Rijkswaterstaat
Ministry of Infrastructure and the Environment

Laying Asphalt at Low Temperatures

A pilot project in the Netherlands

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Summary

When a severe winter causes substantial road surface frost damage such as excessive ravelling of porous asphalt pavement, conventional maintenance methods have little to offer when it comes to effecting repairs. It is well known that laying asphalt by conventional methods at temperatures below 5°C can lead to an asphalt layer of less than the customary quality. For contractors this is sufficient reason not to give a guarantee on pavements that they have had to lay under such conditions. When excessive ravelling occurs in the course of a lengthy period of sub-zero temperatures there are thus two options open to the highway authority. The first is to effect temporary repairs followed by permanent repairs when weather conditions have improved. The second is to mill the ravelled Porous Asphalt and then allow drivers, subject to speed restrictions, to use the resulting temporary surface until weather conditions permit resurfacing.

To find out whether paving is possible in winter conditions without prejudicing quality, Rijkswaterstaat first carried out a preliminary investigation or 'Quick Scan'. This report presents a concise overview of the results of this Quick Scan. The main conclusion is that special measures have to be taken if paving is to be carried out at low temperatures without poor quality. These measures have to be taken in a range of areas: asphalt transport, modifications to or settings on the paver, preheating the binder layer, protecting and conditioning adjacent existing asphalt, and particular attention to the compaction process. The Quick Scan provided sufficient evidence to justify a trial under operating conditions.

In February 2010 Rijkswaterstaat commissioned a trial on the A58 motorway, where in sub-zero temperatures two contractors each laid a PA+ (improved PA) test section 300 metres in length. During construction extensive measurements were taken using equipment which included infrared cameras and GPS for tracking paver and roller movements. Core samples were also taken for testing in the laboratory. Laser measurements were carried out on the test sections in order to obtain a clear picture of the ravelling process over time. Visual inspections of the test sections were carried out for as long as possible, i.e. until shortly before they were removed due to reconstruction work (over eighteen months after the sections were laid).

On the basis of the measurements conducted during construction, shortly afterwards and something over a year and a half after the work was completed, it may be concluded that the special measures taken contributed to achieving a PA+ layer of good quality. The results of mainly mechanically oriented tests directly following construction indicate that the mechanical qualities of the PA+ laid at low temperatures corresponded to those of PA+ laid under normal conditions. These relatively short-term results are promising, but it is not yet possible to draw definitive conclusions with regard to behaviour in the long term.

Laying asphalt at low temperatures has always been attended by the risk of poor quality. In view of this and the cost of the extra measures needed, paving in cold winter weather is recommended only in situations in which major road surface repairs are urgently needed in order, for example, to keep traffic moving and/or maintain road safety.

1 Introduction

1.1 Background

Wintry conditions with severe frosts and numerous freeze-thaw cycles increase the danger of damage to a road surface. Both excessive ravelling over wide areas and localized damage such as potholes and widening of longitudinal joints can put road users' safety at risk, so they must be repaired as expeditiously as possible. A severely damaged road surface can also affect traffic mobility.

Road-builders all over the world have long known that using conventional methods to lay asphalt in ambient temperatures below 5°C is liable to result in an asphalt layer of less than the accustomed quality. During the paving operation the temperature shock and rapid cooling set in train processes that can substantially reduce the life of the asphalt. This is particularly true in the case of relatively thin top surfaces (<50mm) and open wearing courses. As a result, contractors are unable to give a guarantee for asphalt that the client requires to be laid at excessively low temperatures. Under the Dutch National standard (RAW Bepalingen 2005) laying asphalt at low temperatures is not permitted and must be avoided in the drafting of maintenance plans.

However, during a period of severe frost the highway authority can be faced with sudden ravelling, particularly in the case of an open wearing course such as PA nearing the end of its planned service life. Road safety considerations may then dictate the removal and reinstatement of the surface. After milling off the wearing course the highway authority has two options. It can use what remains of the surface as the surface course, and wait until less inclement weather permits laying a new wearing course by conventional maintenance methods. Allowing traffic to use milled asphalt that has not been resurfaced is permitted as a temporary measure provided that appropriate speed restrictions are enforced. However, the binder layer is not designed to be a wearing course and there is therefore a real risk of its being completely destroyed. Reinstatement costs and damage escalate while traffic mobility deteriorates further. The second option is to resurface the road temporarily despite the unfavourable weather conditions and thereby risk mediocre quality. Poor quality at this stage means that it will be necessary to return at a later juncture when weather conditions permit the laying of a permanent surface. If it were possible to put down a good surface straight away despite the low temperature, this ought to cut both disruption to traffic and ultimate costs.

Plate 1: Cleaning a milled road surface.

During the severe winter of 2008-2009 frost damage was widespread to old PA road sections which displayed excessive ravelling. Due to persistent below-zero temperatures it was impossible to repair this damage effectively with the knowledge then available, so the Innovatie Test Centrum (ITC) investigated whether ways could be found of laying PA at low temperatures without loss of quality and, if so, what technical modifications would be needed. Trials were conducted by Rijkswaterstaat in February 2010. On the A58 motorway two contractors each laid a test section of PA+ at sub-zero temperatures, employing a number of additional measures. While the test sections were being paved extensive measurements were taken using a range of modern techniques including the use of infrared cameras to monitor asphalt temperatures and GPS to track all plant movements. Core samples were also taken for laboratory testing to determine ravelling resistance and sensitivity to water. In addition, immediately following the paving work, several months later and shortly before the surface was removed to be replaced by a permanent surface, laser measurements were taken with an ARAN (Automatic Road Analyzer) to establish whether aggregate loss from the road surface had been above normal in the test sections compared with the adjacent asphalt.
The results of this research are discussed in this paper.

1.2 Object

The object of this paper is to report the results of the project trialling the laying of asphalt on the A58 motorway in low ambient temperatures. The aim of the trial was to determine whether the use of additional measures when laying asphalt at low ambient temperatures produced a quality of asphalt that was equal to that achieved when asphalting under normal weather conditions. On the strength of this research, recommendations are made regarding the possible applicability, in the context of emergency repairs following frost damage, of the methods developed. Answers are also given to such matters as when asphalting at low temperatures is and is not advisable, what extra measures are necessary and how procurement and contracting can best be organized.

Plate 2: The trial site.

1.3 Who is this paper aimed at?

This paper is intended not only for internal use by Rijkswaterstaat but also as information for the road construction industry, advisory bodies and agencies, and universities. The internal target groups for the original Dutch text were first and foremost Rijkswaterstaat's district offices, which is where in a harsh winter decisions have to be taken about how to tackle frost damage in the Netherlands. Externally, the paper is intended to provide information on recent developments in paving at low ambient temperatures.

1.4 Guide to the reader

Chapter 2 looks at the results of the preliminary study (based on a survey conducted by email) and a limited literature search. The preliminary study ('Quick Scan') summarizes inter alia the experience already gained with laying asphalt at low temperatures, both in the Netherlands and elsewhere.

The A58 trial is described in Chapter 3, which begins with the procurement procedure for the two test sections. This is followed by a description of the weather conditions during the work, paying attention to all the special measures taken to mitigate the effects of working at low temperatures. The laying process was monitored closely and extensive measurements were taken of the test sections when completed.

Chapter 4 presents the results of the monitoring and measurements, together with those from tests with core samples, and ends with the technical conclusions.

Chapter 5 contains recommendations for the use of low-temperature paving as an alternative for temporary repairs or having traffic use a surface that has been milled but not resurfaced. This chapter also sets out what considerations play a part in determining whether asphalting at low temperatures is likely to be cost effective.

To ensure the confidentiality of commercially sensitive data the empirical results obtained from the work of the two contractors have been anonymized. The terms 'contractor 1' and 'contractor 2' are used variously and arbitrarily.

2 Preliminary research

2.1 Quick Scan

By and large, asphalting at low ambient temperatures is discouraged due to the risk of the result being a poorly performing road surface. Countries which commonly experience cold winters with temperatures around freezing point and well below impose limits for ambient temperatures and wind chill factors. Below these temperatures, laying asphalt is generally prohibited. However, dictating temperature limits does nothing to prevent situations arising in which laying a new road surface in a low temperature environment cannot be avoided. With judicious use of additives and adjustments to standard asphalt mixes coupled with additional measures in their application it is nevertheless possible to limit the risks of a low-quality product.

To gain an impression of the likelihood of a trial being successful, Rijkswaterstaat's highways and waterways department (Dienst Verkeer en Scheepvaart) commissioned a 'Quick Scan' of practical experience of the subject. A limited survey canvassing the views of experts and a similarly limited search through the literature produced a picture of current knowledge of asphalting at low ambient temperatures in the Netherlands and abroad. This chapter is a summary of the Quick Scan, the full report of which is also available[1].

The Dutch national standard, Standaard RAW Bepalingen 2005, updated May 2008, sets out the requirements for the conditions under which asphalt may be laid on roads in the Netherlands (sections 31.22.10 – 14). Temperature-related aspects are:

- Layers of PA may only be laid if the ambient temperature (t in °C) is at least t = w+5, where w is the wind speed in m/s (31.22.10.02);
- Asphalt must be transported in such a way that temperatures within the load vary by no more than 25°C (31.22.12.01).

This means that in windless conditions the lowest temperature recommended for laying asphalt is 5°C. Other European countries also take 5°C, or sometimes 10°C, as the lower limit. In addition to the technical aspects, of course, there are also limits to the working conditions to which roadworkers can be exposed. For example, special clothing is required if the wind chill temperature is below -5°C. It follows that even where adequate measures have been taken to avoid a loss of quality in the asphalt laid, actually laying it may be difficult if not impossible. It should also be noted that asphalt cannot be laid in rain or snow etc., or in mist or fog.

2.2 Deleterious effects of low temperatures

There was a time when delays due to cold weather were part and parcel of the construction industry in general. Work ceased because at low temperatures many building materials either became unusable or produced a substandard end product. In the Netherlands, until well into the nineteen-eighties laying comparatively thin surfaces such as dense asphalt concrete was prohibited between 15 November and 15 March because of high relative humidity and accelerated cooling of the thin asphalt layer. However, as long as ambient temperature remained at or above freezing it was still permitted to lay thicker sub-bases of around 120mm.

[1] Asphalt paving at temperatures below freezing; a quick scan of available information and experts opinions. KOAC-NPC, December 2009.

Contractors took advantage of the winter break to overhaul asphalt mixers, spreaders, rollers and other equipment. When it began to look as if harsh winters had become a thing of the past, the road surfacing season was gradually extended. The result was that drivers were now hardly ever surprised by road closures due to surfacing work in the depths of winter. Paralleling the expansion of the surfacing season there were also new developments in surfacing mixes, such as low-noise open-structure surface courses and thin surface courses. Mixes like these are inherently more difficult to work than dense surfaces, even in conventional conditions.

The decline in the quality of surfaces laid at low temperatures manifests itself in stone loss and gaps in the surface relatively soon after laying. This points to mediocre or poor aggregation and/or adhesion of the stone particles in the asphalt mix, or alternatively to inadequate adhesion to the binder layer. Precisely what the cause of this is has yet to be established, but it is thought likely that in part at least it is a combination of the following phenomena:

- **Adhesion**
  Laying PA at sub-zero temperatures is risky because both adhesion to the sub-base and cohesion within the asphalt are adversely affected. Due to PA's coarse and open stone skeleton the number of contact points with the underlying layer is comparatively low and the same applies to the points of contact within the skeleton. This means that there is an increased risk that during compaction the steam and water released during laying will become trapped between the binder film and the aggregate. With continuing cooling this water and steam, now condensed to water, can fail to evaporate adequately. This is clearly not beneficial to adhesion. At the same time the adhesion layer itself is a problem because the bitumen emulsion is aqueous.

- **Thermal cracking**
  When low ambient temperatures cause newly laid asphalt to cool too rapidly it is also possible for thermally induced stresses to occur in the layer, which will be detrimental to the initial quality of the asphalt. During the cooling process the enclosed binder film has to follow the thermal shrinking of the stone skeleton and this can lead to high micromechanical stresses in the binder film. At the same time there is a risk of small roller cracks appearing when compacting with steel rollers. At low temperatures, if they are not given an opportunity to heal (as they would in normal circumstances from the effect of traffic passing over them, for example) this can cause considerable initial damage. This is particularly true in the case of porous asphalt.

- **Roller damage**
  In contrast to the position with dense surface courses (air void content <4%), the problem with low temperatures coupled with PA is not so much achieving the desired density (air voids 20-22%) as preventing damage to the adhesion between mastic/mortar and the aggregate. Behind the asphalt paver heat is removed from the fresh layer of asphalt: beneath it by the cold binder layer and above it by the cold air. The result is a sandwich of thin crusts and stiffening material on the outside with a layer of more or less plastic material on the inside. The process of compaction can adversely affect adhesion between the mastic/mortar and aggregate of this more rapidly cooled upper and lower boundary of the asphalt layer. Similar adhesion loss can also develop locally at asphalt temperature inhomogeneities.

- **Conditioning**
  It is impossible to rule out the possibility that rapid cooling of the asphalt has implications for the development of the molecular structure of the binder, and hence for the ultimate strength of the asphalt layer. There are signs that asphalt, after laying, needs a degree of conditioning at both relatively high temperatures and traffic loading in order to develop its optimum strength. The suggestion is that it is only after a conditioning period – the length of which varies from mix to mix – that the surface course should be exposed to wintry conditions. Comparable mixes (i.e. same composition, aggregate, binder and laying method) are found to perform better when laid in summer or early autumn than when laid in late autumn or winter, when the prospects for conditioning are clearly less favourable than in late spring or summer. These findings support the idea that when laying asphalt it is important to consider not only the conditions prevailing at the time but also those likely to obtain in the near future.

Problems with PA laid at low ambient temperatures have been encountered in both Sweden and Estonia. In both countries there was stone loss as early as the end of the first winter. However, it should be noted that studded tyres are commonly used in both countries.

2.3 Constraints

In laying asphalt at low temperatures, proper compaction of the mix is crucial. The most crucial element is the time available for rolling, since it is vital to ensure that compaction is completed while the mix is still at a temperature appropriate to its compactability. For hot asphalt mixes the range is between 135° and 80°C. Factors in the time it takes the mix to cool to 80°C include:

- Initial temperature;
- Layer thickness;
- Total volume of air voids;
- Ambient air temperature;
- Wind speed;
- Whether or not the sun is shining;
- The surface on which the asphalt is to be laid, and its temperature.

The most crucial of these factors are the temperature of the mix, the thickness of the layer and the air voids. For more open mixes wind speed also plays a part. Where circumstances preclude compaction being completed within ten minutes it is doubtful whether effective compaction can be achieved. With layer thicknesses of less than 50mm, air temperature and especially wind speed have a significant effect on mix compactability. In short, the biggest challenge in laying asphalt at low ambient temperatures is good compaction. Difficulty in achieving it increases as the thickness of the layer to be laid decreases.

The Quick Scan reveals that there is no benefit to be derived from laying the asphalt more slowly or from having the compaction machines travel at higher speeds. The key to success lies in thicker layers (e.g. 150mm). This, however, is not a practical layer thickness for PA. Because of its higher air void content, the cooling time for PA will be somewhat shorter than for denser mixes. Cooling curves are available for both open-texture and dense surface courses and these can be used to determine how much time there is for compaction, depending on ambient and mix temperatures. PaveCool software makes it possible to calculate the time needed for compaction for a range of laying conditions, as well as allowing comparison of the effects of varying layer thickness and mix temperature.

