LCA AND ENVIRONMENTAL BENEFITS OF REJUVENATION MAINTENANCE SOLUTIONS FOR POROUS ASPHALT PAVEMENTS

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ABSTRACT

The paper presents the test results of an innovative and preventive maintenance solution for porous asphalt pavements. This type of asphalt has become very popular in the Netherlands, Japan and some south-eastern Asian countries due to its noise reduction, driving comfort and driving safety in wet weather. However this type of asphalt pavement suffers from a premature damage, so called ravelling or stone loss, due to fast ageing of the binder. The preventive maintenance principle is based on a rejuvenating product, cold-applied in the form of a special mixture of bituminous emulsions by a spraying truck. This paper firstly gives a brief introduction to the theoretical background, research approach and test results, i.e. the effect of the treatment on the properties of bitumen binder as well as the mechanical performance of the existing asphalt pavements. Then some field test results and the LCA investigation results are presented and discussed. The results have revealed that the new binder is able to migrate into and activate the aged binder in porous asphalt, the mechanical properties are improved and the life time is extended for porous asphalt pavements. The LCA analysis has shown that this maintenance solution is cost-effective and climate-beneficial, with ca. 25% reduction in the environmental and climate impact compared with the current maintenance method for porous asphalt pavements. This contribution is a sister paper presented at 4th EE congress in Copenhagen in 2008, which dealt with dense asphalt pavements

Key words: maintenance, emulsion, rejuvenators, environment, LCA, social and economic cost-benefit, porous asphalt

1. INTRODUCTION

Porous asphalt (PA) is an open-graded asphalt mixture, which consists of a large amount of course aggregates in combination with a relatively small amount of fine materials resulting in a very open structure (20-25% of voids by volume). As a result, PA shows various functional advantages over traditional asphalt, such as driving comfort, noise reduction, water drainage as well as improvement of skid resistance in wet weather [1-2]. Due to these undeniable advantages, PA has become very popular as a wearing course of the major roads in the Netherlands, Japan and Southeast Asia countries. PA was first applied on the Dutch road network in the early of 80's and accepted as a wearing course in 1987. Since then the application has been rapidly increased and nowadays ca. 90% of the primary road network has been surfaced with this type of wearing course.

Despite the various advantages of PA, a fatal problem is its durability, manifested in the form of premature damage - ravelling, i.e. early stone loss. This type of damage mostly occurs after a severe winter. Every year ca.10-15% of PA surface layer has to be maintained or re-surfaced. In order to improve the quality and extend the life time of PA pavements, the Dutch Ministry of Infrastructure and Environment (RWS) has launched several huge research projects [3-6]. One piece of PhD investigations at TU Delft was carried out into the effect of ageing on binder properties of porous asphalt concrete [4]. It was found out that the ageing process of PA took place much faster than that of dense asphalt. Furthermore the ageing degree of the binder on the top side is almost the same as one at the bottom side due to its high voids content. As a result, the ageing process significantly increases the "critical" temperature, at which the binder starts to behave brittle. On the other hand, the ageing also reduces the strain level and stress relaxation behaviour, which thus results in the accumulation of micro damages (defects) in PA pavements during the service period by traffic loading and climate variation. This could be the major reason for PA ravelling, particularly after a severe winter. Another piece of PhD looked into the damage development in the adhesive zone and the mortar of PA mixture. A theoretical model to predict the life time of PA pavements was established, indicating when the maintenance PA pavements should be carried out [5]. It could be concluded that the ageing of the binder is the major cause of the premature damage (ravelling) of PA pavements. If this is the case, then the rejuvenation technology could be a right solution for the maintenance of PA pavements.

In 2010, the Dutch Ministry of Infrastructure and Environment (RWS) initiated a project – "The life time of PA pavements and maintenance strategy (LVO)", including field practical tests and laboratory theoretical investigations [6]. The aim of this project is to encourage the material suppliers and contractors to come up with new ideas, new materials and new technology to extend the life time of PA pavements. Icopal/Esha Group Infra Solutions is one of 4 industrial participants with their innovative product and technology of Eco-PenTack. This is a preventive maintenance product and technology based on a rejuvenating principle, cold-applied in the form of a special mixture of bituminous emulsions by a spraying truck. For a successful research and development, two requirements must be fulfilled: one is the high rejuvenation power of the product to the aged binder of PA mixture; the other is the structural and functional requirements, such as the stability, skid resistance, acoustic (noise) effect and water drainage power of porous asphalt pavements as compared with the untreated one.

