Winter problems with Porous Asphalt in the Netherlands

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ABSTRACT: Since 1987 Porous Asphalt (PA) is applied on Dutch motorways, firstly because of safety reasons but since 1990 noise reduction was the main reason.
In 2009 about 80% of the total surface of the Dutch motorways was covered with PA. The end of service life of PA is mainly determined by the loss of too much stones from the surface, called raveling. The average service life of PA is on the slow lane 12 years and on the fast lane 16 years.
Normally due to the mild sea climate the winters in the Netherlands are quite soft, but the first weeks of 2009 the temperatures in the Netherlands were significant lower than normal. In that time on much locations premature raveling and potholes developped in road sections with PA. The potholes were repaired with cold or mastic asphalt, but road sections with severe raveling couldn't be repaired because of the too low temperatures. Because of safety reasons on some locations the total layer of raveled PA was milled and the traffic had temperory to drive on milled asphalt with a speed limitation until the temperatures were suitable to lay new PA again.
In this paper possible causes of frost damage in PA will be discussed and recommendations will be given to reduce frost damge as much as possible.

KEY WORDS: Porous Asphalt, winter damage, raveling. maintenance

1 INTRODUCTION

1.1. General background

A frost period in the winter increases the possibility of premature damage, specifically on wearing courses. Frost damage manifest itself mainly in the form of excessive loss of stones, leading to serious raveling, open and/or widening of transversal and longitudinal joints and potholes in the pavement. The stronger the frost period and the older the wearing course, the more extensive this frost damage will reveal itself. Every type of wearing course that approaches the end of its particular service life is more sensitive to frost damage. Wearing courses with an open structure, like Porous Asphalt (PA), are much more sensitive to frost damage than dense wearing courses. The frost damage of open wearing courses can develop much more aggressive in time in comparison with dense wearing courses.

Loss of stones, serious raveling, widening of longitudinal joints and potholes are negative for the safety and comfort of the road user. Therefore this type of damage requires a fast and adequate action of the road authority in order to avoid accidents. In cases where in a short period of time on relatively many locations simultaneous damage occurs, the attention of the press will also be drawn. Negative publicity will probably be the consequence. Besides that the road authority can be charged by claims of road users when they have damage caused by frost damage of asphalt wearing courses. All these aspects ask for extra attention of the road authority during a frost period, especially if open wearing courses are a large part of the covered surface.

1.2. Background of Porous Asphalt in the Netherlands.

Since 1987 PA is applied in the Netherlands as a wearing course on motorways. First PA was primarily used to reduce the amount of accidents with 50%. However, it was found out soon that PA was in reality not safer than Dense Asphalt Concrete (DAC) with regards to the number of accidents. The reason why PA was not safer than DAC was that road users drive at higher speeds during rainfall on PA road sections in comparison with DAC road sections. PA is safer under the same rainy conditions and same speed because aquaplaning doesn’t occur on PA and PA reduces splash and spray during rainfall, but the extra safety is consumed by faster driving during rainfall. A benefit is that the capacity of PA road sections is much higher during rainfall. Since 1990 the main reason to apply PA is noise reduction.

In the Netherlands no studded tires and snow chains are allowed.

The standard wearing course in the Netherlands is single-layer PA (SLPA) 16 with a layer thickness of 50 mm and an air voids content of 20%. It produces 4 dBA less noise under traffic in comparison with DAC. The end of service life of PA is determined by the loss of too much stones from the surface, called raveling. The average service life of PA is 11 years for the slow lane (heavy traffic) and 16 years on the fast lane. Since 2007 a more durable PA (PA+) is applied and this is now the standard wearing course in the Netherlands (Voskuilen, 2004). In comparison with the old standard PA with 4.2% bitumen (pen grade 70/100), PA+ contains 5.2% bitumen in the mix and drainage inhibitors. The service life of PA+ is 2 to 3 years langer thann standard PA.

