Self Healing Asphalt - Extending the service life by induction heating of asphalt

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ABSTRACT

Extending the service life of an asphalt surface layer is always a continuing desire. This can be done by improving the quality of the product when laying. Another possibility is to upgrade the quality throughout the service life. This is the method to Self Healing Asphalt.

The aging of asphalt under weather and traffic is associated with the formation of micro cracks in the mortar fraction. By adding a conductive material in the asphalt production, such as steel wool fibres, the possibility arises of heating up the mortar of the asphalt by an induction device. A short "heat shot" through the steel fibres, causes melting of the bituminous binder and because of that, hairline cracks in the asphalt layer are closed. The asphalt mixture will "reset" and start a new life. This can be done several times during the service life.

In The Netherlands from 2010 several tracks have been laid with Self Healing Asphalt. In 2014 also the first healing action on site was carried out. The results are promising.

This development for instance opens new ways to a broader application of noise-reducing road surfaces. These surfaces are susceptible to damage from twisting movement of traffic and therefore cannot be applied to many projects. By providing the most critical locations with Self Healing Asphalt the quality during the life can be maintained by periodic induction action.

Also, making noisy expansion joints noiseless, this material can play an important role.

In the paper the principle of Self Healing as well as several applications will be reported.

Keywords: Healing, Maintenance, Noise reduction, Porous asphalt, Ravelling

1. INTRODUCTION

The social preference for wider use of noise reducing road surfaces is growing and growing. On the other hand there are also many negative experiences with this type of road surfaces, especially at locations with high traffic loads. This causes an inhibitory effect on the application of silent roads. For example durability problems occurs on roads with large amounts of motorized vehicles, at intersections, in road bends or alongside parking lots. If some of these critical locations are present in a road, the entire stretch of road can then not be provided with a noise reducing asphalt surface layer.
The new availability of the Self-Healing technique changes that. By adding fine steel fibers to the asphalt mix at the critical locations, the road surface will be able to "be healed" locally at those critical locations during its life span. This healing action takes place by a mobile induction apparatus along the road surface. By using the steel fibers as a heat transport medium, a short "heat-shot" is brought into the surface asphalt layer. This will cause the binder inside the asphalt to partially melt, closing the possible fine cracks within the asphalt mixture. The asphalt mixture will thus be "reset" and a new life span can begin.

2. UNLIMITED APPLICATION OF NOISE REDUCING ROAD SURFACES?

The call for noise reducing road surfaces, in order to lower the perceptible traffic noise, is still in full force today and will only increase in the future. For Dutch highways the very silent two-layer porous asphalt (also known as 2L ZOAB or Twinlay) has been available for some 15 years now. For urban roads with lower traffic speeds the thin noise-reducing asphalt surface layers [also known as "DGD's" in Dutch] have been available in the Netherlands in the past 15 or so years. Nevertheless, applications of such noise reducing asphalt surface layers are still problematic in many situations.
On the one hand there is a technical problem with the use of two-layer porous asphalt (Twinlay) and sometimes even with the application of thin noise-reducing asphalt (DGD) layers. On the other hand those DGD layers sometimes simply doesn't give enough noise reduction. This second problem stands in relation with quicker decline of noise reduction of the DGD's as a result of the clogging of the fine pores of that asphalt composition.
Because of these limitations, the application of 'silent roads' is often still hindered and impossible, even though for environmental reasons it is highly desirable to diminish that vicinity hindrance. A contribution in solving this problem can be delivered by using the recently developed Self-Healing technique. With this technique, developed by TU Delft together with Heijmans Infra, the asphalt can be "renewed" on site, without having to replace it.