This paper firstly deals with some laboratory test results, i.e. the reactivity of Eco-PenTack with aged binder and the mechanical stability of PA mixture. Then it will present and discuss some field test results, followed by LCA investigation results. The LCA analysis has shown that this maintenance solution is cost-effective and climate-beneficial, with ca. 25% reduction in the environmental and climate impact compared with the current maintenance method for porous asphalt pavements [14]. This contribution is a sister paper presented at the 4th EE congress in Copenhagen in 2008 and elsewhere [8-11], which dealt with rejuvenation of dense asphalt pavements.

2. MATERIALS AND TEST METHODS

2.1 Materials:
Eco-PenTack – a special bitumen emulsion mixture with a high rejuvenation power to aged bitumen.
Broken sand – 0-2mm fraction of broken sand.

2.2 Test methods:
Extraction and recovery of the binder: The asphalt cores (15cm in diameter) were taken out of the roads. The extraction test was done in accordance with Test Method NEN-EN 12697-1 B.1.3 at KOAC-NPC Laboratory in Groningen, the Netherlands.
Reactivity of Eco-PenTack with aged bitumen: The same dosage of Eco-PenTack is applied on the surface of extracted binder from PA cores in a penetration cup. The reactivity of Eco-PenTack is determined by means of a modified penetration method described elsewhere [12].
Dynamic creep test: A dynamic axial stress is applied to a specimen (Ø = 100mm) for a specified number of load cycles （otherwise up to 10% of deformation）while axial strain is monitored. The samples are pretreated to be sure the top surface is parallel to the bottom surface. Before the test, the specimen is preconditioned at 50°C till reaching the constant temperature. The test conditions are listed in Table 1. The test method was also described in Reference [13].

Table 1: Parameters of dynamic creep test

Parameter	Value	Parameter	Value
Temperature	50°C	Test loading stress	250 *kPa*
Pulse width	200 *ms*	Conditioning time	10 *minutes*
Pulse Period	1000 *ms*	Preload rest time	1 *minutes*
Conditioning stress	25 *kPa*	Recovery time	1 *minutes*

Field skid resistance test: Standaard RAW Bepalingen 2010 – Proef 72.
Field brake deceleration rate test: KOAC-NPC test method (http://www.koac-npc.com via Download).
Field asphalt drainage test: KOAC-NPC test method (http://www.koac-npc.com/Flex/Site/Download.aspx?ID=1277).
Life cycle assessment (LCA): Done according to NEN 8006 by a Dutch research institute TNO.

3. RESULTS AND DISCUSSIONS

3.1 Laboratory test results

The principle of the rejuvenation technology was described in a previous contribution [8]. It is essential to find out a proper type of component, which has a high rejuvenation (softening) power to aged asphalt. An investigation has shown a good reactivity of the rejuvenation product with hard-type of fresh bitumen and aged bitumen in dense asphalt in situ In order to understand the reactivity of rejuvenation product with aged binder in PA pavements, the binder was extracted and recovered from asphalt cores taken out of PA pavement. The same dosage of Eco-PenTack (ca. 1mm thick layer) is applied on the surface of extracted binder from PA cores in a penetration cup. The reactivity of Eco-PenTack is determined by means of a modified penetration method described elsewhere [12].

Figure 1 shows that the rejuvenation effect is significant. The reacted depth of Eco-PenTack in the aged bitumen is 0,58mm in the first 24 hours, reaches a maximum value (0.79mm) at 3 days. After 7 days, the reacted depth appears to be stabilised at ca. 0,4mm, the surface of the test sample becomes “drying”, meaning that the main part of the activator either migrates into the aged bitumen; or is slowly evaporated (the weight loss of the sample is 0.0065g from 7 days to 14 days). The test results also demonstrate that the thickness of Eco-PenTack applied is ca. 1mm thick. Furthermore, around 50% of it (in fact water from the emulsion) is evaporated within the first 24 hours, eventually the remained Eco-PenTack film on the aged bitumen surface is 0,5mm, meaning that Eco-PenTack has ca. 50% of residual binder in it.