2.4 Experience in the Netherlands

In the Netherlands, asphalt was first laid in sub-zero conditions many years ago. Before the asphalt was laid, the binder layer would be heated by the application of a layer of hot sand. This was produced by heating sand in the asphalt mixing unit. Immediately before the new asphalt was laid the sand would be removed and the surface swept and provided with a layer of tack coat. The empty asphalt lorries would then take the sand back to the asphalt mixer where it would be reused in asphalt. Sadly there appears to be no record of how successful this method was, nor have any other experiments been turned up that were specifically intended to lead the way to asphalting at low ambient temperatures. However, in the course of other projects there have been a number of developments in recent years that have the potential to make a contribution to improved asphalt quality when laying in low-temperature conditions. We shall now look at a number of these.

Plate 3: SurfaceJet.

Heating the binder layer

The SurfaceJet was first used in the Netherlands some years ago. Designed as a means of rapidly heating and/or drying road surfaces, it consists essentially of a turbojet engine mounted on a lorry. A variable exhaust nozzle is used to direct a stream of hot air that can be as wide as a lane or even a carriageway or as narrow as a wheel track. The SurfaceJet has been successfully used several times to lay road surfaces in unfavourable weather, including drying and heating the sub-base when laying a Rollpave test section at sub-zero temperatures (A32, 2007). The SurfaceJet was also used when halfway through the laying of a test section of Poro Elastic Road Surface (PERS) the work was unexpectedly disrupted by rain showers (A50, 2009). The SurfaceJet made it possible to blow the binder layer dry after the showers and successfully complete the operation despite the contractor's fears.

Working under canvas

To protect delicate construction operations against the weather, shelters are sometimes erected over the site. Examples include the laying of high strength concrete on the Moerdijk bridge, part of the A16 motorway south of Dordrecht (2006), and the laying of poured asphalt on the Galecopper bridge, part of the A12 near Utrecht.

Plate 4: Working in a protective shelter.

Shuttle Buggy in use

The Shuttle Buggy is a sort of container-on-wheels between the paver and the asphalt lorries. Used for remixing newly arrived asphalt, it ensures that the asphalt is returned to being a homogeneous mix in terms of temperature and composition. One major advantage is that the Shuttle Buggy holds a large supply of asphalt at the ready so that laying can continue unabated even if new deliveries are temporarily held up. Having no stop points improves the quality of the asphalt.

Plate 5: Shuttle Buggy.

Whether the use of a Shuttle Buggy will prove an advantage or a disadvantage when laying asphalt at low ambient temperatures is still a moot point. It may be that the extra storage time and the open conveyor belt from the Shuttle Buggy to the asphalt paver lead to faster cooling. When operating below zero it will almost certainly be necessary to use insulation to prevent excessive cooling. The physical speed of the asphalt paver is not increased by the use of a Shuttle Buggy, but without having to stop from time to time the average laying speed ought to be higher – a distinct advantage in wintry conditions.

Rollpave

Rollpave was designed as a rollable noise-reducing asphalt layer. It is prefabricated under controlled conditions in a production facility and has a bituminous steel carrier mat. After production the Rollpave mat is rolled up and transported to the site, where it is unrolled and bonded to the sub-base by inductive heating.

Plate 6: Laying Rollpave.

As part of the Noise Innovation Programme (Innovatieprogramma Geluid, IPG) three test sections were paved with Rollpave. One of these was laid in sub-zero temperatures. As an extra measure the prefabricated mats were rolled up and packed in insulating material.

Rollpave's suitability as a means of laying an emergency road surface in below-zero temperatures is limited. Where frost damage has occurred in the form of excessive ravelling of PA the surface course will first have to be milled off, and since a newly milling surface is unsuitable as a sub-base for Rollpave the product is unsuitable as a means of repairing frost damage.

Remix

The Remix method was designed to make it possible for a single machine in a single pass to heat the existing surface, scarify it, take it up into the machine's mixer, add new material, mix, relay and finally compact with rollers. The Remix machine has been successfully used to turn surface course mixes that were performing poorly in terms of wheel track rutting into stable mixes in situ. In advance of the resurfacing operation core samples would be analysed to determine what materials needed to be added to improve the mix.

This method may have the potential to repair frost damage in standard PA at low ambient temperatures and, for example, at the same time to convert it into a PA+ mix. Since the binder in the old PA will be quite old, one obvious enhancement would be to add rejuvenators and/or (possibly softer) bitumen. To bring the air void content back to the desired level it will also be necessary to add some coarse aggregate. One advantage of a Remix machine in sub-zero temperatures is that it preheats and dries the binder layer, which when ambient temperatures are low should lead to improved adhesion at the underside. In the Netherlands no experience has yet been gained with using the Remix method at low temperatures. It should also be noted that the method can only be used if there is no water in the PA.

The cost effectiveness of using the Remix machine to reinvigorate PA depends on the length of the sections that need to be repaired: if they are too short, it is not worth the effort. This means that for cost effectiveness reasons it will be necessary to consider using the machine on adjacent sections that have not suffered frost damage but which will need maintenance within the next few years. Besides, since there are no Remix machines in the Netherlands they will have to be brought in from elsewhere, and bringing machines in from abroad will only make sense if there are sufficiently long sections of road capable of being remixed to a consistent quality by this method.

The Remix in situ technique also has advantages when it comes to sustainability. All the materials are 100% reused and the Remix process causes less disruption to traffic because everything happens in a single pass: there is no need for separate transport to remove asphalt granulate or bring in new asphalt.

EOS Edelsplit

One of the problems with laying asphalt at low ambient temperatures is that open-textured mixes cool faster than denser ones, particularly in a wind. The time available for compaction is thus shorter, making it more difficult to compact the asphalt to the design air void content for the mix being used. One way to stretch this window is to use a coarse aggregate of higher density which will retain heat for longer. This was the principle underlying Dura Vermeer's laying of twin-layer PA test sections on the A35 motorway, albeit under normal conditions.

EOS-Edelsplit, a proprietary steel slag based aggregate, was used as a coarse aggregate at a density of 3800kg/m^3 to widen the compaction window and bring about enhanced homogeneity. The expectation was that twin-layer PA made with EOS-Edelsplit would be easier to compact safely and would thus have a longer life than standard twin-layer PA with its risk of roller cracks caused by exceeding the compaction window. When laying asphalt at low ambient temperatures, using a heavier aggregate such as EOS-Edelsplit may offer benefits for the compaction process.

Two-layer paver

Rijkswaterstaat has laid a number of double layer PA test sections using two-layer paver capable of laying both lower and upper layer in a single pass (hot on hot). Apart from the faster laying process and improved adhesion between upper and lower layers the advantage is that the thin open-textured surface course cools down more slowly than with a two-pass operation with a normal paver operating hot on cold. This means that the compaction window is longer. The guideline document Tweelaags ZOAB published by VBW Asfalt[2] recommends that two-layer PA should only be used if the ambient temperature is at least 10°C. With a two-layer paver it is possible to lay two layers of PA at lower temperatures with no loss of quality.

Roller damage in adjacent old surface courses

One of the risks of replacing PA one lane at a time is damage to adjacent old PA. When the work is carried out no damage may be visible, but after a few weeks ravelling will be seen to have accelerated. The reason for this is that during compaction the rollers are also driven onto the old asphalt of the adjacent lane as part of the work to achieve satisfactory grading. The lower the temperature, the brittler the adhesion bridges between the stones and the more easily the PA will ravel. Driving rollers over old PA causes tiny cracks in these adhesion bridges which then proceed to grow under the strains and stresses of traffic passing overhead until the stage at which stone loss begins. It is therefore imperative to take steps to protect adjacent asphalt. The options are as follows:

- Modifications to rollers;
- Covering adjacent asphalt with steel road plates;
- Heating the adjacent asphalt;
- Treatment with rejuvenator;
- Unloading of material on plastic road plates or on the milling surface;
- Ensure rollers do not encroach on adjacent old PA.

Another cause of accelerated ravelling is the spilling of asphalt mortar on the adjacent old PA as stones entering the voids act as wedges.

2.5 Experience outside the Netherlands

Most of the experience of asphalting below zero outside the Netherlands has been gained from laying dense surface courses. For various reasons road operators in other countries tend to be somewhat reluctant to use porous asphalt. A number of experts in other countries were consulted for the Quick Scan; some relevant insights are discussed below.

Constraints

Achieving the required low air void content, i.e. the right amount of compaction, is of particular importance for the quality of dense mixes. When it comes to laying asphalt at low ambient temperatures there are a number of options:

- Increase the temperature of the asphalt mix;
- Increase asphalt layer thickness;
- Keep transit times and/or distances between mixer and site to a minimum;
- Have rollers operating as close as possible behind the paver;
- Use more rollers, possibly with a higher ratio of roller weight to roller diameter;
- Mix additives that reduce the viscosity of the bitumen within a given temperature range. (Warm mix asphalt (WMA), especially in Iceland.)

In the United Kingdom the Specifications for Highway Works (SHW) and accompanying guidelines set out the requirements for the conditions under which asphalt may be laid. Asphalting is permitted down to an air temperature of -3°C, provided that certain other requirements are also met. For example, the logistics have to be properly organized and the hot mix must be transferred to the hopper as rapidly as possible and in a single mass. In asphalting at low ambient temperatures it is axiomatic that the time between mixing

[2] VBW Asfalt, Richtlijn Tweelaags ZOAB (guideline, two-layer PA), July 2002.

and compaction the mix should always be as short as possible. From this it follows that the time between loading and unloading asphalt lorries must also be as short as possible.

The need to ensure that compaction takes place as swiftly as possible dictates the use of more rollers and/or rollers that are more efficient at compacting the mix. In this respect the use of tyre rollers, which have more of a kneading effect, may offer advantages for achieving the required density quickly. It must be borne in mind that the tyres of such rollers need to be heated to prevent the asphalt adhering to them. However, where a heavier type of roller is being used with rapidly cooling asphalt there is a risk of roller cracks and/or destruction of the aggregate.

The coarser types of crushed stone are also more difficult to compact than mixes containing coarse gravel. It should be noted that coarse gravel mixes are more susceptible to wheel track rutting than crushed stone mixes.

In the United States, the National Asphalt Pavement Association (NAPA) highlights the following points regarding cold weather paving with warm asphalt:
- Drying and heating the aggregate;
- Temperature during mixing and compaction;
- Transport;
- The influence of the binder layer on which the asphalt is being laid;
- Pre-treatment of the binder layer;
- Manual work required;
- Expansion joints and other discontinuities.

Practical applications
In Hamburg, Germany, the authorities advise that where asphalt is to be laid in unfavourable weather conditions viscosity reducing agents such as waxes (e.g. Sasobit) should be added to the binder, though they do not address the full potential of reducing temperatures. Instead of the lower mixing temperature (130°C), mixing still takes place at the usual temperature (160°C). Adding waxes has a significant effect on reducing binder penetration value at the same time as considerably increasing the softening point. This may mean that the binder becomes more susceptible to cracking at low temperatures, though long-term experience in countries with harsh winters (e.g. Norway, Sweden, Iceland) has yet to turn up any adverse effects.

In Iceland asphalt is regularly laid at temperatures below zero in windless or almost windless conditions and the results are good. Points for attention include:
- The asphalt mixer needs to be monitored with extra care;
- Preheating the load floor of the lorry to be used for transporting the mix;
- Shortest possible distance between asphalt paver and rollers;
- Addition of 1-3% Sasobit to the bitumen. It is claimed that the asphalt mix can be properly compacted even if it has cooled to 50°C.

Other important factors that need to be considered are the compactability of the mix, the hardness of the bitumen and the susceptibility to moisture of the asphalt layer to be created. With comparatively low-temperature warm mix asphalt (WMA[3]) mixes developed with a view to energy conservation, mix compactability is adjusted by the use of additives to reduce its viscosity, enabling these mixes to be used under normal asphalting conditions. The available information on the performance of WMA in low ambient temperatures shows that when enhanced with additives such mixes have the potential to be used in wintry conditions, though adhesion enhancers would appear to be necessary to improve resistance to wheel track rutting and sensitivity to moisture. Many of the advantages of producing WMA at normal HMA temperatures are also of considerable benefit precisely when asphalting at low temperatures:
- Extends the asphalting season;
- Facilitates compaction in extreme weather and the compaction of stiff mixes.

[3] WMA = Warm Mix Asphalt produced at approx. 130°C.
HMA = Hot Mix Asphalt produced at approx. 160°C.

In the conditions pertaining in Iceland it is concluded that laying asphalt in winter is probably best served by the addition of a wax (e.g. Sasobit).

If new asphalt has to be laid over an existing surface, the existing surface must be dry and provided with an effective bonding layer. This can be effected with rapid-curing liquid bitumen. In some cases hot air guns (as used for drying racing tracks) are employed, or infrared heaters, to dry the surface before the asphalt is laid. The binder layer can also be preheated to ensure good adhesion and reduce heat losses from the new asphalt into the underlying structure. Tents or rigid movable shelters are sometimes erected over the worksite to protect workers from cold, wind and precipitation.

To optimize the compaction of asphalt at low temperatures, softer binders and a slight increase in binder content were used. Both approaches have potential disadvantages as regards the behaviour of the final surface. Depending on climate, these can include wheel track rutting in high summer temperatures.

Point for attention: compaction

Incipient damage to an asphalt layer that was laid in unfavourable conditions may be the result of thermally induced stresses and strains in the binder film. Being enclosed in the asphalt, during the cooling process the binder film has to follow the thermal shrinkage of the stone skeleton and this can lead to high micro-mechanical strains. These in turn create a risk of roller cracks developing when compacting. If these are not given an opportunity to heal, e.g. in normal circumstances from the effect of traffic passing over them, this can cause considerable initial damage. This is particularly true in the case of porous asphalt.

In the United States, research in Washington state has shown that a drop of a few per cent in the density of dense mixes can be at the expense of a lifetime reduction of many per cent. That is why investing more in optimizing compaction makes sense if working at low ambient temperatures is unavoidable. The most important point to be considered here is the controllability of the asphalt temperature, so it is crucial at all stages of the work to keep a close watch on temperature control. Often wind speed will be found more important than air temperature in determining the speed at which the mix cools.

In the conventional production and laying process, inhomogeneity of asphalt temperature is found to be caused principally by differences in insulation in the transport lorries. In particular, the sides and corners of the load space often have cold spots. Imperfect closure of the load space can also cause cooling at the top of the load. Because an asphalt paver is poorly equipped to effectively mix the asphalt delivered to it, temperature differentials arising in the mix in transit are generally still largely present when the paver has moved on.
It was this that prompted the development of the Shuttle Buggy, a kind of extra hopper between the paver and the asphalt lorry. A specially designed worm mixer mixes the asphalt homogeneously in terms of temperature and compensation. Naturally these effects will all be more pronounced in wintry weather.

2.6 Conclusions from the Quick Scan

The following general conclusions may be drawn from the results of the Quick Scan:

- With the appropriate precautions, high-quality durable asphalt can be laid at low ambient temperatures, the principal factors being careful temperature control of the warm asphalt and the achieving the right compaction for the mix. Logistics and asphalting method must be adjusted accordingly;
- The biggest challenge in laying asphalt in wintry conditions is achieving the right compaction of the asphalt mix. The difficulty of this increases with increasing air void content and decreasing layer thickness;
- As soon as conditions prevent the desired degree of compaction being achieved within ten minutes the quality of the new surface course must be deemed unreliable;
- Because of their open texture, laying PA or other types of open wearing courses at low ambient temperatures is more difficult than laying dense wearing courses;
- The effect that relatively rapid cooling caused by laying at low ambient temperatures has on the course of the chemical reactions and physical processes within the mix at the micro level has yet to be determined, so that ultimate quality continues to be unpredictable;
- There are indications that, in order to develop its optimal strength, asphalt that has been laid at low ambient temperatures calls for a degree of conditioning at comparatively high temperatures and traffic loads. Where asphalt has been laid in late autumn or winter the prospect of achieving such conditioning is considerably less favourable than in late spring or summer;
- Laying asphalt at low ambient temperatures will always be attended by higher costs than asphalting under normal conditions;
- Although laying asphalt at low temperatures appears to be possible in terms of technical execution, when it comes to the quality achieved there remains a degree of uncertainty, so that in many countries the rule still applies: when ambient temperature is low, lay asphalt only if there is no other option.