3. THE TECHNOLOGICAL PROBLEM

First of all, the application of a noise reducing asphalt surface layer can be a problem because of the extensive traffic load. On highways and motorways the traffic drives in one direction; braking and accelerating is limited and dispersed. Roads of a lower order however have in general a different layout and use: driveways, side roads, intersections and roundabouts. Wringing forces that the vehicles thereby exert on the road surface, form in general a great taxing on the open stone structure of the ZOAB/Twinlay or DGD layers. These asphalt mixtures typically have less binder/mortar support between the stones when compared to conventional dense asphalt mixtures. This is for instance the case with the SMA-mixture.
The second problem caused by this road layout, is that the laying process of the asphalt on site is less optimal. Because of all the interruptions (compared to an unhindered straight stretch of road) it is impossible to apply a full continuous asphalt out roll. Also, all stopping places (during the process of placing the asphalt) as well as all handiwork usually lead to a suboptimal quality, causing premature Ravelling (stone loss) or even end of life span.
These problems have led to the cessation of the initial application of two-layer porous asphalt (Twinlay) on lower order roads in the Netherlands between the years 1990 and 2000.

4. THE DAMAGE MECHANISM IN STONE SKELETON MIXTURES

Figure 1: Ravelling in a stone skeleton mix

The asphalt mixtures that are generally used for noise reducing surface layers such as ZOAB, Twinlay or DGD, generally consist of stone skeleton mixtures. Within this type of mixture there is a stone structure wherein the stones are pressed against each other (during the asphalt compaction) into a robust sustainable skeleton. Rutting is thus no concern for this type of mixture. If it does occur, it is usually caused by the underlying layers. The decisive damage type for this type of surface layers therefore is Ravelling: the loss of stones (larger than 2 mm in diameter) from the asphalt road surface. This stone loss is caused by a rupture within the so called 'adhesive bridges' of the mortar between the stones in this skeleton. If we want to intervene in this process, it is particularly interesting to determine which process is taking place in the road surface before the first stones come out.

The tires of the vehicles exert forces on the road with each passage. It is important to understand that these forces have not only got a vertical component, but also several horizontal components.

Figure 2: Forces at a road surface caused by tires

As a result of the deformation of the tire (or tire thread to be more exact) during the passing movement, shear forces are exerted unto the stones within the road surface. This causes strain within the adhesive bridges between the stones. With the extensive repeating of this forces 'fatigue taxation' will occur.

Fatigue in these adhesive bridges leads to the first of three damage mechanism stages: crack initiation. This is followed by the second stage: crack growth. Finally the third stage is reached: a complete breakage of a singular adhesive bridge. When enough adhesive bridges have been broken, the stone will literally jump out of the road when enough force is applied by the passage of a tire thread.

It is this specific three stage damage mechanism in which the Self-Healing technology seeks to intervene. More specifically, the intervention optimally takes place during the first stage. A short "heat-shot" is then send into the mastic (or mortar) of the asphalt mixture in the road. This causes the (initiated) fine cracks to close and thus restore the adhesive bridge to its 'original position'. Giving this "heat-shot" takes place via the Inductive Healing technique; see also here below.

5. INDUCTIVE HEALING TECHNIQUE

Figure 3: Conventional heating method: Bleu smoke

The heating of an asphalt surface layer "in situ" has long been in use. It became widely in use in particularly with the Repave and Remix techniques.

Infrared heaters were often used in order to heat up the road surface.

Asphalt however is a poor heat conductor due to the mineral aggregate. As a result, in order to obtain the desired increase of heat level at the bottom of the asphalt layer, the road surface always had to be strongly overheated and be under this 'additive heat radiation' during a relative long period of time.

This method is accompanied by great energy loss as well as frequent burning of the bitumen in the asphalt surface layer (see also the blue smoke in this photo). Especially in situations where there is still some moisture present in the asphalt (such as porous asphalt surface layers!), the desired temperature could only be obtained by great strenuous effort.

The newly developed induction technique makes use of a completely different, more direct method. During the production of the asphalt mixture, a small amount of highly refined steel filaments (or fibers) is added. It are these steel fibers within the asphalt mortar (or mastic) that makes it possible to heat the asphalt layer via induction.