Since 2005 it is also allowed to use Two-Layer PA (TLPA) on the Dutch motorways. The 25 mm thick top-layer is a PA 8 and the 45 mm bottom-layer is a PA 16. The average service life of the more expensive TLPA (8 years) is much shorter than SLPA, but the noise reduction in comparison with DAC is much better (6 dBA). It is only allowed to apply TLPA if it can be proven that TLPA is cost-effective. This can only be achieved, if alternative costs of noise barriers can be saved. In 2009 approximately 90% of the total surface of the Dutch motorways was covered with PA, of which about 5% is TLPA.

1.3 Climate in the Netherlands

The Netherlands has a soft sea climate. The average month temperature is around 17ºC in July and around 3ºC in January. Normally the winters are quite soft, but the first weeks of 2009 the temperatures in the Netherlands were significant lower than normal. The probability of such a period is statistically seen once in the 10 years. The lowest temperature in January was -20ºC. The frost period was followed by a frost/thaw period. During this period extensive frost damage was observed.
Figure 1 (Hagos, 2008) gives the temperatures for the year 2003. The minimum and maximum temperatures for each month are given and also the mean monthly temperatures for 2003 are compared with the mean temperatures over a period of 25 years.

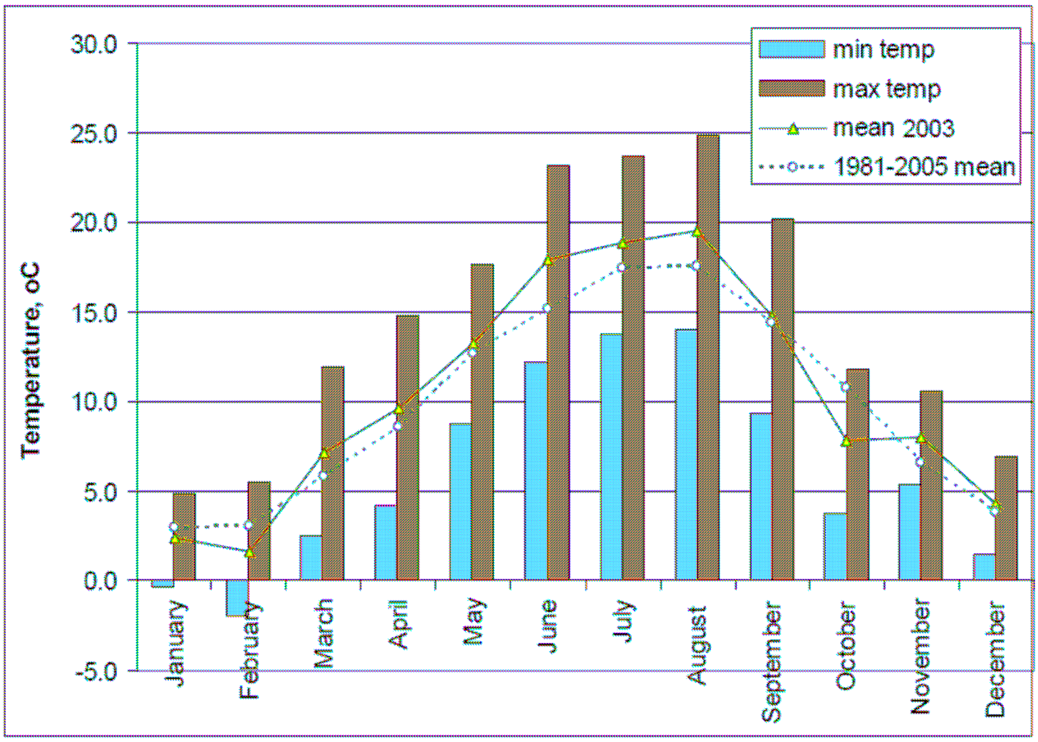

Figure 1: Monthly mean, minimum, maximum and average temperatures for 2003

Temperature - Let us now consider the winter of 2008/2009. Normally the mean monthly temperature in January is 2.8ºC. However, January 2009 was much colder with a average temperature of 0.8ºC. Seventeen frost days were counted with a minimum temperature lower than 0ºC. That is four more than normal for January. Four ice days with a minimum temperature above 0ºC were reported, what is normal for this time of the year. In the south east of the Netherlands locally 4 days with severe frost with temperature under -15ºC were measured. Also twentytwo frost days and seven ice days were reported. In January 2009 the lowest temperature was measured in Ell in Limburg, on 6 January the temperature was –20.8ºC! During the period from 1 to 11 January the average temperature was –2.64ºC, in ranking the 9th place for lowest average temperature in the last 100 years.
Precipitation - January 2009 was also drier than normal. The long-term average rainfall for this month is 69 mm. In his January only 47 mm was fallen. The northwest part had the most rainfall (64 mm), in the north it was the driest (27 mm).
Black ice on 2 January was dangerous for the traffic. On 4 and 5 January there was snowfall

in the southeast part of the Netherlands. The snow layer was 1 to 12 cm thick and stayed until 12 January. On 23 January the highest rainfall was measured (22.6 mm). On this day the lowest air pressure ever was measured in the Netherlands (961 hPa).
Sun hours - January 2009 was the second sunniest month since 1901 with 95 sun hours. The average amount of sun hours is 65.
Summary - The first 11 days were very cold for the Netherlands. Due to the many sun hours this period was followed by many frost/thaw days. It is known that due to sunshine the temperatures of asphalt wearing courses are much higher than the air temperatures. This causes many changes around the freezing point of the upper part of PA.