Highway authorities and contractors must ensure they have a proper understanding of the risks of working with asphalt in wintry conditions. In some cases asphalting in bad weather is not the right decision to achieve the desired quality, and in those circumstances it may be necessary for reasons of road safety and traffic mobility to decide on a temporary solution and only effect a permanent surface when weather conditions have improved. However, despite the limitations revealed by the Quick Scan, it also showed sufficient reason to carry out a trial with asphalt paving below zero. The following chapter looks at this in more detail.

3 Plan of action for the A58 project

3.1 Procurement

At the end of 2009 Rijkswaterstaat's Innovation Test Centre (ITC) invited six contractors to tender for the laying of a test section of motorway with long-life porous asphalt, known in the Netherlands as ZOAB+ and referred to here as PA+, at low ambient temperatures and while maintaining the quality of the surface. The procurement documents drew particular attention to the following points:

- Availability of an asphalt mix plant or plants (must not be undergoing overhaul);
- In freezing conditions there is greater cooling and more mix separation when in transit (particularly over long distances);
- Mixes are more susceptible to separation in transit if production temperature is increased;
- Adhesion to cold binder layer with over-rapidly cooled porous asphalt interlayer;
- Mix separation in the asphalt paver;
- Over-rapid cooling leads to inadequate compactability;
- Protection for adjacent old PA;
- Protective clothing for operatives in sub-zero conditions;
- Protection of machines aginst e.g. freezing lines;
- Care in handling bitumen emulsion (contains water).

All six contractors submitted a tender. An independent committee of experts consisting of specialists from Delft University of Technology, Cyrus Infra Engineering, TNO and Rijkswaterstaat then assessed the tenders on the following criteria:

Assessment of tenders for asphalting below 0°C

Criterion	Remarks
Quality	Durability: the requirement is that on the basis of engineering judgement the product is estimated to have the same lifetime as PA laid under normal conditions. The minimum expected lifetime must be twelve years. This criterion also covers the protection afforded to adjacent existing PA while the work is being carried out.
Feasibility	Feasibility: is there a high degree of certainty that the idea can be put into practice in the near future?
Traffic mobility	Availability of the road to traffic: is the time need for the work essentially the same as that needed for asphalting in normal conditions?
Response time	How soon can work start? To score maximum points the contractor must be able to start work within 48 hours of receiving a request from the highway authority.
Cost	Extra cost of work compared with asphalting under normal conditions.
Environment	Will putting the idea into practice lead to a greater burden on the environment that that caused by asphalting under normal conditions? (Points include recycling/reuse, noise, energy consumption, use of environment-unfriendly materials, etc.)
Safety	A sine qua non: if the proposed method of asphalting or transporting asphalt is judged to be unsafe, the idea will be automatically eliminated from consideration.

Table 1: Criteria for assessing the tenders.

The best tenders came from Dura Vermeer and KWS. Each was contracted to lay a test section of PA+ 300 metres in length on the left-hand (fast) lane of the north carriageway of the A58 south of Breda between the Sint Annabosch and Galder intersections. The remit was to replace the consisting old PA layer by new PA+ in sub-zero conditions. The total width to be laid was 4.15 metres. The new road markings were also to be applied at low temperatures.

3.2 Weather conditions

Winter 2009-2010

The winter of 2009-2010 stood out for various reasons:

- Considerably colder than an average winter; the coldest since 1996;
- Very high number of daily freeze-thaw cycles (particularly damaging to porous asphalt);
- Relatively large amounts of precipitation (40 days of snow cover compared with fewer than ten in an average winter);
- A prolonged period of low temperatures:
  - 55 days of frost (days in which the minimum temperature is below zero degrees Celsius), compared with 38 in an average winter;
  - 20 ice days (days in which the maximum temperature remains below zero degrees Celsius), compared with 8 in an average winter.

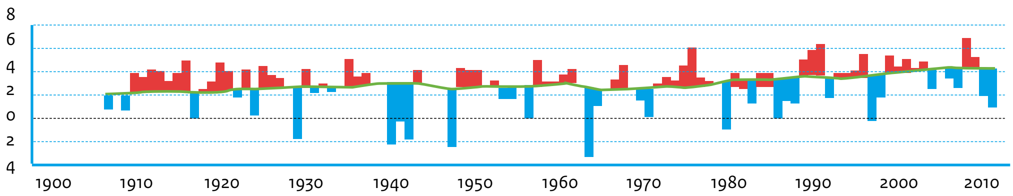


Figure 1: Winter temperature, central Netherlands, 1907 - 2010 (source KNMI).

Average winter temperatures in the Netherlands have been rising since 1950. In Figure 1 this rising trend is shown by a green line. The average winter temperature is now approximately half a degree higher than in the mid twentieth century. The Netherlands' national weather forecasting body KNMI estimates the probability of a winter comparable to that of 2009-2010 at about one every fifteen years.

Plate 7: Low temperatures coupled with relatively high precipitation.

Weather criteria for the trial

A number of criteria were established to ensure that the trial modelled real life as closely as possible and at the same time to retain the possibility of a successful outcome. As soon as the forecasts indicated that weather meeting the criteria was imminent it would then be possible to give the green light within forty-eight hours. This was dubbed the 'Frost Go'.

The criteria established for forecast weather conditions were as follows:

- Wind chill temperature during workable hours not below -6°C. This is to comply with working conditions legislation;
- Daytime temperature no higher than +5°C and maximum temperature during workable hours no higher than +2°C;
- Temperature of asphalt mass during workable hours no higher than +5°C;
- Wind speed no higher than 5m/s;
- No precipitation, mist or fog;
- The forecast had to be for a 'cold' period of at least three consecutive days with a minimum temperature of 0°C or below; the trial had to take place no earlier than the third day of this cold period.

When considering the above criteria it should be borne in mind that in addition to the technical aspects there is also a human factor in the limits to the weather conditions for the trial. Roadworkers can be protected against extreme cold with the right clothing and e.g. hot catering, but restrictions are imposed by working conditions legislation.

For the meteorological monitoring of the trial criteria MeteoConsult was brought in to provide effective local forecasting. Forecasts were based partly on data provided by sensors already embedded in the road surface as part of the existing ice alert system (GMS). Another factor taken into account was the precise location of the test sections and the effect of the surrounding landscape on wind speeds at the site, as well as height above sea level. On the basis of the advice given by MeteoConsult the ITC decided to issue a 'Frost Go' forty-eight hours in advance so that the trial could proceed on the night of Friday 19 to Saturday 20 February 2010.

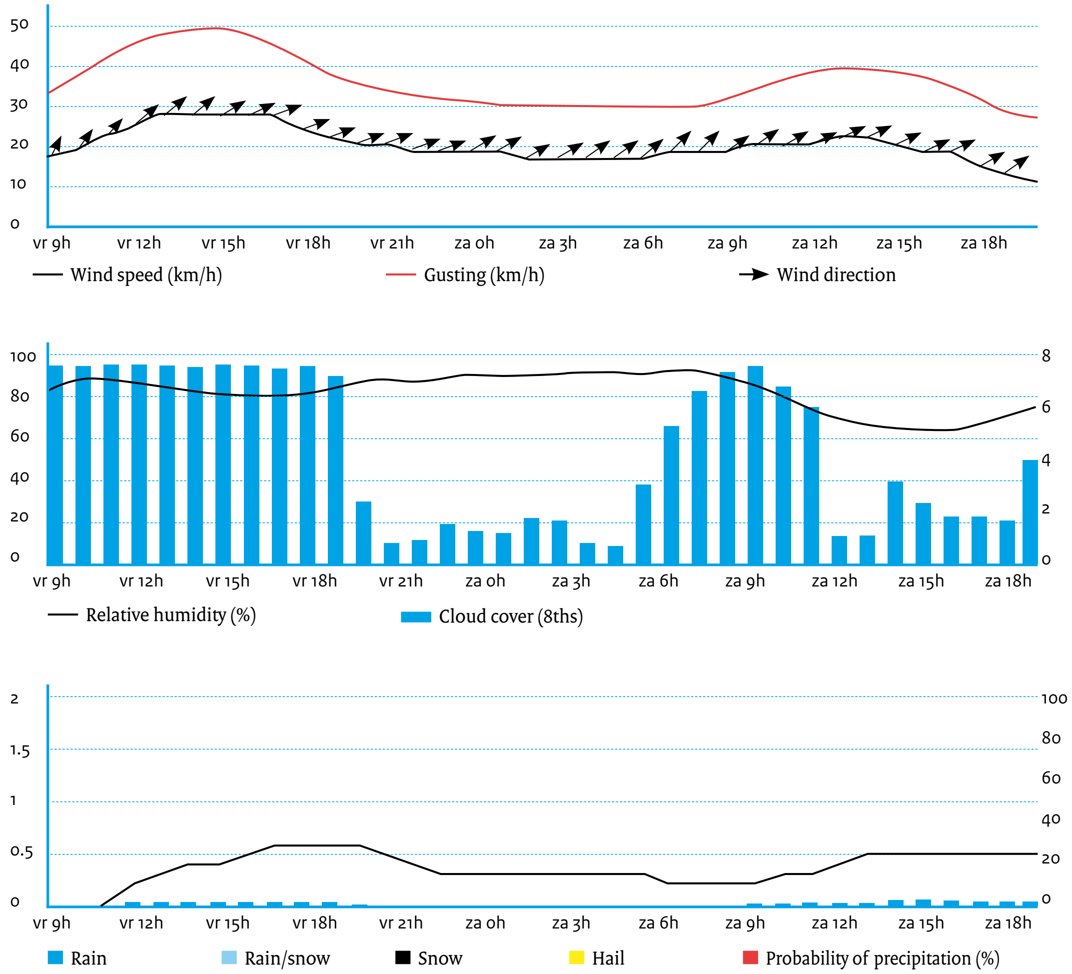


Figure 2: 36-hour forecast based on data from the Galder automatic monitoring unit (source: MeteoConsult).

Actual weather conditions

The actual weather conditions (see Figure 2) during the trial were entirely within the parameters established by the ITC and were in close agreement with the 36-hour forecast. During the work the weather conditions were recorded by a mobile weather station (see Plate 8) set up in the central reservation. Measured average values were as follows:

- Air temperature: -0.1°C;
- Wind speed: 0.5m/sec;
- Wind chill temperature: -2.3°C;
- Road surface temperature: -3.9°C;
- Precipitation: none

Plate 8: Mobile weather station in central reservation.

3.3 Execution

The trial was carried out in the night of 19/20 February 2010. Rijkswaterstaat's Breda district office not only made the test sections available but also oversaw the smooth running of the whole operation. The test sections contained no detection loops or expansion joints. A speed limit of 70km/h was imposed and traffic was diverted over the hard shoulder, which had been gritted/salted for this purpose in advance. Traffic heading for Antwerp was re-routed.

Plate 9: The site of the test sections.

We now turn to the extra measures taken by the contractors to cope with the weather conditions, in the order in which they were dictated by the chronology of the work. In all cases these are overall summaries of the measures taken by both contractors, i.e. not all the measures described were taken by both contractors.

Changes to plant and equipment and changes affecting workers

To lay asphalt at sub-zero temperatures it is essential that all asphalt mix and all plant and equipment is fully protected against freezing. Changes were also made to facilitate effective monitoring of the asphalting process. To cope with the conditions, the following changes to asphalt mix, plant and equipment were effected:

- All coolants with adequate antifreeze;
- Hopper insulation, wind protection for cooling-sensitive areas of the paver;
- Rollers which are normally operated with a water film over the drums to prevent asphalt pick-up now used water with added glycol;
- Integral binder spray bar on paver;
- Extra heating for vital parts of the screed;
- Paver fitted with boom-mounted infrared temperature camera (Plate 10);
- Paver and rollers fitted with GPS equipment;
- Extra heating equipment on hand at all times;
- Use of SurfaceJet.

Plate 10: Infrared temperature camera mounted on paver.

The low temperatures also call for extra protection for the roadworkers. The following should be considered:

- Clothing with high insulation lining, insulating gloves and headgear;
- Thermal underwear;
- Ear defenders (particularly when using the SurfaceJet);
- Heated hut for breaks;
- Hot catering service.

Plate 11: Attention to protective clothing.

Asphalt mixing plant and mix

One of the first problems when asphalting below zero is the availability of asphalt mixing plants, since winter is when most mixers have their annual overhaul. This may mean that the asphalt has to be brought to the site from some distance away, with concomitant added problems of mix cooling and separation. Increasing the production temperature to compensate for this cooling in transit is hardly an option since it is attended by the risk that the binder will age too fast and the mix will become even more susceptible to separation. The contractors are therefore forced to have an asphalt mixer available on standby, preferably somewhere not too far away from the site. Nevertheless, for the A58 trial one contractor chose deliberately to use an asphalt mix plant that was 100km distant as a way of making the point that the process being used was satisfactory even if the mix had to spend two hours in the asphalt lorry.

To sum up, the trial contractors took the following additional steps to cater for the weather conditions:

- Changes to the mix composition in the form of the use of an additive (wax) which improves workability at low temperatures;
- Preheating of the asphalt mixing plant;
- Just-in-time production, i.e. keeping the time the asphalt spends in the mix storage silo before being loaded onto the lorry as short as possible;
- Parts of batches that were outside the desired temperature range were removed and returned to the mixer for reuse.

Transport

It is important that the production temperature of PA+ is as far as possible maintained in transit to the work site. The following steps were taken:

- Extra insulation (particularly at places with the largest cold bridges) plus wind and airflow screening on asphalt lorries;
- Using smaller lorries so that the mix was carried as compactly as possible. This limits heat losses by having minimal surface area in relation to useful capacity;
- Using lorries with pneumatic suspension to reduce the risk of mix separation and binder draindown due to road-induced vibration;
- Preheating of vehicle load space using hot mineral aggregate;
- Separating off the first (i.e. coolest) part of the load behind the asphalt lorry loading flap before tipping the rest into the asphalt paver hopper. The asphalt separated off was then returned to the asphalt plant for reuse;
- Issuing asphalting team members and transport drivers with mobile phones for use in the event of disruption to the process.

Plate 12: Separating off the coolest asphalt immediately behind the loading flap before the rest of the load is tipped into the hopper.

Milling and treating the binder layer

Milling was with ordinary road milling machines but without the use of water. Dust proved much less of a problem than expected, thanks in part to low wind speed. Particular points for consideration given the weather conditions were:

- Preheating the edges of the milling area with the SurfaceJet in order to avoid damage to the adjacent old asphalt;
- Comparatively low milling speed for a flatter binder layer;
- Vacuum sweeper with brush to ensure milling grooves are swept clean;
- SurfaceJet not only preheats but also blows binder layer extra clean and dry.

Plate 13: Milling off the wearing course and removing material.

Applying the tack coat

Both contractors opted for the use of a SprayJet paver so that applying the tack coat (a bitumen emulsion) was carried out in the same pass, immediately before the asphalt was laid. Direct contact with hot PA+ causes the bitumen emulsion to foam so that it can escape through the open texture asphalt layer, so this system provides optimum adhesion at low ambient temperatures. It also prevents tack coat material coming into contact with transport and handling plant and equipment, as well as ensuring that dust or dirt are not blown upwards where they can have an adverse impact on adhesion. When taking core samples it was found that PA adhesion to the binder layer was good.