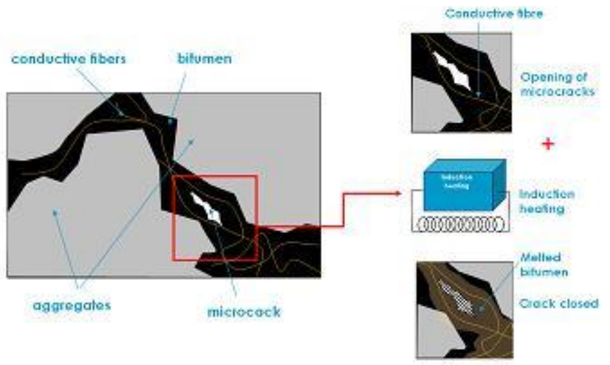

Figure 4: The principle of induction heating

During the induction heating process, the iron molecules inside the steel fibers are subjected to a rapid changing magnetic field, causing the iron material to heat up. It is a well-known technique used in many kitchens today: an induction cooking plate directly heats the bottom of the pan, instead of transferring contact heat via an electrical cooking plate. So by induction, it is not the cooking plate itself that becomes warm, but the base of the pan. Also, less energy is lost compared to heating via gas burning. It is a completely harmless technique that can be applied with great capacity.

By applying this technique to asphalt (with steel fibers inside the mortar), the steel fibers become hot. They in turn yield their heat to the surrounding mastic. This way,

the mastic (or mortar) inside the asphalt mixture can be intensively heated equally as well as evenly and directly across the entire thickness of the asphalt surface layer – causing the mastic (or mortar) to momentarily melt. The fine cracks inside the mortar will then ‘flow close’ again and the asphalt is reset at the original state. This technique is developed together with the Technical University of Delft, see lit. [1].
The great advantage with this method is that the energy (or heat) is applied directly to the mastic (or mortar). That is exactly the part of the asphalt wherein the fine hair cracks are formed in the course of time. Thus there is hardly any loss of energy during the transfer of heat via induction. The desired result (or transfer of required energy to the right location) is already obtained before the stones have had the chance to become warm indirectly. Only the effective part of the asphalt mixture needs to be heated.

6. LABORATORY TESTS

The effect of (inductive) Self-Healing has first been examined on ‘basic asphalt mastic mixtures’ at the Technical University of Delft in de Netherlands [TU Delft]. [lit. 2]. A beam of asphalt mastic with steel fibers is first produced and then at a temperature of - 20 ˚C is completely broken (vertically), placed together again at the matching breakage surface and then warmed up via induction. After the induction healing, the mastic beam appeared to be whole again in such a way, so that as a singular object it could be broken again.