2 FROST DAMAGE

2.1 Possible causes of frost damage

2.1.1 Asphalt wearing courses

The stronger the frost and the more temperature changes around the freezing-point in combination with moisture, the greater the possibility of damage of asphalt wearing courses. And of course older wearing courses, are more sensitive to frost damage. This is valid for all types of wearing courses, but more specific for open wearing courses. These wearing courses are more sensitive for frost damage due to the open structure and the fact that the damage of open wearing courses developes more progressive in time (see figure 11).
With full coverage of the surface with PA and if the average service life of PA is 13 years, this means that as an average yearly 7% of the total PA surface is very sensitive to frost damage due to the age of PA.
The critical factor in the damage development of PA is the thin bitumen (mortar) film, especially in the top of the layer, that provides the bonding between the stone grains of the stone skeleton. In the first years the bitumen acts as a tough glue, but due to climate loading (rain, sun, temperature) this binder will become brittle. Oxygen, water, UV and high temperatures will change the bitumen on micro/molecular level. The asphalt mixture ages and will become more stiff. Due to heavy traffic and climatic loadings the asphalt mixture will be exposed to relatively high stresses and strains. In the long run initial micro cracks in the asphalt mixture will develop, which will grow further until stones at the surface loose their bonds and will be driven out by the cars.
At low temperatures the brittleness of the binder will increase more extreme which will accelerate the raveling process. Frost/thaw cycles can accelerate this even more. If water is present in the cracks and the temperature gets below the freeze point, than this water will freeze. Due to volume expansion the crack growth will be more aggressive. The older the wearing course and the lower the temperature, the earlier and greater the chance of frost damage. One night-frost followed by a day with temperatures above the freeze point can start this frost damage process. When at day time the temperature gets above the freeze point, the cold wearing course will become wet by condensation. This moisture creeps into the initial cracks, freezes during the night again and does the harmful work. The more successive freeze/thaw changes, the faster the damage development. Actually a long frost period is less harmful than a number of short periods with successively freeze/thaw cycles in combination with moisture.
By sprinkling salt in the winter, the freeze point of the water can be decreased to maximum minus 12° C. At lower temperatures the salt looses its effect.
The decrease in bitumen and mixture properties is different for each asphalt mixture type. For

all types of asphalt mixtures it will result in loss of stones from the surface in time. However, this will occur much earlier in the case of open wearing courses, because weather elements will penetrate deeper in the asphalt layer in comparison with dense wearing courses. As soon as the first stone disappears, the surrounding stones loose their support, resulting in a domino effect.