Plate 14: SprayJet paver with integral spray bar.

The following extra measures were taken for laying the tack coat:
- Bitumen spray bar on asphalt paver;
- Use of a modified bitumen emulsion;
- Preheating of binder layer with SurfaceJet.

With reference to the last of these points: the SurfaceJet can be used to heat the binder layer of the milling section between the arrival of the loads of asphalt. Using the SurfaceJet the surface can be heated faster and more homogeneously than with a flame, the speed of heating being adjusted by varying the pass speed and the distance between nozzle and surface. The heating of the binder layer can be monitored with infrared temperature cameras. The system permits heating to approximately 30°C.

Plate 15: Asphalt paver closely followed by roller.

Laying the asphalt

One contractor started by preheating the paver's hopper by putting hot asphalt through it and then carrying out an actual pass but without spraying binder. The newly laid asphalt would then be removed again by a mobile crane. One slight drawback to this was that to the uninitiated spectator it looked as if a mistake was being rectified. The operation also took a relatively long time to complete.

Laying the desired width of PA+ should wherever possible be achieved in a single pass in order not to create extra joins. In the trial it was possible to lay the full width of approximately 4.15 metres in a single pass.

Unloading the lorry loads was effected direct into the hopper via the steerable metering nozzle, the aim being to allow the asphalt to flow into the hopper loading chute en masse and without interruption but without free fall. After this, with skilled operation it was possible to keep to as continuous an asphalting process as possible in order to avoid interruptions (and hence excessive cooling) in the flow of asphalt.

To sum up, the principal measures applied to laying the asphalt were:

- Crucial parts of the screed were provided with extra heating elements to improve grading and precompaction;
- A joint heater was mounted on one side of the asphalt paver to preheat the adjacent PA;
- Wind protection;
- Hopper preheating;
- Achieving as continuous as possible throughput of material, i.e. no interruption of the asphalt stream while asphalting was in progress;
- The last part of the work was carried out with a relatively well-filled hopper in order to prevent cold material being worked in the final phase.

Compaction

The care with which compaction is carried out is crucial for the durability of the end product. This means not just achieving evenness of compaction close to the paver while remaining within the appropriate PA+ temperature range, but also protection of the adjacent asphalt against being damaged by the rollers.

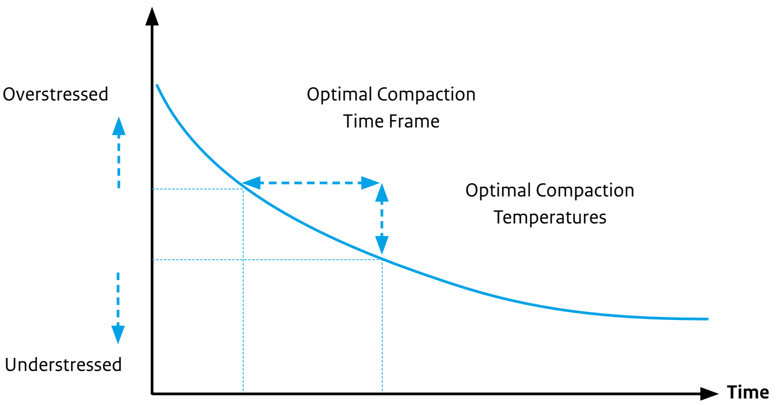


Figure 3: Compaction temperature window.

Compaction has to be carried out within a certain critical temperature range in order to minimize the risk of insufficient compaction. The relation between the critical temperature curve and the optimal time for compaction is shown in the graph[4] above. Throughout the laying of the new test sections all roller movements were tracked by the GPS system. The results are discussed in paragraph 4.2.

Plate 16: The water film sprayed onto the roller drums contains added glycol.

[4] D. H. Timm, 'An asphalt paving tool for adverse conditions', Minnesota Department of Transportation, 1998.

Compaction measures:
- The water film sprayed onto the roller drums to prevent asphalt pick-up contained glycol antifreeze;
- A quality controller was employed to indicate the precise area to be rolled by continuously measuring the surface temperature with a thermographic camera (this meant that knowing the minimum roller temperature was imperative);
- Special instructions for roller drivers.

Rolling calls for considerable skill at all times, but even more so in wintry conditions when the quality of the final surface depends largely on achieving adequate compaction. With the more rapid cooling brought about by low ambient temperatures the trick is to design the rolling pattern so that enough roller passes can be fitted into the limited time available. Roller drivers were required to adhere to the following special instructions:
- Use the GPS system when compacting to determine when the number of passes stipulated by the contractor have been carried out;
- Work as closely as possible behind the paver;
- Keep passes short so that enough passes can be made within the critical temperature window;
- At low temperatures older PA is more brittle than usual, so as far as possible avoid contact with the existing PA abutting the working area.

Plate 17: Unloading heavy plant and equipment on soft plastic road plates.

Protecting adjacent asphalt
The following steps were taken to protect adjacent asphalt:
- Plant and equipment parked on soft plastic road plates or unloaded onto the milling/milling area;
- Immediately prior to laying PA the adjacent asphalt was preheated with the SurfaceJet;
- Use of a modified and warmed variant of rejuvenator;
- Use of joint heaters to ensure good adhesion between newly laid and existing PA. Joint heaters were also used to heat adjacent PA to prevent roller damage;
- Use of smaller, lighter roller at the edges;
- Extra protection for new joints with bituminous tape (Hermatec).

3.4 Overview of special measures

The previous paragraph described all the extra measures taken in laying the test sections. Table 2 is a summary.

Production component	Possible measures
Asphalt mix	Modifying mix with additives Preheating asphalt mixer and storage silo Just-in-time production Returning batches outside the required temperature range
Transport	Preheating lorry load spaces Smaller lorries, perhaps with pneumatic suspension Extra insulation Removal of excessively cool PA behind the loading flap
Milling	Preheating edges Milling without water Milling more slowly for a flatter result
Brushing	Protecting vacuum sweeper against frost Not using water Use of long-handled broom to clean milling grooves Extra high pressure
Applying tack coat	Preheating binder layer with Surfacejet Modified bitumen emulsion Tacking and asphalting in a single pass with SprayJet paver
Laying asphalt	Integral spray bar on paver Insulation on hopper Protection against cold wind Preheating hopper
Compaction	GPS system for rollers Glycol added to roller drum spray water Rolling as closely as possible behind paver Short roller passes Infrared monitoring of optimum temperature window Avoiding contact with existing PA
Joints	Heating with SurfaceJet Use of joint heaters
Adjacent asphalt	Preheating by Surfacejet Special measures on rollers Use of rejuvenator
Other points for attention	Parking and loading plant and equipment on soft plastic road plates Unloading plant and equipment on milling section Extreme caution re detection loops (none present in test sections) Extra protection for roadworkers against low temperatures and wind Provision of hot catering

Table 2: Summary of special measures.

4 Results of the trial under operating conditions

4.1 Monitoring and measurements

During the trial the work was closely monitored. Among the data collected were the following:
- Asphalt mixer production data;
- Raw materials;
- Transport (transit times / heat loss);
- Temperature readings: binder layer / adjacent asphalt (before and after preheating);
- Infrared temperature readings following laying and during compaction;
- Paver and roller movements.

In addition to the standard measurements and the material and production data that Rijkswaterstaat always requires of its road-building contractors, monitoring concentrated principally on the particular weather conditions during construction of the test sections. For this reason both contractors employed the services of the Asphalt Paving Research and Innovation group (ASPARI[5]) at the University of Twente for the measuring of:
- Weather conditions (mobile weather station);
- Paver and roller movements (GPS);
- Asphalt temperature directly behind the screed (infrared);
- Cooling of asphalt surface (infrared) and in the PA+ wearing course (digital).

For the last of these, three methods were used:
- A boom-mounted infrared line scanner immediately behind the screed;
- Surface temperature measurements with infrared cameras;
- Temperature readings from within the asphalt layer taken with thermocouples.

Each of these methods delivered its own data set. These data could then also be combined as follows:
- Compaction animations and contour plots;
- Temperature contour plots;
- Cooling graphs.

The results of the process monitoring will be discussed in paragraph 4.2. The customary operational control checks were carried out and before the test sections were reopened to traffic safety checks were conducted in the form of friction and braking measurements.

[5] ASPARI stands for Asphalt Paving Research and Innovation.

Plate 18: Taking core samples.

Measurements relating to construction are given in Table 3. Column 0 shows measurements immediately after completion. Under standard rules the skid resistance and brake deceleration tests ought not to have been carried out below 0°C, but it was assumed that the results nevertheless reflected the reality. To provide greater reliance on the results the measurements were repeated as soon as the temperature rose above 2°C (column 1). The condition of the test sections was then monitored for a further two years ('after winter'), the final measurements being taken 1¾ years after the asphalt was laid. (Soon afterwards the test sections were removed as part of a motorway reconstruction.) The results of the measurements after laying are discussed in paragraph 4.3.

Measurements after laying of the test sections

Trial	0	1*	After winter**
Skid resistance, l/h lane (70km/h)	X	X	
Brake deceleration test, l/h lane	X	X	
ARAN l/h lane longitudinal irregularity			X
ARAN l/h lane transverse irregularity			X
ARAN l/h lane transverse slope			X
ARAN l/h lane texture			X
ARAN Laser measurements (ravelling)	X		X X X
Rolling straight edge***			
Core sampling			
Visual inspiration	X		X X

* Measuring as soon as temperature above 2°C

** Number of crosses = number of measurements

*** National standard RAW 2005 Art. 31 22 03, see standard contract (Modelbestek 01 01 10)

Table 3: Measurements carried out after laying of test sections.

4.2 Results of monitoring the asphalt laying process

Monitoring the laying process produced a wealth of information. Thanks to modern technologies such as GPS and infrared cameras it was possible to create animations of plant movements and contour plots of temperature changes during compaction[6].

Mix

As a result of the steps taken to minimize heat losses in transit it was possible to maintain the usual mixing temperature in the asphalt mixers. The mixers themselves were preheated. One contractor elected for a standard PA+ mix; the other used an additive (Sasobit wax) to improve workability at low temperatures.

Transport

To minimize heat loss one contractor brought asphalt to the site in more compact lorries with extra insulation. Vehicles with pneumatic suspension were also used to combat mix separation. When each vehicle arrived at the site, one contractor first removed the asphalt that was immediately behind the loading flap (where it was subjected to the fastest cooling) before the rest of the load was discharged into the asphalt paver's hopper. As the monitoring shows (see Table 4), even where the distances involved were relatively long it was found possible to keep heat loss in transit within manageable bounds.

Heat loss from asphalt mix in transit and pending use (one contractor only)

Load no.	Mass (tonnes)	Temp when loaded (°C)	Transit and waiting time (hours)	Temp when discharged into hopper (°C)	Heat loss (°C)
1	30	158	2.59	150	8
2	30	158	3.21	149	9
3	30	159	3.04	146	13
4	30	153	3.01	148	5
5	30	157	3.02	149	8
6	30	156	2.59	149	7
7	20	155	3.11	136	19

Table 4: Heat loss in transit.

Excluding one outlier (load 3), asphalt mix heat losses (as measured with infrared cameras) from full loads averaged under 10°C, despite the fact that the average time spent in transit was almost 3 hours. The outlier at 19°C (load 7) was a lorry that was only two-thirds full.

Preheating

The two contractors in the trial took different approaches to preheating. One used preheating only on the adjacent asphalt along the longitudinal joint, using the SurfaceJet. The other decided in addition to this to preheat the entire milling area by having the SurfaceJet travel ahead of the asphalt paver. Both contractors also used joint heaters.

The measurements show that the SurfaceJet warmed the binder layer by approximately eight degrees Celsius, while the mean surface temperature directly preceding the paver was raised by four degrees. In the test section where no preheating was used the temperature before asphalting began averaged -3.9°C, from which it may be concluded that in sub-zero temperatures the SurfaceJet made a difference of approximately eight degrees in the temperature of the binder layer immediately in front of the paver. In preheating the edges of the milling area with the SurfaceJet infrared cameras were used to ensure that the established limit of 60°C was not exceeded.

[6] See also: André Dorée and Sergei Miller (University of Twente), 'Hot mix asphalt – the paving under sub-zero temperatures experience' (CROW Infradagen 23/24 June 2010).

Asphalting

The special measures taken when laying the asphalt were discussed in paragraph 3.4. The temperature of the mix immediately behind the screed was monitored continuously over the full width using infrared cameras. It is possible to determine the homogeneity of a surface course by analysing fluctuations in temperature.

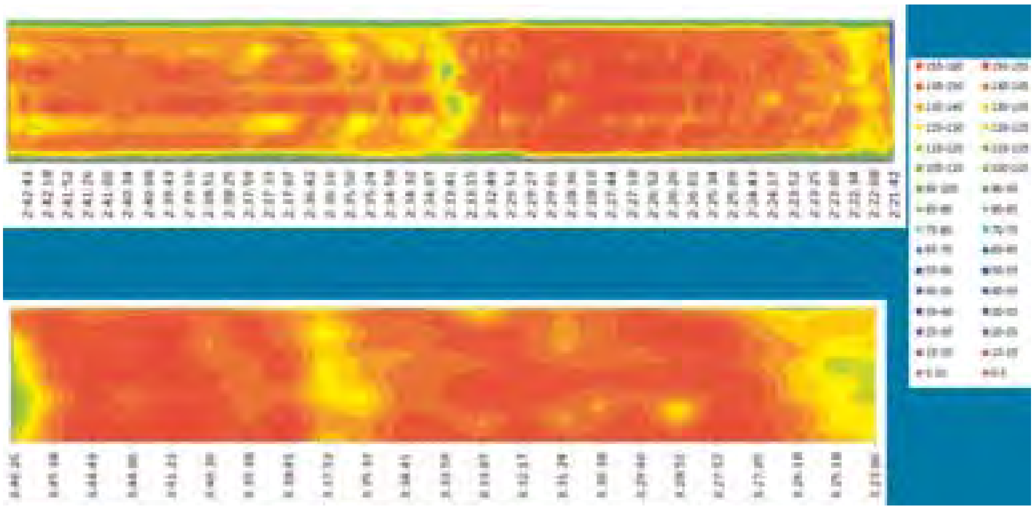


Figure 4: Temperature homogeneity when laying asphalt (temperatures in °C). (source: ASPARI, University of Twente)

Figure 4 shows clearly where each lorry-load was laid (red areas), but it also shows where the paver stopped, allowing the asphalt mix to cool down (yellow and green areas). Where the hopper became almost empty between two loads this led to heat loss and the risk of relatively weak patches in the surface course. Preheating of the longitudinal joint was also measured. It will be seen from Figure 5 that the average rise in joint temperature due to preheating was approximately 20°C. (The red line indicates the joint heater; blue shows the absence of joint heating on the open side, i.e. where there was no adjacent asphalt.)