It is well known that the thickness of bitumen film around minerals in PA is 10 to 15 µm maximum. The reaction speed of this product with bitumen is obviously quick enough to activate the aged binder in PA within a short period of time.

The point is how to bring the rejuvenating product homogeneously into a PA mixture, instead of remaining on the surface of the pavement. Figure 2 demonstrates the penetration of Eco-PenTack into the PA mixture (indicated by green-yellowish colour). Eco-PenTack was treated with a trace amount of fluorescent dye, which emits a distinguished colour under a UV light. The test result shows that Eco-PenTack penetrates homogeneously throughout the PA mixture via voids. The ageing happens the same way through the whole PA mixture layer in practice [4]. This means that the rejuvenation of the aged binder at the bottom of PA layer is also required.

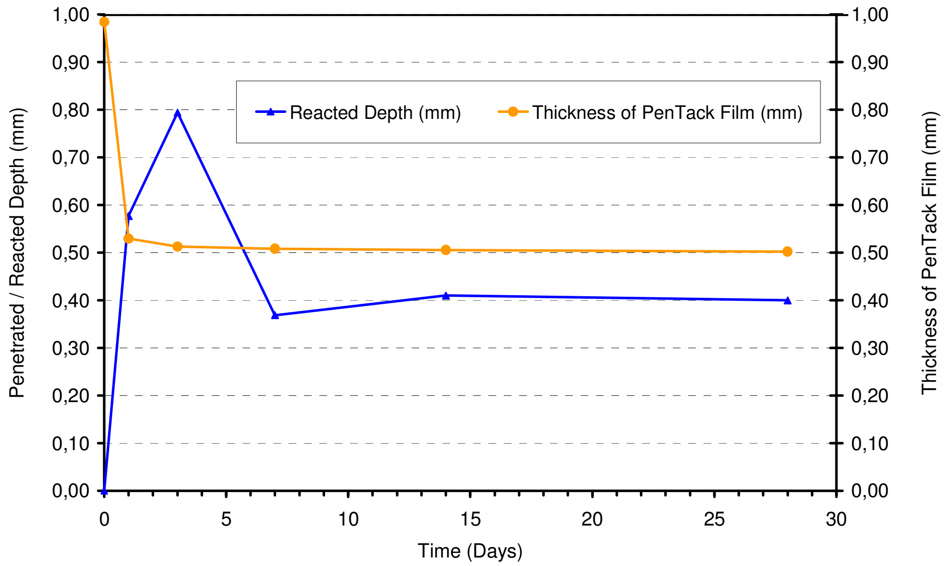


Figure 1: Reaction depth (blue curve) of Eco-PenTack with the recovered bitumen against time

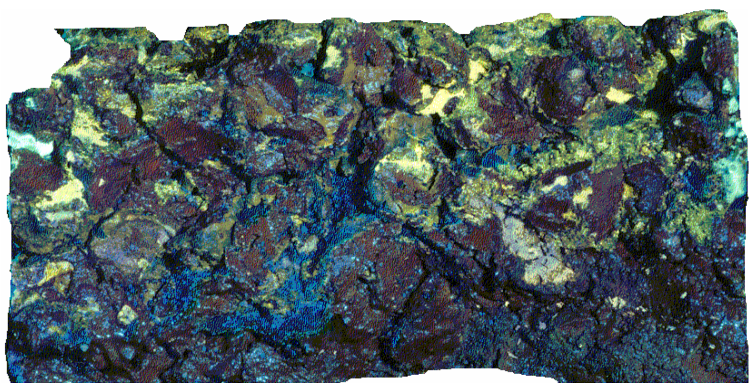
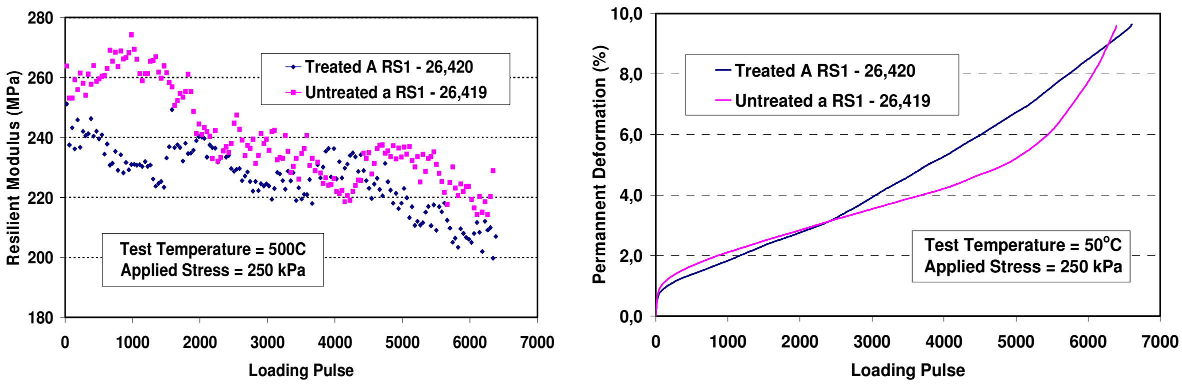