2.1.2 Asphaltic Plug Joints

Asphaltic Plug Joints (APJ) are a separate category within frost damages. The dilatation (thermal shrinkage) is highest at low temperatures. Also the binder will get more brittle. As a consequence of this the relaxation of stresses in the APJ is low and the allowed maximum tensile strength can even be exceeded. Aged or too brittle binder can result in a thermal crack over the width and in the flanks between the AJP and the adjacent wearing course. If this happens a crack can grow further by traffic and climatic loading. Due to the cracks, it is possible that the AJP can't fulfill the requirement for water tightness.

2.2 Consequences of frost damage

2.2.1 Road users

The direct visible consequences of frost damage for road users are loose stones resulting in chipped and/or broken windscreens, paint damage and broken headlights. Especially for motorcyclists traffic safety plays an important role (potholes). Indirect consequences are congestion and loss of travel time. Temporary closure of lanes or carriageways is necessary for needed maintenance works. Speed limitations can be necessary to guarantee the safety, which will influence the mobility negatively.

2.2.2 Road authority

The consequences of frost damage for Rijkswaterstaat during the extreme winter of 2009 were:

- decrease of the traffic circulation
- negative attention in the national press (including TV news) with danger of loss of image of Rijkswaterstaat
- more maintenance costs
- damage claims of road users (extra costs for Rijkswaterstaat)
- extra work for Rijkswaterstaat employees
- problems with repair methods under freezing point.

3. OBSERVED DAMAGE

During the frost period of January 2009 and the frost/thaw cycles afterwards more frost damage was observed on some locations of the Dutch motorway network than usual. The frost damage occurred in all types of wearing courses, but was extremely concentrated in PA. Wearing courses like DAC, SMA and emulion asphalt concrete had experienced mostly potholes as frost damage and especially old PA road sections showed severe raveling, potholes (not deeper than 50 mm) and open longitudinal joints. In figures 2, 3, 4 and 5 examples are given of such frost damage in PA.

Figure 2: Example of severe raveling

Figure 3: Difference in raveling new/old PA

Figure 4: Example of potholes in PA.

Figure 5: Example of an open longitudinal joint

4. BACKGROUND INFORMATION

4.1. Aging bitumen

In (Voskuilen et al, 2004) the decrease in penetration in time of recovered bitumen from several PA test sites was given. Besides the standard pen grade 70/100 bitumen also PA test sites were investigated with rubber bitumen, EVA and SBS modified PMB's and a softer pen grade bitumen 160/210. In figure 6 an example is given of the results of the PA test sites with 4.5% binder on 100% aggregate (= 4.2% in the mixture). The PA test sites with 5.2% binder in the mixture gave approximately the same results. From figure 6 can be seen that all bitumens harden strongly the first 3 years and have almost the same penetration after 9 years in service.