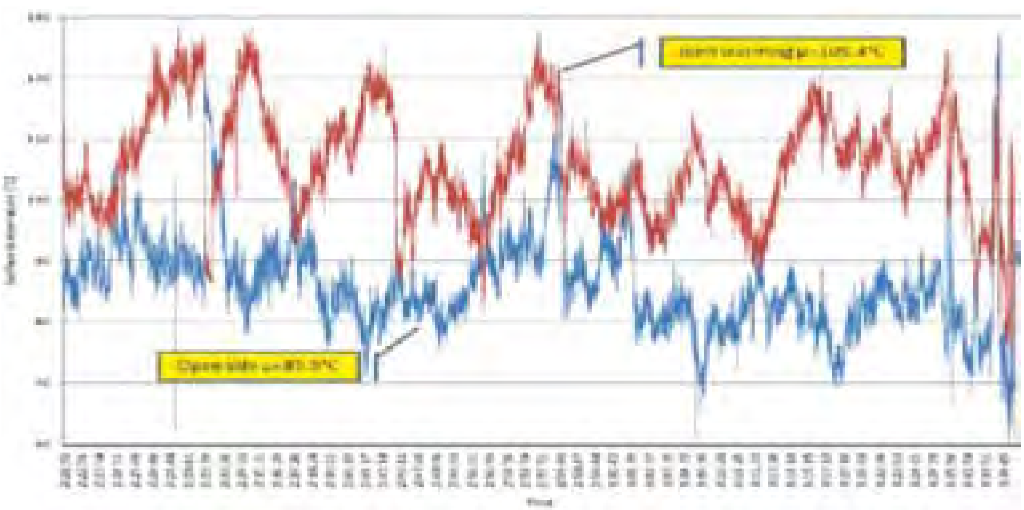


Figure 5: Preheating of the longitudinal joint: analysis. (source: ASPARI, University of Twente)

Compaction

The movements of both asphalt pavers and rollers were tracked by GPS. By analysing GPS and temperature data together it is possible to establish after the event whether the rollers have compacted the asphalt as evenly as possible within the optimum temperature window. Combining GPS and infrared readings produces compaction contour plots (CCP). In Figure 6, for example, it is possible to see that the first hundred metres of one of the two test sections received considerably fewer roller passes than the next two hundred metres.

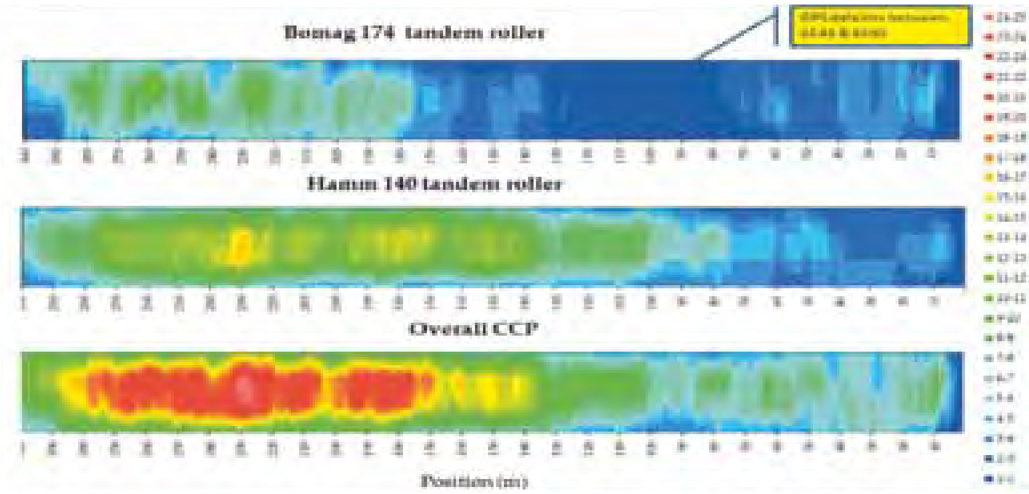


Figure 6: Compaction contour plots per roller and in total. (source: ASPARI, University of Twente)

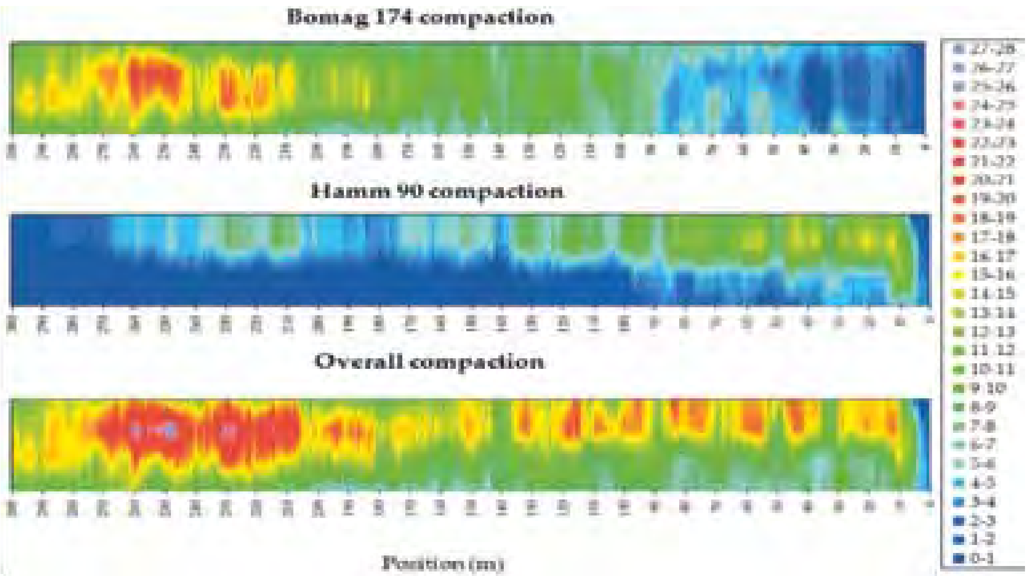


Figure 7: Compaction contour plots for the other test section. (source: ASPARI, University of Twente)

In addition to the static representations of the compaction process it was also possible to make animations; examples in Plates 19 and 20.

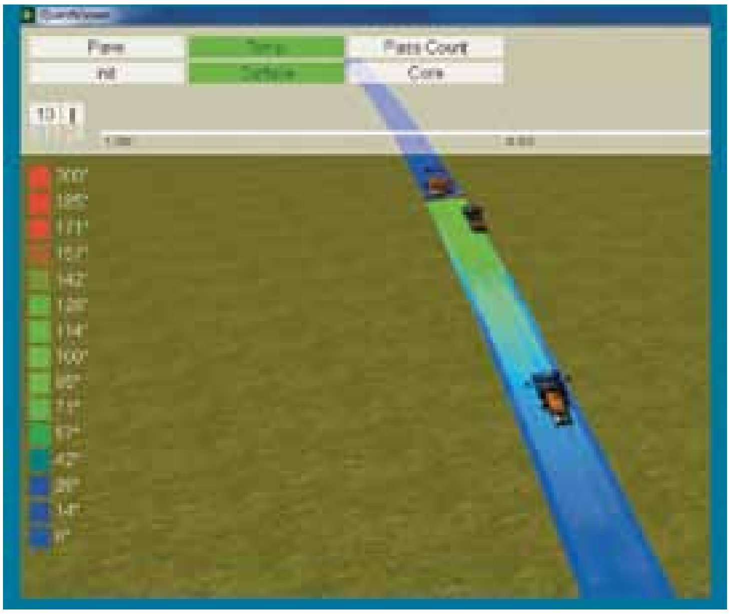


Plate 19: 3D animation of plant movements. (source: ASPARI, University of Twente)

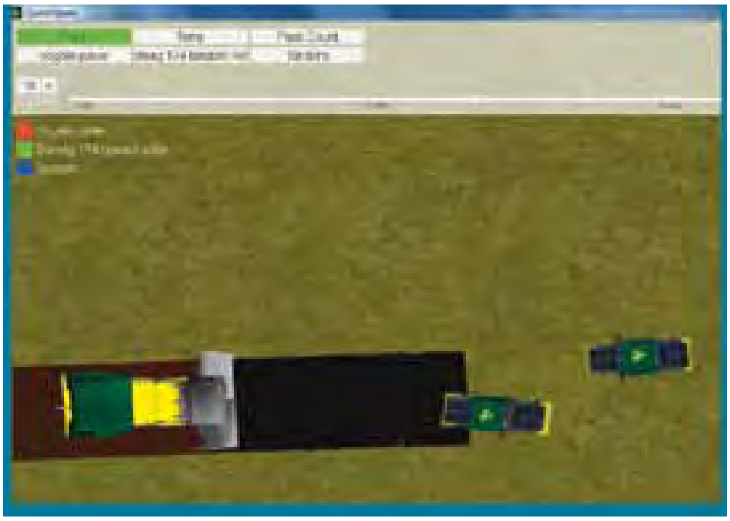


Plate 20: 2D animation of plant movements. (source: ASPARI, University of Twente)

From the tracking of plant movements it emerged that throughout the process of laying the test sections the asphalt pavers were able to maintain a reasonably constant speed, ranging from 5m/min to 5.8m/min. The exceptions were the stops of two minutes on average for taking on a new load of asphalt (on both test sections).

The rollers operated very close to the pavers. The monitoring shows that despite the instructions to the roller drivers the rolling patterns were not evenly distributed over the entire test section. In the work of one contractor there were differences over the length of the test section. In the work of the other there was greater compaction in the middle of the lane than at the edges.

It may be concluded that temperature homogeneity (Figure 4) was extremely good, and that the pavers were able to maintain a constant speed, but that in the compaction process there were still fluctuations that are susceptible of improvement.

4.3 Results of measurements on the finished test sections

A range of measurements and observations were carried out to gain an insight into the quality of the test sections. These began with skid resistance measurements and brake deceleration tests as a safety measure before opening the new surfaces to traffic. In addition, longitudinal eveness was measured and the ARAN was employed to carry out laser scans to identify any ravelling over the life of the sections. Core samples were also taken in order to determine ravelling and water resistance. Detailed visual inspections were conducted at various times. Taken together, the results of all these tests give an insight into the durability of these sections of road surface. We now proceed to a discussion of the design and results of the various measurements.

Plate 21: Pavement friction tester.

Skid resistance

Skid resistance measurements were carried out in conformity with test (proef) 150 of the Dutch national standard RAW 2005, except that measurements were taken at 70km/h instead of 50km/h. Water was sprayed in front of the test wheel, which had a friction resistance of 86%. The measured skid resistance of the test wheel was then converted into a pavement skid resistance value. Since the asphalt was laid in sub-zero conditions, the first measurement to determine whether the test sections could be opened to traffic was also carried out at about freezing point. According to the protocol for test 150 it cannot be carried out under 2°C, so the test was repeated as soon as temperatures rose. In this case that meant 16 March 2010.

Skid resistance (averages) contractor 1				
	t0 (20 February 2010)		t1 (16 March 2010)	
	Track R*	Track T*	Track R*	Track T*
0 – 100m	0.54	0.64	0.52	0.58
100 – 200m	0.58	0.68	0.52	0.56
200 – 300m	0.50	0.63	0.51	0.53
average	0.54	0.65	0.52	0.56

Skid resistance (averages) contractor 2				
	t0 (20 February 2010)		t1 (16 March 2010)	
	Track R*	Track T*	Track R*	Track T*
0 – 100m	0.53	0.57	0.53	0.57
100 – 200m	0.56	0.59	0.49	0.56
200 – 300m	0.54	0.62	0.49	0.55
average	0.54	0.59	0.50	0.56

* Track R is in the wheel tracks and Track T is between the wheel tracks. The discrepancies between R and T at t0 are curious, given that no traffic had yet passed over the test sections.

Table 5: Overview of skid resistance measurements on test sections.

New work is tested against the requirement for skid resistance of at least 0.44 (open wearing courses measured between the wheel tracks). The initial skid resistance of both test sections on the A58 when wet was in compliance with the standard. As observed above, the initial measurement was not itself carried out in accordance with the testing requirements, since both surface and air temperature are supposed to be +2°C. During the measurements the air temperature was 0°C and the road surface temperature 13°C. The follow-up measurements show that after three weeks pavement friction was of the same order as when the sections were reopened, and was therefore compliant.

Plate 22: A brake deceleration test in progress.

Braking tests

Braking deceleration tests were carried out on a closed lane. A car was brought to a standstill from 80km/h on a completely dry surface, with wheels locked (ABS off). Braking power was determined by measuring the braking distance. Both test sections passed the test, which requires braking of at least $5.2m/s^2$.

Braking deceleration test Contractor 1		
	t0 (20 February 2010)	**t1 (18 March 2010)**
Brake deceleration (av.)	6.35m/s^2	6.29m/s^2
Number of measurements	3	3
Braking distance at 80km/h	50.17m	49.30m

Braking deceleration test Contractor 2		
	t0 (20 February 2010)	**t1 (18 March 2010)**
Brake deceleration (av.)	6.27m/s^2	6.40m/s^2
Number of measurements	3	3
Braking distance at 80km/h	50.47m	48.70m

Table 6: Overview, braking deceleration test measurements.

Plate 23: Rolling straight edge.

Rolling straight edge

As part of the completion inspection longitudinal eveness was measured with a rolling straight edge in conformity with test 149 of the Dutch national standard RAW 2005. This is a standard procedure and is not discussed here since it is not expected to be relevant to the lower laying temperatures.

Plate 24: The Automatic Road Analyzer (ARAN).

ARAN inspections

When the lanes were reopened, and again after 6, 28 and 79 weeks, the ARAN was used to carry out laser measurements to determine whether ravelling had occurred in the meantime. The results of these measurements are summarized in Tables 7, 8 and 9. Blue denotes the PA+ test sections (A and B) and white the adjacent existing PA surfaces. The table values are also shown schematically in Figures 8-10.

test section	hm	1-3-210	13-4-2010	22-9-210	13-9-2011
	61.0	22.0%	20.5%	21.0%	44.0%
	61.1	32.0%	33.5%	29.0%	33.0%
B	61.2	7.5%	4.0%	3.0%	6.0%
B	61.3	7.0%	5.0%	1.0%	2.0%
B	61.4	7.0%	6.0%	0.0%	4.0%
	61.5	46.5%	39.0%	44.5%	40.0%
	61.6	51.5%	47.5%	48.5%	39.0%
	61.7	46.0%	48.0%	48.5%	25.0%
A	61.8	5.0%	2.5%	0.5%	3.0%
A	61.9	8.0%	5.5%	1.0%	3.0%
A	62.0	10.0%	2.0%	0.0%	0.0%
	62.1	44.0%	43.0%		
	62.2				

Table 7: Percentages of light ravelling per hm per measuring date.

test section	hm	1-3-210	13-4-2010	22-9-210	13-9-2011
	61.0	1.5%	0.0%	1.0%	7.0%
	61.1	2.0%	1.0%	3.0%	12.0%
B	61.2	0.0%	0.0%	0.0%	1.0%
B	61.3	0.0%	0.0%	0.0%	0.0%
B	61.4	0.0%	0.0%	0.0%	1.0%
	61.5	9.0%	8.5%	13.0%	33.0%
	61.6	11.0%	13.0%	21.5%	50.0%
	61.7	13.5%	18.5%	25.0%	61.0%
A	61.8	0.0%	0.0%	0.0%	0.0%
A	61.9	0.5%	0.0%	0.0%	0.0%
A	62.0	1.0%	0.0%	0.0%	0.0%
	62.1	8.0%	9.5%		
	62.2				

Table 8: Percentages of moderate/serious ravelling per hm per measuring date.

test section	hm	1-3-210	13-4-2010	22-9-210	13-9-2011
	61.0	4.1%	3.8%	4.1%	6.2%
	61.1	4.7%	4.5%	4.7%	6.0%
B	61.2	2.6%	1.8%	1.7%	2.6%
B	61.3	2.8%	2.5%	1.5%	2.0%
B	61.4	2.5%	2.3%	1.4%	2.2%
	61.5	6.3%	5.9%	6.4%	8.7%
	61.6	6.8%	6.8%	7.2%	10.8%
	61.7	6.6%	7.2%	8.0%	12.1%
A	61.8	2.3%	1.5%	1.0%	1.4%
A	61.9	2.7%	2.1%	0.8%	1.6%
A	62.0	3.0%	1.8%	0.7%	0.9%
	62.1	5.8%	5.9%		
	62.2				

Table 9: Average percentage stone loss per hm per measuring date.