Figure 2: Penetration of Eco-PenTack in PA mixture (indicated by green-yellowish colour)

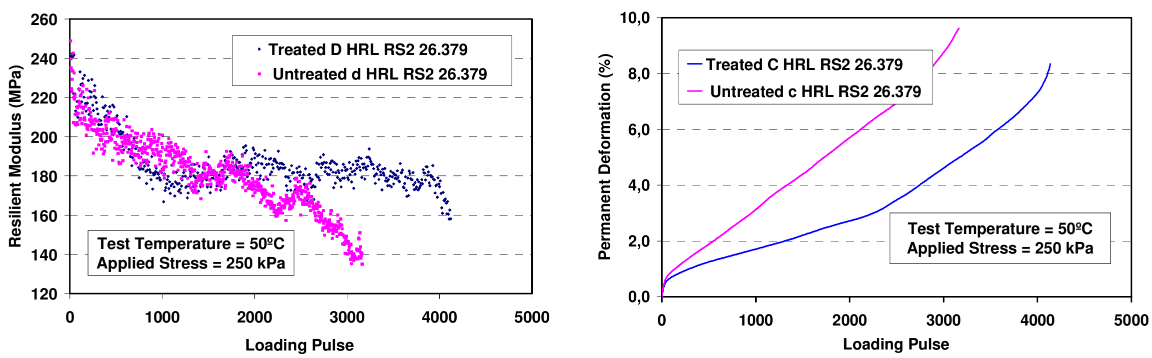
The test results reveal that the rejuvenation effect of Eco-PenTack is clear. A question may be proposed whether the treated PA mixture is still stable enough to bear the traffic loading in daily service time in case the rejuvenation degree is too high. The treated and untreated porous asphalt cores were taken out of the pavement for mechanical tests. For a relevant comparison purpose, the attention was paid to take each pair of the treated and untreated cores as close as possible to have identical structure, composition, as well as the similar traffic experience in service time.

Figure 3 and Figure 4 present the dynamic creep test results, i.e. the resilient modulus and permanent deformation against a number of loading repetition, respectively. Figure 3 (I) shows the treated core with a lower resilient modulus than the untreated one, meaning rejuvenating or softening effect on the aged binder in PA mixtures, particularly in the first 2000 loading repetitions. Furthermore, the modulus of the untreated core decreases more remarkably against the loading repetitions than that of the treated one, meaning that the micro defects in PA starts growing, coupled with stress accumulating and dissipating under the dynamic loading pulses. Figure 3 (II) demonstrates that there is no much difference in the permanent deformation in the first 3000 loading repetitions; afterwards the permanent deformation increases much faster than that of the treated cores, implying that the micro-damage in it grows more rapidly and the pavement lost its bearing capacity. On the other hand, the treatment has also a healing effect on the micro-cracks in the PA pavement. Figure 4 presents the dynamic test results of the second pair of cores from the same piece of pavement. Figure 4 (I) shows that there is not much difference in the modulus between the treated and untreated cores in the first 2000 loading repetitions, then the modulus decreases very rapidly in a form of saw-tooth. Figure 4 (II) clearly demonstrates that the permanent deformation develops much quicker than that of the treated core from the beginning of the test. It could be concluded that the rejuvenation treatment helps to soften the aged asphalt, heal the micro-defects in PA mixtures, thus to improve the stability and bearing capacity of PA pavement.