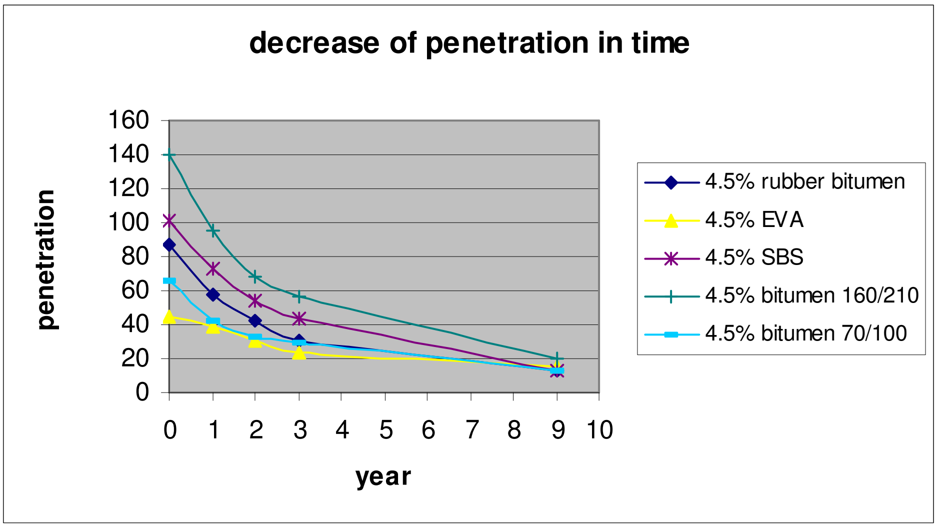

Figure 6: Change of bitumen penetration in time.

In figure 8 (Hagos, 2008) is shown that the ageing of the upper zone is more severe than ageing of the binder in the whole layer thickness. For this test the cores of 50 mm thick were horizontally cut in two equal parts and only the bitumen of the upper part was recovered for testing.

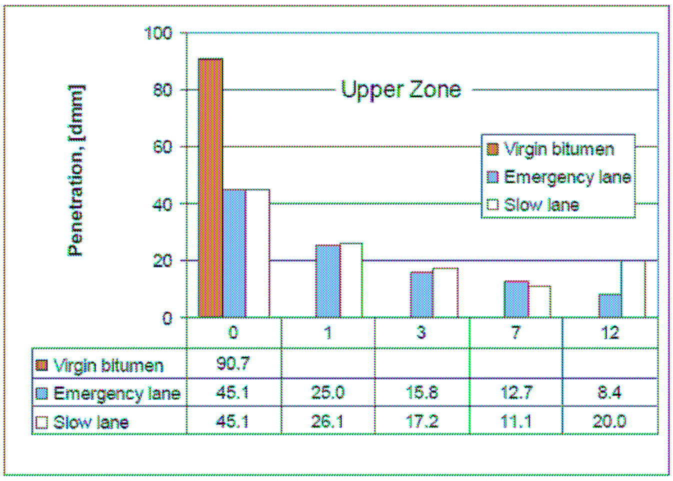

Figure 8: Change in penetration of bitumen recovered from field cores up till 12 years.

The effect of ageing on the temperature dependency of the laboratory aged and field binders from the emergency lane is nicely shown in figure 9. A horizontal shift in the temperature dependency of the properties can be observed, which suggests a higher temperature at which the bitumen becomes brittle.
The consequence can also be shown with the predicted relaxation modulus from Bending Beam Rheometer (BBM) stiffness data at a reference temperature of -18 C as shown in figure 10. The relaxation behavior of the bitumen and the mortar is similar to the stiffness behavior. This means that at higher relaxation modulus it takes longer to relax stresses. Consequence is that (thermal) stresses stay longer in the material, causing the material to crack.