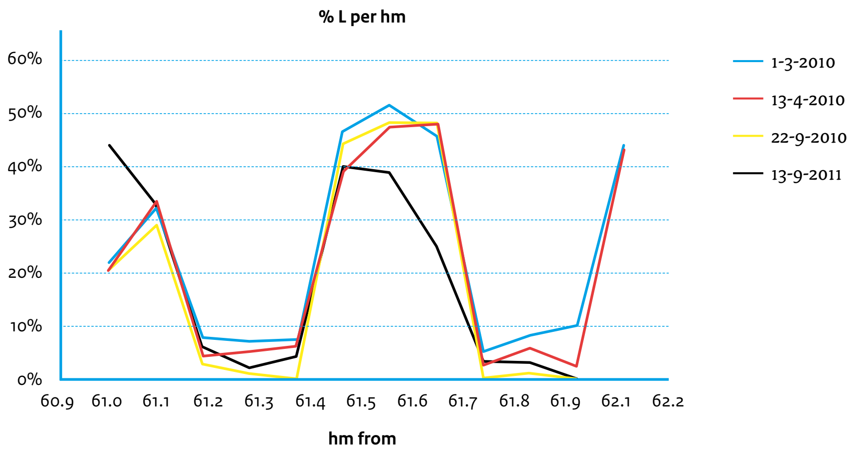


Figure 8: Percentages of light ravelling per hm per measuring date.

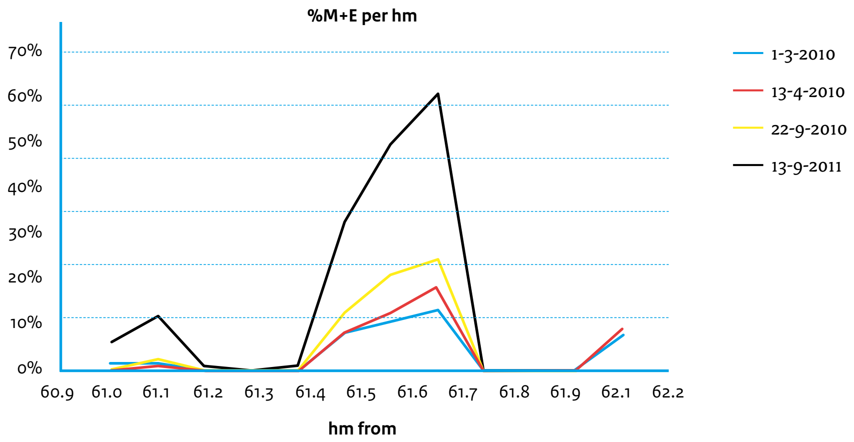


Figure 9: Percentages of moderate/serious ravelling per hm per measuring date.

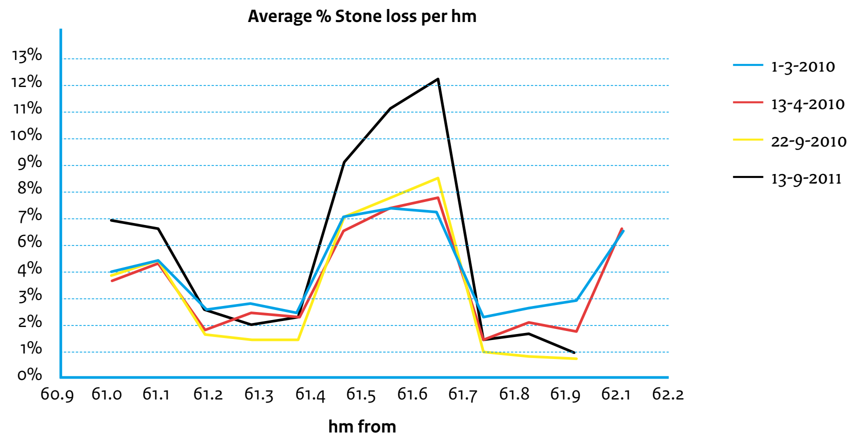


Figure 10: Average percentage stone loss per hm per measuring date.

The laser measurements (see Figure 8) show that the percentage of light ravelling on the test sections is very low and considerably lower than on the adjacent existing PA areas. Nevertheless, there does appear to be a downward trend in the test sections in the first six months, followed by a rising trend. This effect appears not to exist in the adjacent sections. One explanation for the apparent decline in ravelling at the start may be abnormal reflections on newly laid PA due to the gloss of bitumen and/or the presence of blinding material or chippings. Once the mastic film has been weared off the laser saw ravelling develop according to the pattern expected: a very limited increase is seen some six months after the initial decline in measured ravelling. The percentage of moderate and severe ravelling is zero for both test sections. Figures 9 and 10 also show that there was virtually no ravelling in the test sections; this is in line with experience on PA sections laid under normal weather conditions.

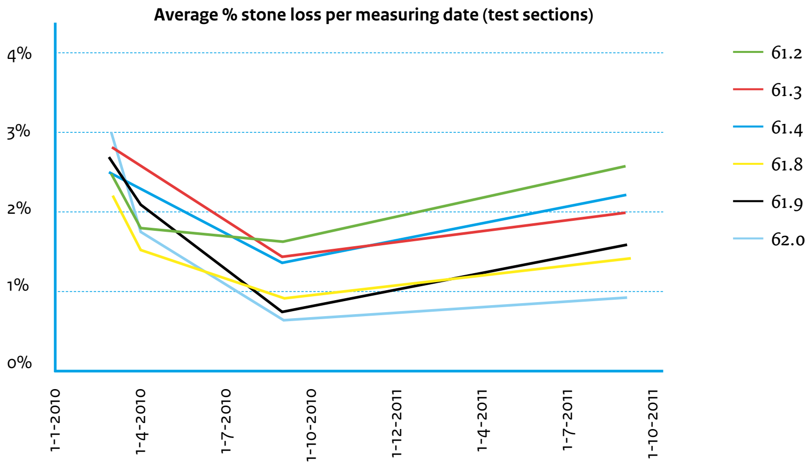


Figure 11: Average percentage stone loss in the test sections.

The Stoneway data were additionally used to derive the average stone loss per ten metres in both left and right wheel track and both within and outside the test sections. From Figure 11 it will be seen that in the test sections there was some increase over time, though this was very slight – certainly when compared with the sections outside the trial area (here the increases were in the range 2-6%).

The overall conclusion is that more than eighteen months after construction there was no sign whatsoever of premature ravelling in the PA+ test sections laid in below-zero conditions.

Plate 25: A laser on the ARAN.

Results of core samples

A total of thirty core samples[7] were taken from each test section. These were used for a range of tests:

- 6 cores (Ø 150mm) for the Rotating Surface Abrasion Test (RSAT) as per Breijn testing protocol (test protocol Breijn);
- 18 cores (Ø 100mm) for the Cantabro and indirect tensile strenght ratio (ITSR);
- 6 cores (Ø 100mm) as quality controls for the contractor.

The averaged results of these tests (apart from the quality controls) are summarized in Table 10. Below is an interpretation of these results, where possible contrasted with data from conventionally laid highway sections.

Averaged results of tests on PA+ cores, A58

	Stone loss RSAT (g)	Stone loss Cantabro (g)	Indirect tensile strength (MPa)	Indirect tensile strength after conditioning in water (MPa)	ITSR(%)
Contractor 1	17.0	47.4	1.15	0.99	86.2
Contractor 2	9.3	37.6	0.91	0.74	81.4

Table 10: Results of core sample testing.

RSAT

The Rotating Surface Abrasion Test is designed to determine resistance to ravelling. Six cores of 150mm diameter were investigated per mix or road section. Usually the RSAT is conducted on asphalt slabs removed from a site and prepared in the laboratory. However, removing slabs from a road is both difficult and undesirable, so in this case the decision was taken to carry out the RSAT on core samples, using three samples to make one test specimen. It should be noted that the results of RSAT testing on core samples cannot be compared with those obtained from slabs and therefore cannot be assessed by comparing them with the figures cited in the paper CROW Infradagen 2008 'Classificatie van asfaltmengsels met behulp van de RSAT proef'[8].

[7] The core sampling plan appears as appendix 2.

[8] J.M. Hartjes and J.L.M. Voskuilen, 'Classificatie van asfaltmengsels met behulp van de RSAT proef' (Classification of asphalt mixes by the RSAT test), paper CROW Infradagen 2008.

Nevertheless these results can be compared with earlier RSAT research using PA+ core samples from test sections of the A2 (PA+ proefvakken A2 Verbetering Aanvangsstroefheid, 2007[9]). This also used test specimens consisting of three bore samples taken together instead of an asphalt plate. Table 11 shows the results of the five PA+ test section mixes examined then. The result of the sixth mix is disregarded because this was a different mix with an experimental filler. The five PA+ mixes in Table 11 were laid under normal weather conditions and were gritted to improve their initial skid resistance. The RSAT results of the five PA+ mixes can be used to test whether the ravelling resistance of the trial mixes laid in below-zero conditions corresponds to that of PA+ laid under normal weather conditions.

Results of RSAT tests of PA+ trial sections, A2 near Eijsden (reference)

PA+ mix	Stone loss RSAT (g)
PA+ gritted with 200g/m² crusher sand	49
PA+ gritted with 100g/m² Neorough	38
PA+ gritted with 200g/m² Neorough	53
PA+ gritted with 300g/m² Neorough	54
PA+ reference (ungritted)	64

Table 11: Results of RSAT on reference road sections.

The comparison with the results of the RSAT tests on PA+ test specimens from the A2 demonstrates that the ravelling resistance of the PA+ laid below 0°C is better and that test section mix scores can vary.

Plate 26: Core sample Ø 150mm.

Cantabro

Abrasion resistance was determined by the Cantabro test in conformity with NEN-EN 12697, part 17, after 300 revolutions at a testing temperature of 18°C. It is customary to conduct the Cantabro test on test specimens prepared in the laboratory, but because in this case the purpose was to determine the properties of PA laid at sub-zero temperatures the test was carried out on core samples from the test sections. In the Netherlands the Cantabro test had previously been used mainly on specimens of asphalt compacted by the Marshall method.

9 Van Kleef, 'Onderzoeksrapport aanvangsstroefheid ZOAB+ Proefvak A2 bij Eijsden' (Research report: initial skid resistance of PA+ trial section, A2 near Eijsden) (7 April 2008).

In the DWW project Hergebruik ZOAB[10] a requirement (material loss = 30%) was specified for the Cantabro test on Marshall compacted PA specimens. It is well established that the results of the Cantabro test when carried out on Marshall specimens cannot be compared with those from core samples as the latter have a different type of edge and are therefore more vulnerable to loss of material. There is no material loss requirement for a Cantabro test carried out on core samples, but the results can still be compared with Cantabro tests carried out in the past on core samples from PA+ test sections.

The research report 'Gaat gemodificeerd PA langer mee?'[11] (Does modified PA last longer?) included Cantabro results after 200 instead of 300 revolutions for core samples of PA+ with organic fibres (98.4g), PA+ with inorganic fibres (35.6g) and PA+ with Polybilt 103Z (30.3g). It is legitimate to suppose that material losses will be higher after 300 revolutions. This means that the mass loss performance of the PA+ mixes that were laid under sub-zero conditions – 47.4 and 37.6g (see Table 10) – is more or less in the same bracket as that of PA+ core samples investigated hitherto. However, since it has also been concluded that the power of the Cantabro test to predict performance in practice is slight, it is not possible to conclude that the ravelling resistance of the tested PA+ mixes is sufficient. On the other hand it is possible to say that the Cantabro results of the new core samples lie in the same range as those found earlier with PA+ that was performing well.

ITSR

To determine water sensitivity, tests for indirect tensile strength were conducted on unconditioned and water-conditioned core samples. The ITSR (Indirect Tensile Strength Ratio, the ratio between the indirect tensile strength of unconditioned and water-conditioned core samples) establishes the sensitivity to water of the PA+ as prescribed by NEN-EN 12697, part 12. The requirement of ISTR80 for the sensitivity to water of PA as set out in RAW 2010 applies to mixtures compacted by a gyratory compactor, so that the results of the test on core samples can only be interpreted as indicative. If it is assumed that, as a result of being drilled through, core samples will automatically give a worse result, it may be concluded that the PA+ mixes laid below freezing point offer good resistance to water sensitivity.

Plate 27: Core sample 100mm.

The core sample tests lead to a general conclusion. On the basis of the new RSAT, Cantabro and ITSR results it is now established that the mechanical properties of PA+ immediately after it has been laid at below 0°C are comparable to those of PA+ immediately after it has been laid under normal weather conditions. This observation opens perspectives for behaviour in the longer term, since the fact that a combination of three different tests points in the same direction gives confidence in the durability of such mixes laid in such conditions.

[10] W.J. Bak, M. Kooiman, Projectgroep Hergebruik ZOAB (PA recycling project group), 'Hergebruik ZOAB. Dat gaat zo!!' (Recycling PA: Here's how!!), RWS DWW 1998.

[11] E.R.P. Rutten, J.L.M. Voskuilen and F. Tolamn, 'Gaat gemodificeerd ZOAB langer mee?' (Does modified PA last longer?), DWW-2002-013, Rijkswaterstaat, 2002.

Visual inspection

An extensive visual inspection of the test sections was carried out by SGS on 6 December 2010. In summary, the results were as follows:

- In both sections there were visible signs of incipient ravelling: in one section about five stones per square metre had been lost, in the other fewer than five. This is in line with the usual picture;
- In some places there was visible inhomogeneity in the surface structure, something that for a variety of reasons is not, in itself, uncommon. In most cases it has no effect on PA performance;
- No cracking was observed;
- Visible bleeding was encountered in only a few patches (no larger than 5 x 5 cm): over both sections taken together about fifteen to twenty;
- Surface density had increased in a few places (approximately 1 sq.m each);
- No appreciable deviation in transverse evenness was measured. Maximum irregularity was 0.2mm;
- The sites from which the core samples were taken continued to look good, with no ravelling worth mentioning.

The last visual inspection was carried out by SGS on 26 September 2011. (This was shortly before the test sections were removed in the course of a reconstruction.) In a limited area of the road no observations were possible due to the presence of a barrier. The results were:

- In one section there was a slight increase in ravelling;
- There were a few isolated patches where the stones had disintegrated;
- The last metre of one of the test sections had become blocked;
- There was some mechanical damage due to an accident;
- No cracking was observed;
- There was no increase in transverse irregularity.

Visual observations by the road operator have also shown that even on the adjacent old PA there was no premature ravelling due to roller damage. The general conclusion from the visual inspections is that while one was marginally better than the other, both test sections were in good condition. This picture corresponds to PA+ that has been laid under normal weather conditions.

4.4 Technical conclusions from the trial under operating conditions

Construction of the test sections in the A58 trial was successfully completed. Both test sections met the requirements established beforehand, and the results of the largely mechanical tests immediately after construction paint a picture in which the mechanical properties of PA+ when laid at sub-zero temperatures correspond to those of asphalt laid under normal conditions. Although the absence of a reference section of road (i.e. the same mixes laid under normal conditions) means that this is not a matter of an open-and-shut case, it is nevertheless possible to conclude that the steps taken to accommodate the conditions of operating in below-zero temperatures successfully contributed to achieving a qualitatively high-performing wearing course of PA+.