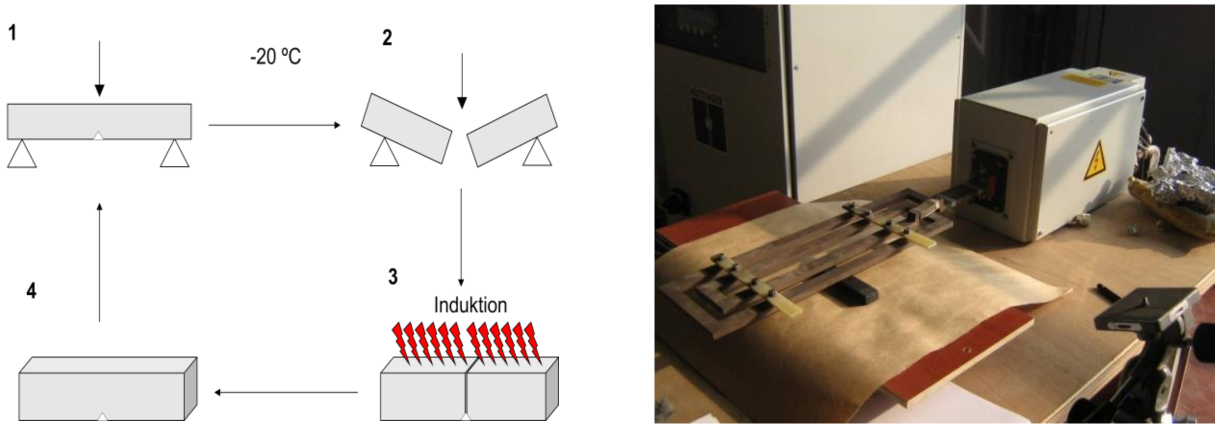

Figure 5: Repeated breaking and healing of a Self-Healing mastic beam

This complete procedure could be repeated for a total number of six to seven times, while the required force to break the beam again (after healing) remained at least 70% of the initial breaking force.
In another study the effect of the induction treatment on the mix and also on the binder is investigated. This shows that no excessive effect on binder hardening occurs. This because of the absence of oxygen inside the mix , see lit. [3].

Subsequently, in the research laboratory of Heijmans the healing effect was done at complete ZOAB [porous asphalt] mixtures. To this end, RSAT tests [Rotating Surface Abrasion Tests to measure Ravelling] were performed on both untreated ZOAB sample plates as well as induction healed ZOAB sample plates.

Figure 6: The Rotating Surface Abrasion Test device of Heijmans

The load exerted on a sample plate in the RSAT test method, roughly corresponds to 7 years of normal traffic exposure in the field. By subjecting the sample plates at specific times to the induction heating, the optimal treatment protocol of induction healing could also be established.

In standard RSAT tests, the load is exerted during a 24 hours period. However, during these first RSAT tests at the Heijmans laboratory, it appeared that because the examined ZOAB (or porous asphalt) material contained steel fibers, there was hardly any damage that took place during the normal 24 hours test duration. Thus, it appears that adding steel fibers into the asphalt mastic also yields a mechanically stronger, more resilient asphalt material.
Because the standard RSAT testing sequence generated such small amount of damage on the sample plates, an aggravated RSAT testing pattern was applied (namely 50% higher wheel load).

The following chart shows the stone loss increase (in grams) of four investigated sample plates. On each of these sample plates, an induction treatment took place after 12 hours of testing in the RSAT machine. After that, RSAT testing continued until a total testing duration of 24 hours was reached.

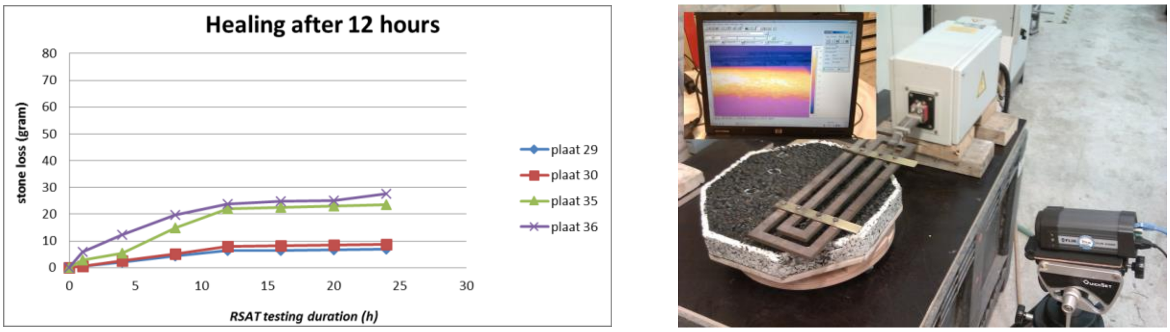

Figure 7: RSAT stone loss of Self-Healing ZOAB sample plates with induction treatment after 12 hours

