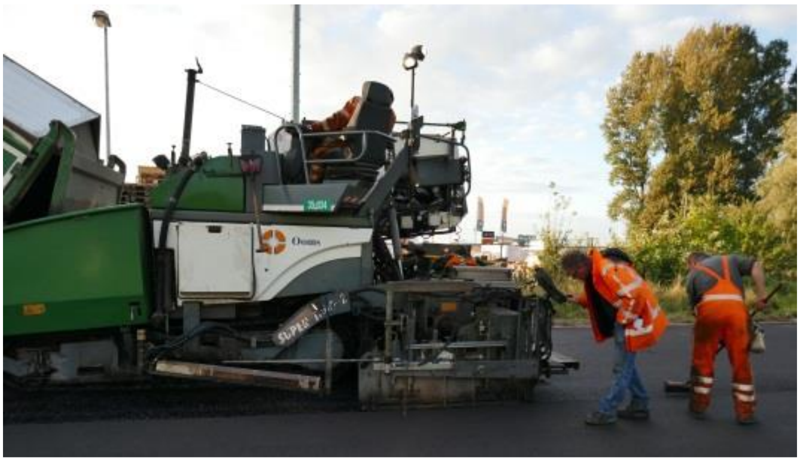

Figure 2: Laying a test road section

Figure 3: Thin surface 5 (left) and SMA 11B (right)