Although the trial sections were still in excellent shape after over eighteen months, the relatively short period of the trial makes drawing firm conclusions about long-term performance inadvisable. The effect of rapid cooling of the asphalt on the chemical and physical behaviour of the bitumen at the micro level is difficult to determine or predict at the laboratory level. In short, the trial sections were not in service for long enough for it to have been possible to predict its ultimate life had it been left to its own devices, but the results that have been achieved thus far give confidence that the quality achieved was sufficient.

Many of the measures implemented in this trial, e.g. steps to protect adjacent older asphalt, the use of an integral binder spray bar on the asphalt paver, and visualization of the compaction process with GPS and infrared asphalt temperature sensing, may also prove useful for asphalting under normal weather conditions.

5 Recommendations

5.1 When to lay asphalt at low ambient temperatures

The A58 trial demonstrates that laying asphalt at low ambient temperatures without prejudice to quality comes within reach when special measures are implemented during both the production and the laying of the asphalt. Provided the right steps are taken, even the adjacent old asphalt need not suffer premature ravelling. The conclusion is that asphalting remains one of the options for effecting immediate yet permanent repairs in the event of frost damage in the form of excessive ravelling.

Laying asphalt at low ambient temperatures can offer the following benefits relative to existing methods of repair:
- The repair is permanent and causes less disruption to traffic compared with taking temporary measures and subsequently having to replace them with a permanent solution;
- If a wearing course needs to be milled off for safety reasons, traffic no longer has to be held up by a speed limit for the duration of a prolonged period of cold weather, as in the past, because a remove-and-replace operation can now be carried out even at low temperatures;
- It is considerably safer for roadworkers and highway authority employees if they do not constantly have to be on the road to effect temporary repairs;
- In short, laying asphalt at low ambient temperatures promotes road safety and traffic mobility.

The method has the following disadvantages:
- The cost of laying asphalt at low ambient temperatures is higher than that of asphalting under normal conditions. Any financial benefit consists solely in not having to return to the site later to effect a permanent repair;
- Asphalting below zero entails greatly higher energy consumption relative to working under normal weather conditions;
- The SurfaceJet causes a considerable amount of noise;
- The additional measures that have to be taken for asphalting at low temperatures need to be implemented with care. Mistakes can greatly compromise the result;
- Working conditions for roadworkers are more onerous;
- Given the limited experience so far gained with asphalt paving at low ambient temperatures we cannot yet be sure that surface durability will be comparable with that for surfaces laid under normal weather conditions.

For these and other reasons Rijkswaterstaat stresses that it has no plans to commission normal road surface maintenance work during the winter period, but as an alternative to having motorists drive over stretches of unfinished road surface or to first carrying out temporary repairs and then having to come back to ‘finish the job’, PA+ can be laid at low temperatures with good prospects of maintaining long-term quality.
The requirements are:
- Temperatures not below -5°C, little or no wind, no precipitation forecast (check local weather forecast, online weather radar service etc.), no mist or fog;
- Sections of roads which require milling for road safety reasons (excessive ravelling, but e.g. also sites where damage tends to propagate alongside earlier repairs).

5.2 Cost aspects, sourcing

The cost of laying asphalt at sub-zero temperatures requires the following aspects to be taken into consideration:

- A certain minimum length of road is needed for the process to be cost effective: the longer the stretch of road to be laid, the smaller the proportion of the total contract sum that is accounted for by the special measures. This minimum is something of the order of one kilometre, one lane wide, laid at night. Special circumstances (e.g. a major accident on a major motorway) may also justify employing the method for shorter stretches of road;
- The effect of the situation on traffic mobility must be considered. The more traffic flows are disrupted by frost damage or accidents in a period of freezing conditions, the sooner laying asphalt below zero will become a viable option: hence the busiest roads and junctions will be the first to become eligible.
- Maintenance planning for lanes adjacent to and road stretches ahead of or behind the section in question, as set out in the government's long-term planning of road surfacing recommendations (MJPV), is one of the factors determining whether any additional costs of a seven-year warranty would be value for money or whether it would be sufficient to opt for a more short-term solution;
- Carrying out the work at night (one lane at a time) where the carriageway is lighted (this also means the busiest roads) in order to eliminate the high cost of using temporary floodlighting.

The minimum stretch length of 1km one lane wide is only an indication and depends strongly on the situation at the site. For example, suppose there are two areas of damage of 150 metres separated by 200 metres scheduled for maintenance in two years: here it is possible to justify a 500 metre remove-and-replace operation. In other words, the chronological remoteness of planned maintenance on the intervening stretch may play a part. Another example might be rapid propagation of damage, as a result of which one day holes are repaired and the next day there are new holes to be repaired between those repaired on the first day. Here again, even a relatively short stretch may be considered for resurfacing even though the temperature is below zero.

In short, the decision to lay asphalt at low ambient temperatures as an alternative for temporary repairs or having traffic use a milled and unsurfaced road can never be taken on the basis of a single unambiguous criterion. It will always be necessary, then, to discuss each individual situation in advance with the relevant highway maintenance planning department.

In the Netherlands there are no framework agreements under which contractors and asphalt mixing plants are contracted on an on-call basis to lay asphalt at low ambient temperatures. Instead, the modus operandi as regards sourcing is that it is conducted in accordance with the emergency clauses of performance contracts.

Appendices

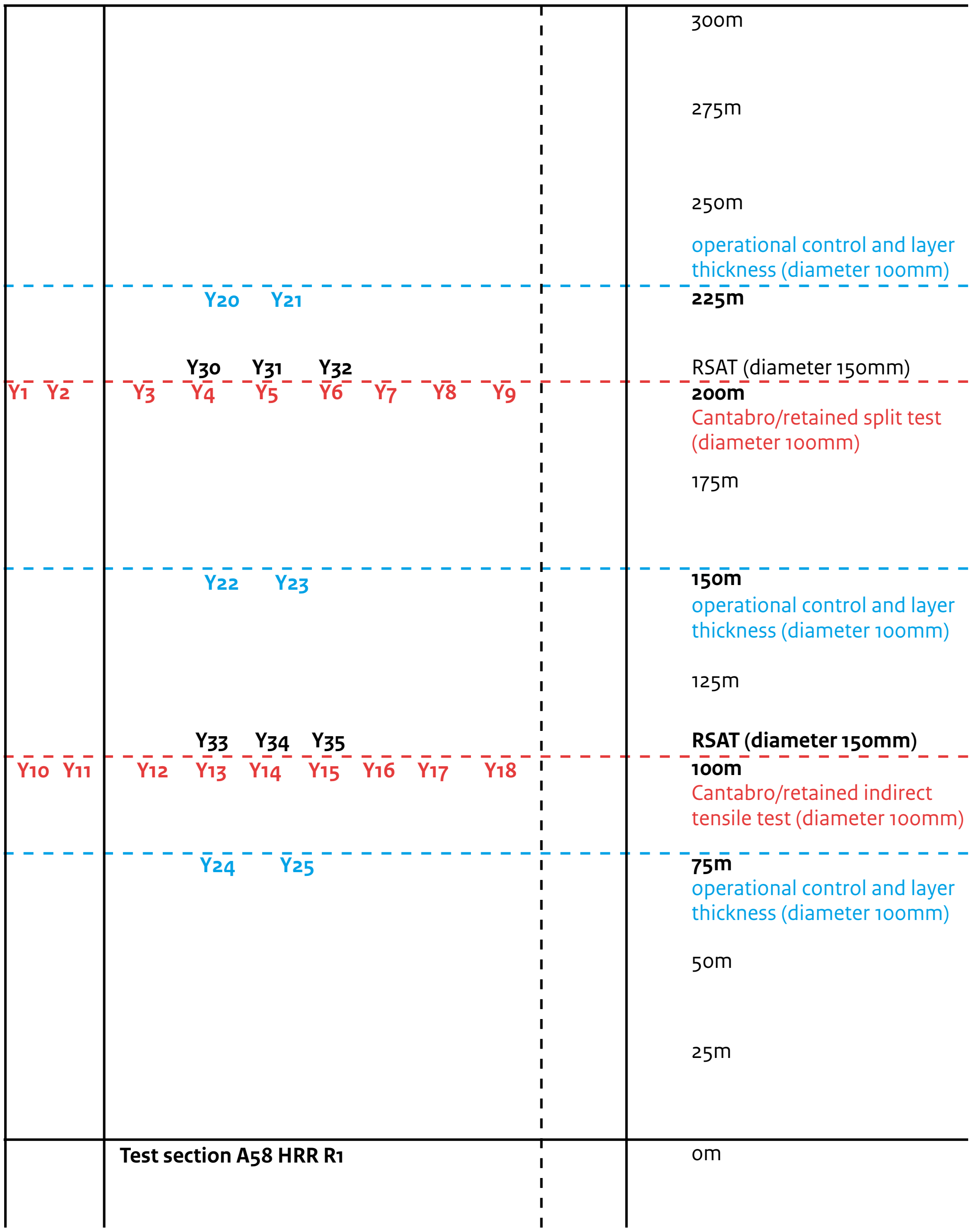
Appendix 1

List of abbreviations and acronyms

AMI	Asfalt Menginstallatie, Asphalt Mixing Plant
ARAN	Automatic Road Analyzer
ARBO	Arbeidsomstandigheden (working conditions legislation)
ASPARI	Asphalt Paving Research & Innovation, University of Twente
CCP	Compaction Contour Plots
DVS	Dienst Verkeer en Scheepvaart (Centre for Traffic and Navigation)
DWW	Dienst Weg- en Waterbouwkunde (Road and Hydraulic Engineering Division)
GMS	Gladheids Meldsysteem (road ice alert system)
GPS	Global Positioning System
HMA	Hot Mix Asphalt
ITC	Innovatie Test Centrum (Innovation Test Centre)
ITSR	Indirect Tensile Strength Ratio (of conditioned test specimens)
KOAC NPC	Netherlands Institute for Materials and Road Engineering Research
MJPV	Meer Jaren Plannen Verhardingsadvies
NAPA	National Asphalt Pavement Association (US)
PERS	Poro Elastic Road Surface
RAW	Rationalisatie en Automatisering in de Grond- Weg- en Waterbouw
RSAT	Rotating Surface Abrasion Test
RWS	Rijkswaterstaat
SHW	Specifications for Highway Works (Highways Agency, UK)
TNO	Dutch independent technical research organization
WMA	Warm Mix Asphalt
PA	Zeer Open Asfalt Beton (Porous Asphalt)
PA+	Durable PA