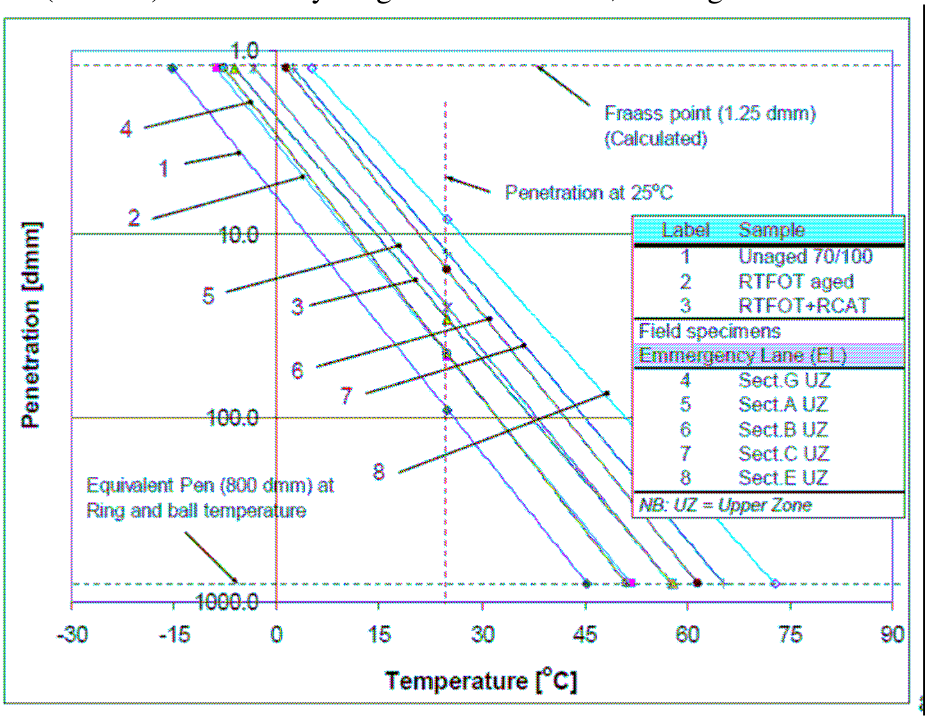

Figure 9: Penetration of Lab aged material compared with field-aged bitumen compared in the BTDC

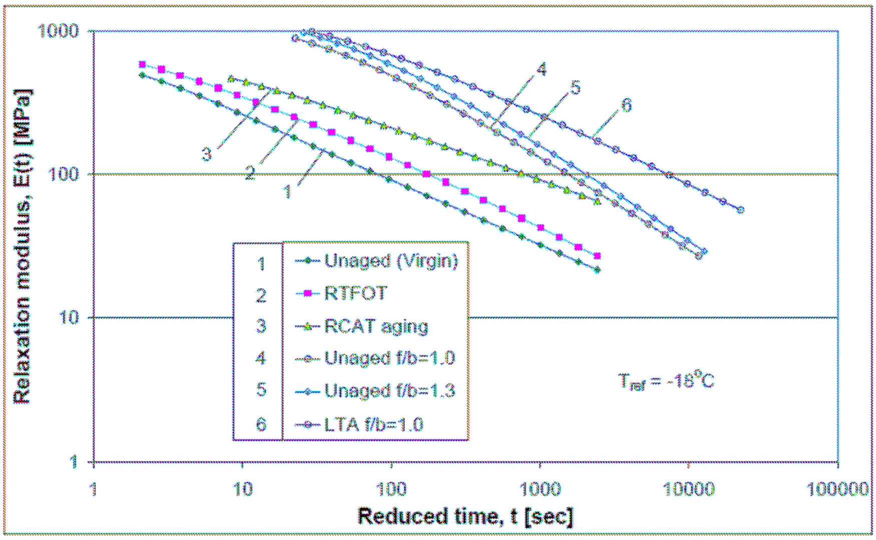

Figure 10: The relaxation behavior of the bitumen

4.2 PA behavior in time

In figure 11 is shown that the resistance to raveling of PA is constantly high until approximately 8 years in service and drops progressively until end of service life. The decrease in the raveling resistance is caused by initial cracks in the mortar caused by binder ageing in combination with traffic and climatic loading and debonding between mortar and aggregate caused by stripping. This process goes on until the stones get loss and raveling occurs. When the bitumen becomes more brittle by ageing and the end of service life approaches, lower temperatures followed by freeze/thaw cycles will speed up the end of service life of PA.