This chart here above makes it apparent that more damage occurs in the pre-induction treatment phase than after the induction treatment took place. There even seems to be a lasting quality improvement. This is probably due to the melting effect of all of the adhesive bridges.
When the compaction process takes place, some less well-formed adhesive bridges always occur (due to causes such as cooling or stone shifting) – causing the brand new asphalt layer not to have a full set of complete optimal adhesive bridges. During the induction treatment, these 'starting adhesive bridges' can take on a more favourable or optimal shape as a result of the melting effect of the mastic (or mortar) – thus 'permanently' becoming less susceptible to damage.
In this regard, a healing action can best be applied at an early stage, thereby also preventing or delaying the 'normal' commencement of damage initiation & damage development.
An estimate could be made of the effect on the life of the asphalt. By taking all available research results into account, an estimation could be made of effects of the healing treatments on the life span of asphalt.
The conclusion is that applying 2 to 3 inductive healing treatments can double the life span of a porous asphalt surface layer.

7. PRACTICAL APPLICATIONS

Up until now, there have been several field applications already realized. These can be divided into several different kinds of application.

7.1 Single as well as double layered porous asphalt (ZOAB and 2L-ZOAB or Twinlay)

The Self-Healing technique has been applied both on single layered porous asphalt as well as double layered porous asphalt. It concerns the most common applications, where the aim is to achieve a longer life. There are also applications beings prepared in which Self-Healing porous asphalt or Self-Healing two layered porous asphalt is used in situations where a short lifespan is expected under normal circumstances, such as road bends with small radius or on entry / exit ramps at intersections etc.

Figure 8: Paving Self-healing Porous Asphalt on the A58 near Vlissingen and the first healing action after three years

In the meantime the first healing action has already taken place at this test track. The results are very promising. The surface can be heated in de expected time. Although the effect at the service life is not quantifiable due to the fact that the roads surface was only three years old. Further information you'll find at the Selfhealing blogspot of TU Delft [lit. 4].

7.2 Silent joints

The name "BrainJoint" stands for Buried Reinforced Asphalt Interlayer Noiseless Joint. It is a type of silent, noise reducing 'jointless' joint that can be used within the limitations of certain specifications. See for more information the multiple choice matrix of Rijkswaterstaat (Dutch agency of the Department of Public Works). [lit. 5].

Figure 9: Self-Healing BrainJoint expansion joint on the A348 at Rheden

By using the BrainJoint at places such as road bridges with an asphalt surface layer, the irritating pulse noise of normal expansion joints can be completely eliminated. In certain situations the application of this new type of joint is highly desirable (for instance in the near vicinity of habitation areas). However, the bridge or viaduct may in some cases fall outside the previously mentioned specifications (such as a bridge span length that is too large) – thus making it impossible to apply the benefits of the BrainJoint.
By producing the specialized asphalt surface layer for the BrainJoint as a Self-Healing version with steel fibers, any potential cracks in the asphalt mastic (caused by the greater than designed movements of the bridge deck) can then be healed over time and thus be managed. It concerns a very local healing treatment (limited to the near vicinity of the bridge deck) that can be performed more frequently, for example once every 2 years.
To this application end, a total of four locations have already been provided with this Self-Healing version of the BrainJoint.

7.3 Application of thin porous asphalt layers (DGD's) at difficult locations

In a number of situations the Self-Healing technique has been applied to a Thin Noise Reducing Asphalt Layer. In this case it was Microflex (a DGD of Heijmans). It has been applied in situations where the application of a normal DGD would simply & certainly lead to a (much) too short a life span. In the municipality of Tilburg the Self-Healing DGD has for example been applied even within the crossing area of intersections. It concerns a route nearby an industrial area with heavy traffic.
For years it has been a well discussed topic within the Dutch field of civil engineering expertise concerning silent roads: can a DGD be continued unto the crossing area of an intersection?

Because of the continuity of the road's imagery as well as desired noise reduction capability of the road, it can be preferable to do so.

Figure 10: Self Healing Microflex being applied on the intersection crossing area of the Grootvenstraat at Tilburg

By applying the Self-Healing DGD on the crossing areas of the intersection and the normal DGD version on the straight stretches in between this crossings, an optimal technical and economical solution can be offered.
Visually there is no difference between the two mixtures and they can both be constructed with one continuous paving operation. The critical locations on the crossroads can be kept on the desired quality level by healing treatments. The healing treatments can be planned through monitoring and registering certain indicators.
Another typical application took place in the city of Enschede. It concerns a very busy access road alongside an industrial area with a large number of heavy vehicle passages.