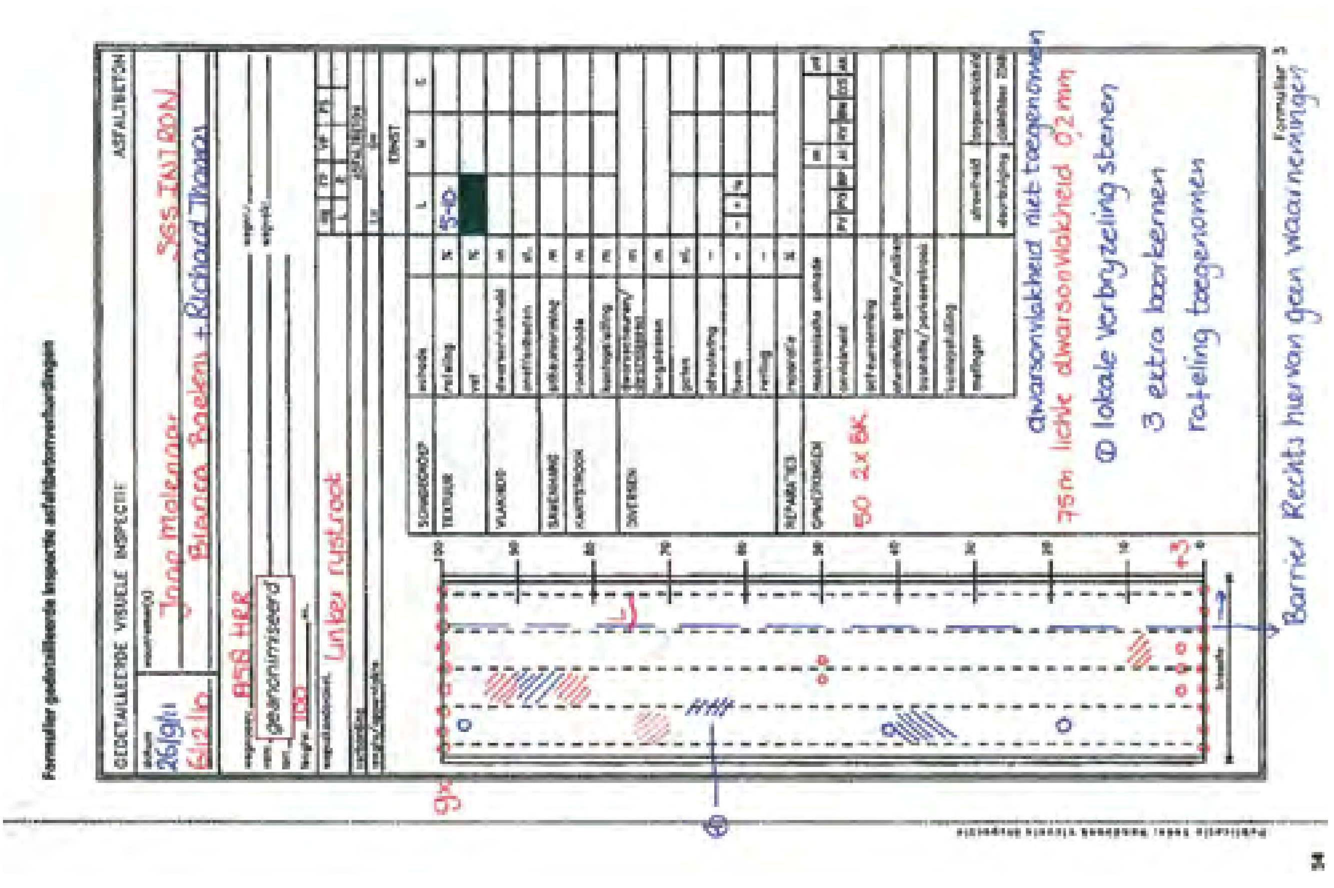
Appendix 2

Core sampling plan



Appendix 3

Visual inspections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ASFALTBETON
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Jaap Molenaar
SGS INTRON
Bianca Baeten + Richard Thomas
A58 HRR
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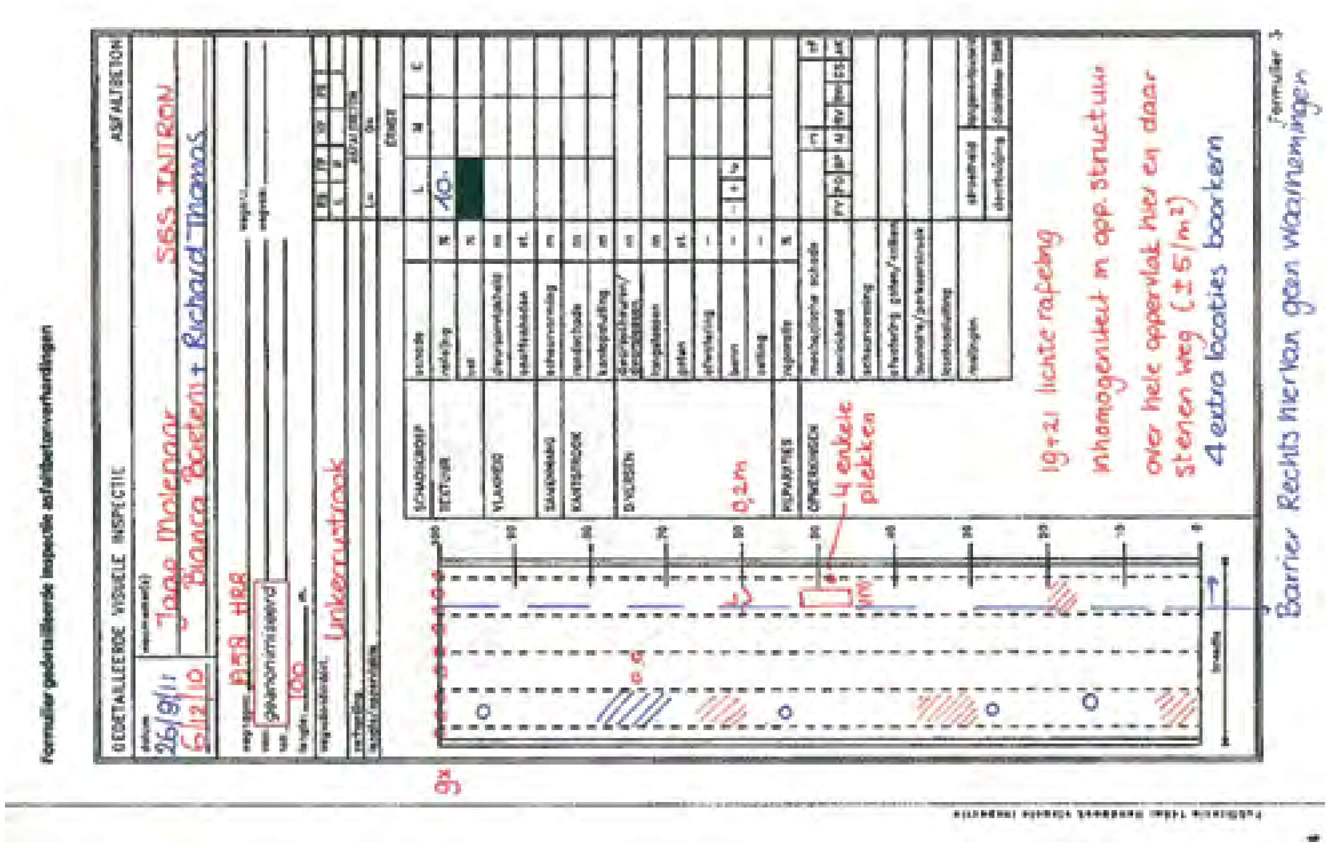
Barrier Rechts hiervan geen waarnemingen
Formulier 3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26/9/11
6/12/10
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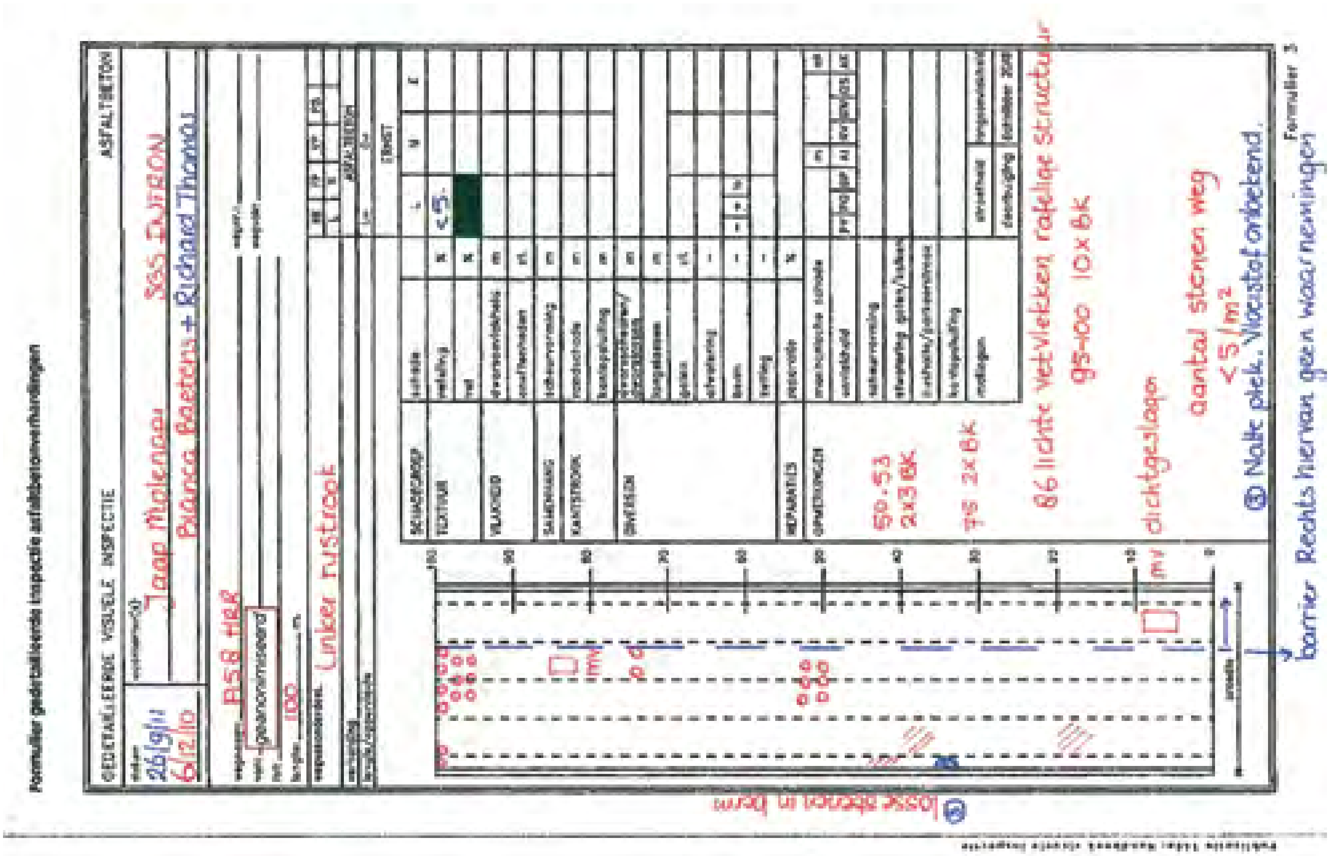
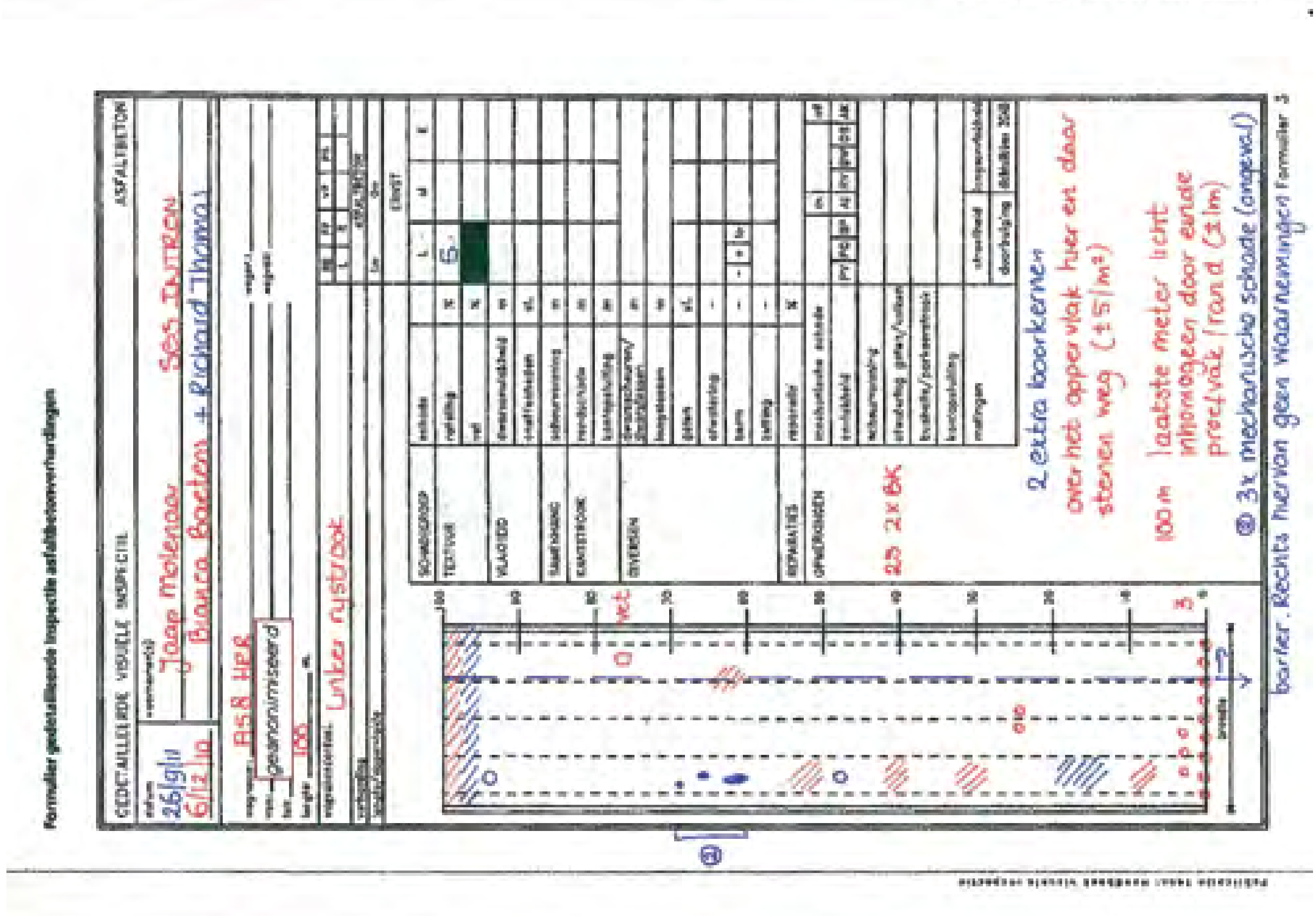
SGS INTRON
Bianca Baeten + Richard Thomas
A58 HRR
geanonimiseerd
100
Linkerrijstrook
10
0,2m
4 enkele plekken
19+21 lichte rafeling
inhomogeniteit in opp. structuur
over hele oppervlak hier en daar stenen weg (±5/m²)
4 extra locaties boorkern
Barrier Rechts hiervan geen waarnemingen
Formulier 3

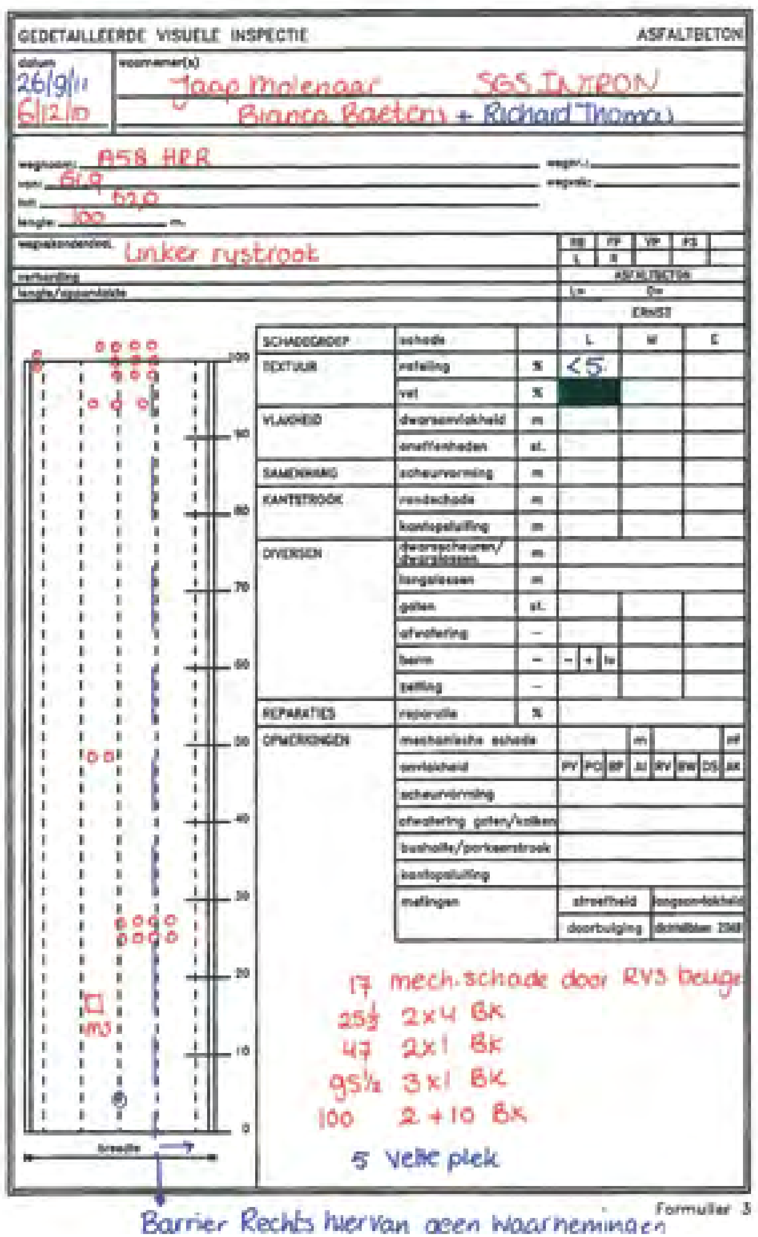


Formulier gedetailleerde inspectie asfaltbetonverhardingen
GEDETAILLEERDE VISUELE INSPECTIE
ASFALTBETON
26/9/11
6/12/10
Jaap Molenaar
SGS INTRON
Bianca Baetens + Richard Thomas
R58 HRR
geanonimiseerd
100
Linker rijstrook
50-53 2x3 BK
78 2x BK
86 lichte vetvlekken rafelige structuur
95-100 10x BK
dichtgeslagen
aantal stenen weg <5/m²
barrier Rechts hiervan geen waarnemingen
losse stenen in berm
Formulier 3



Formulier gedetailleerde inspectie asfaltbetonverhardingen
GEDETAILLEERDE VISUELE INSPECTIE
ASFALTBETON
26/9/11
6/12/10
Jaap Molenaar
SGS INTRON
Bianca Baetens + Richard Thomas
R58 HRR
geanonimiseerd
100
Linker rijstrook
vet
25 2x BK
2 extra boorkernen
over het oppervlak hier en daar stenen weg (±5/m²)
100 m laatste meter licht ingenomen door einde prefvak / rand (±1m)
barrier. Rechts hiervan geen waarnemingen
Formulier 3

Formulier gedetailleerde inspectie asfaltbetonverhardingen



GEDETAILLEERDE VISUELE INSPECTIE — ASFALTBETON

datum: 26/9/11, 6/12/10

waarnemer(s): Jaap Molenaar SGS INTRON, Bianca Baetens + Richard Thomas

wegnaam: A58 HRR

van: 61.9

tot: 62.0

lengte: 100 m

wegvakonderdeel: Linker rijstrook

17 mech. schade door RVS beugel
25½ 2x4 BK
47 2x1 BK
95½ 3x1 BK
100 2+10 BK

5 vette plek

Barrier Rechts hiervan geen waarnemingen

Formulier 3

Formulier gedetailleerde inspectie asfaltbetonverhardingen

GEDETAILLEERDE VISUELE INSPECTIE — ASFALTBETON

datum: 26/9/11, 6/12/10

waarnemer(s): Jaap Molenaar SGS INTRON, Bianca Baetens + Richard Thomas

wegnaam: A58 HRR

van: geanonimiseerd

lengte: 100 m

wegvakonderdeel: Linker rijstrook

25 2x1 BK
50 2x4 BK
90 inhomogeen oppervlak + dichtgeslagen

laatste meter dichtgeslagen opp.

Ⓐ lokale oneffenheid

Formulier 3

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