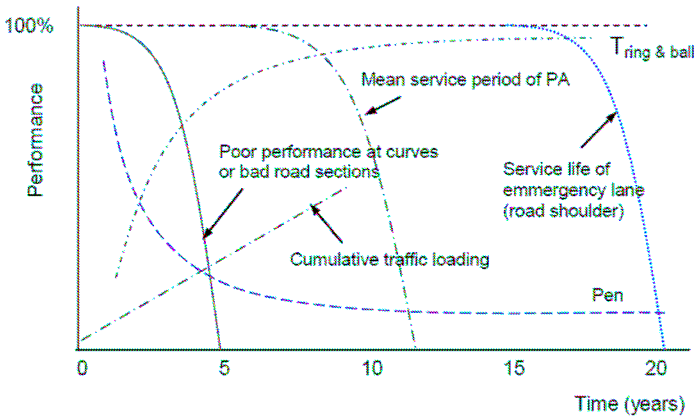

Figure 11: Schematic representation of the performance of PA at straight road sections, emergency lanes (shoulders) and curves (including change in penetration and softening point of the bitumen).

4.3 Deterioration of mortar in time.

Due to a combination of aging of the binder, clogging and high pressures that can occur in with water filled air voids of PA, the mortar can deteriorate in time. This is independent of eachother determined by Danish Road Institute (Bredahl Nielsen, 2007) and Technical University of Aachen (TU Aachen, 2006). The high water pressures in the air voids can act like water yet spraying and can damage the aged mortar. This is determined by analyzing thin layer slices of old PA and by analyzing the type of clogging. A certain amount of clogging exists of sand particles, which are the same as the sand in the mortar. The deterioration creates a kind of micro PA of the mortar, which is very sensitive for frost damage. In figure 12 and 13 examples are given of the deterioration of the mortar in PA of DRI and TU Aachen.

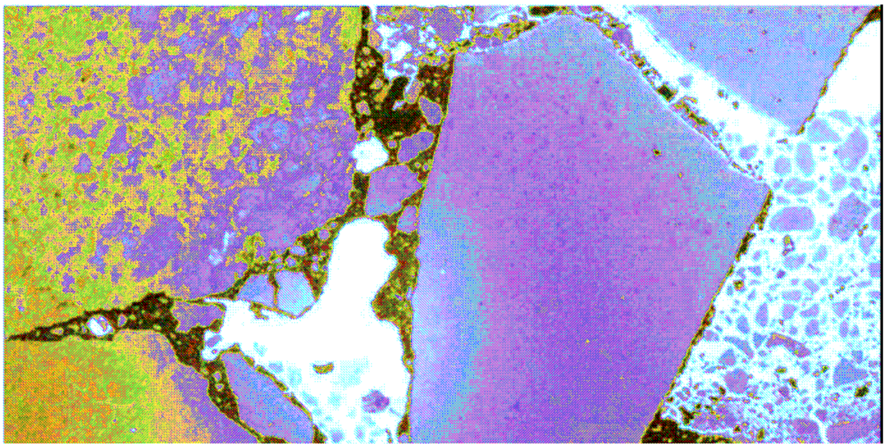

Figure 12: Examples of deterioration of the mortar in old PA (DRI)