Due to a nearby residential area, a noise reducing road surface was more than desirable. However, due to the heavy traffic load on this road, a road surface of standard thin (semi-) porous asphalt would only have a short lifespan. By applying the Self-Healing DGD version, a "match" could be found between noise reduction and durability.

8. FUTURE OPPORTUNITIES: APPLICATION OF TWO LAYERED PA ON LOWER ORDER ROADS

Long-term experience on Dutch Highways has revealed that a finely graded porous asphalt layer has long lasting noise reduction capacity when applied onto the top of a (coarser) porous asphalt layer. This concept is also known as Twinlay or two layered porous asphalt (2L-ZOAB).
The rainwater needs only to drain vertically through the thin top layer, flowing down into the secondary porous layer and then flowing laterally out of that coarser asphalt layer to the side of the road.
The pumping effect of the traffic during rain also has a positive effect on the openness and the uncongested condition required for an effective noise reducing effect. The concept of two layer porous asphalt (Twinlay or 2L-ZOAB) as a durable noise reducing surface layer, appears to be functioning well in the field when traffic speeds are high. Life spans on Highways of 10 years or more appear feasible. In addition, during the life span the noise reduction remains well intact.

Figure 11: Example application of two layer porous asphalt (Twinlay M) on a provincial road: The N302 at Harderwijk (including the BrainJoint as a Jointless Joint)

This is in contrast to single layered DGD layers which very quickly become clogged and lose their effective noise reduction. Because of its fine structure, the water that falls onto a DGD surface layer cannot sufficiently be drained sideways, which leads to congestion and clogging.
A two layered porous asphalt does not seem to have this problem, though it does require good drainage of the water toward the side of the road. From the applications on Highways, we know that a free lateral water flow to the side of the road is a good solution. With proper management of the unpaved road shoulder, there are no drain gutters needed.
However, attention should be given to situations in which no free water flow to the side is possible in the design. When this concerns longer lengths, drain gutters are necessary, even though these are critical in relation to maintenance.

If these preconditions can be met in the design, applying a 2L-ZOAB would be a better and more durable solution than applying a DGD in certain situations on lower order roads. It would mean an improved life span for both the aspect of technical durability as well as ‘acoustic lifetime‘.
The Self-Healing technology may offer a solution to those road sections in the route, which are too critical for application of normal Two Layered PA, due to the heavy loads that occurs at locations such as side roads connections, driveways, crossing areas of intersections, roundabouts etc. As such, the Self-Healing technique can contribute to a wider use of two layer porous asphalt on non-national (or lower order) roads. And thus also to the further reduction of the hindrance caused by environmental unfriendly road traffic noise.

9. CONCLUSION AND FURTHER INVESTIGATION

The above described application shows that the use of Self Healing Asphalt in practice is possible. It can be a solution for areas with dense traffic and with a strong need for noise reduction. Even the first experiments of a healing action has taken place.
However the economic effect has to be validated. Because of the expensive addition of steel fibers, it’s still not clear that these applications are economically justifiable.
For future use also the possibility of recycling is an important issue. Because the material remains a thermoplastic material it can be recycled in the same way as normal asphalt. Preferable of course in a new Self-Healing pavement.

An extensive investigation program is needed to optimize and validate this technique. The conductive material with has to be added in the Asphalt mix (up to now steel fibers) has to be optimized as well as the needed quantity. Also the induction apparatus has to be developed further. This research will take place within an European Infravation project.
A consortium of Universities, Road authorities and industry will take this challenge. Heijmans is one of the partners in this consortium, called “Healroad”. Also in this project LCA calculations will be made to investigate the Eco-footprint of the technology.

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