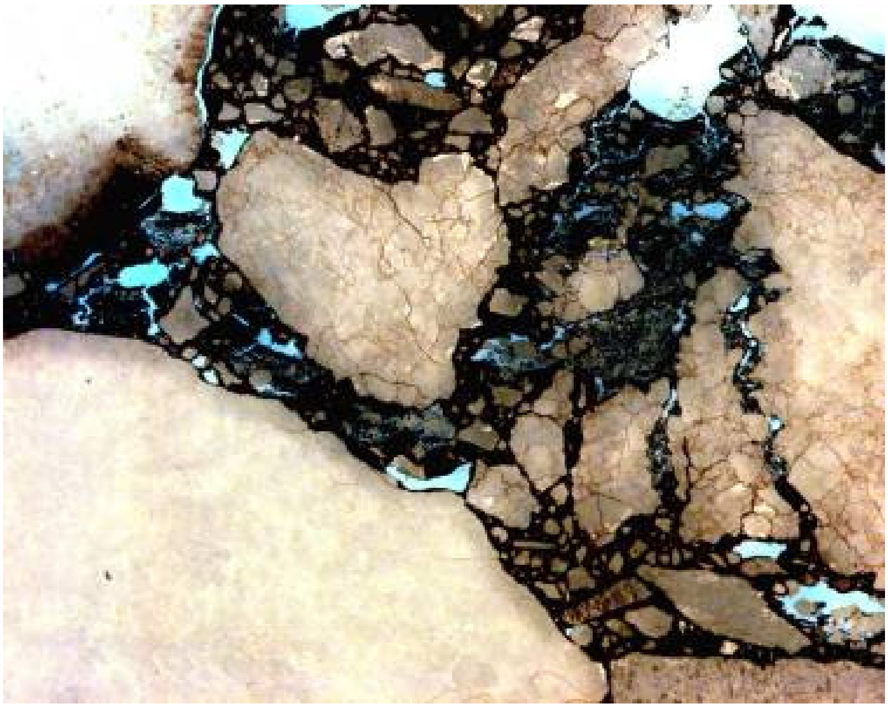

Figure 13: Examples of deterioration of the mortar in old PA (TU Aachen)

5. MAINTENANCE TECHNIQUES (strategy, possibilities)

5.1 Preventive methods

Preventive maintenance by milling off the old PA layer and bringing back a new PA layer two to three years before end of service life is the best method, but is not cost-effective. Statistically seen there is a small chance that much forst damage will occur, because oce in the ten years there is a severe winter. Normally the winters are quite soft.
Preventive maintenance is very costly and causes a lot of congestion. Also it is a drain of resourses in a mild winter. So frost damage is for Rijkswaterstaat a calculated risk.
It is very important to carry out maintenance before the winter if it is already planned. Delay

of PA maintenance can have serious consequences, because aged old PA is very sensitive to frost damage. So, if because of budget problems some maintenance can't be carried out, the management has to know what the consequences are of delayed maintenance on PA. In such cases it is better to choose for a delay of maintenance on DAC instead of PA.
If the emergency lanes of old PA are clogged, earlier frost damage can occur in the lanes because of the possibility that water freezes in the air voids of PA. In such cases the PA emergency lanes can better be cleaned just before a freezing period.
If it is known that the binder is strongly aged in PA, one can consider to make the binder softer before a freezing period by spraying a conservation agent on the old PA. This conservation agent must contain an emulsion bitumen with a special rejuvenator.

5.2 Repair techniques

Potholes can be filled with cold asphalt or hot mastic asphalt mixtures. The cold mixtures are less durable in comparison with the hot repairs, but are always available and easy in use.
In the winter 2009/2009 the road administration decided in some cases not to repair the PA road sections with severe raveling, because laying of new PA below the freezing point will result in poor quality of PA. Also the contractors wouldn't give any guarantee. Because of safety reasons the road administration decided to mill off carriageway wide the whole damaged PA wearing course. The traffic had to drive on milled asphalt with a speed limitation of 90 km/h (normallay 120 km/h is allowed) until the weather conditions permit to lay new PA again. This caused congestion, but no unsafe situation.
Open longitudinal joints were temporary filled with cold or hot asphalt until the weather conditions were good to repair them durable.
Another maintenance technique in the Netherlands for PA is a thin inlay. The upper 20 mm of the raveled PA is milled and 20 mm of an noise reducing thin layer is laid back. When there is frost damage, the thin inlay technique is not recommended, because the 30 mm left bottom part can also be damaged by frost.

6. HOW TO AVOID FROST DAMAGE?

Don't delay already planned maintenance on old PA, because these road sections are very sensitive for frost damage. The management who decides about the maintenance budget has to be aware of this.
Carry out preventive maintenance just before a frost period.
Try to modify the PA in such a way that it is less sensitive to frost damage. One way is to choose a binder that is less sensitive for aging and/or a binder, which is less brittle at lower temperatures. The other way is to design the mortar more robust for deterioration.

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