(I) Resilient modulus (II) Permanent deformation

Figure 3: Dynamic creep test results of first pair of PA cores out of Dutch motorway A12



(I) Resilient modulus (II) Permanent deformation

Figure 4: Dynamic creep test results of second pair of PA cores out of Dutch motorway A12

3.2 Field test results

It remains a major subject to improve the durability and extend the life time of PA pavement. A large scale field test was carried out, for example on Dutch highways A6, A50 and A73 in 2010 and 2011, aiming at finding out a practical and efficient way to do the maintenance of porous asphalt. Some of the test results will be presented and discussed.

Figure 5 presents 2 photos, showing the application of Eco-PenTack at night (see Photo A) and open to the traffic next morning immediately after the treatment. The advantage of the night maintenance is to avoid traffic congestion during the day, particularly in the rush hours.

(A) Application Eco-PenTack at night (B) Immediately open to traffic next morning

Figure 5: Application of Eco-PenTack at night and open to traffic next morning

Figure 6 shows the surface characteristics of the treated and untreated porous asphalt. Compared with the untreated PA surface texture, Eco-PenTack homogeneously penetrates (or runs) into PA mixture through the voids, still with a very thin film on top of the stone aggregates.

(A) Before the treatment (B) A few hours after the treatment

Figure 6: Surface structure of porous asphalt pavement before and after the treatment

The laboratory test results reveal that the Eco-PenTack treatment does rejuvenate the aged binder, but does not influence the stability of PA pavements. The question is whether the treatment has any influence on the functional requirements of PA pavements, particularly concerning the initial skid resistance due to the presence of a very thin film on the top of the aggregate surface shown in Figure 6 (B).

Table 1 lists the field test results - effect of Eco-PenTack treatment on the functional properties of PA pavement. The test results include brake deceleration rate, skid resistance and water drainage properties. For porous asphalt pavements, the brake deceleration rate and skid resistance should be above 5.2 m/s² and 0.38, respectively. The brake deceleration rate is most important concerning the safety, since it can be correlated to the brake distance of a vehicle as it travels with a certain speed, for instance 80km/hour. As shown in the Table, the brake deceleration rate and skid resistance of the test section are indeed lower than that of the reference (untreated), but almost meet the minimum requirements (with the exception of the skid resistance of treatment -2). The initial low skid resistance appears to be correlated with the presence of a very thin film on the top of aggregates. 90% of the skid resistance of treated section will come back after 1 day under the traffic, which will gradually remove the thin film from the top of the aggregates. Therefore, a speed limit sign (70-90km/hour) is erected on the side of the pavement, as shown in Figure 5 (B), in the first a few days after the treatment. The results also show that the water drainage power is only slightly influenced by the treatment, meaning no significant clogging of the voids structure by sprayed materials after treatment. The PA pavement keeps its original open structure; this means that the treatment has no influence on the noise level as reported in reference [14].

Table 1: effect of Eco-PenTack treatment on the functional properties of PA pavement

Test section	Test Length	Brake deceleration rate	Skid resistance	Water drainage (Bekerproef)		
				Test -1	Test - 2	Test -3
Reference	100m	6,99 m/s²	0.45	32 sec	>180 sec	65 sec
Treatment - 1				72 sec	58 sec	>180 sec
Treatment - 2		5.22 m/s²	0.36			
Treatment - 3				100 sec	>180 sec	>180 sec
Treatment - 4		5.31 m/s²	0.38			
Treatment - 5				71 sec	50 sec	48 sec
Treatment - 6		5.24 m/s²	0.38			

Notes: Brake deceleration rate (remvertraging in Dutch) and skid resistance done directly after the treatment
Water drainage test done 14 days after the treatment

3.3 LCA investigation results

In recent years, there has been increasing attention to environmental impact and sustainability of asphalt pavements. As a result, the government encourages and awards industrial enterprises to purchase and use environmental friendly and sustainable raw materials, as well as reduce emissions and energy. The environmental performance is measured using an environmental life cycle assessment (LCA). The purpose of the LCA is to establish a reliable and accurate quantitative environmental profile which includes all environmental interventions (raw materials, emissions and energies) during the total life cycle of the product ("from cradle to grave"). Referring to this development, the LCA profile of road maintenance systems was studied in accordance with LCA NEN 8006:2004 (which follows the framework of NEN-EN-ISO 14040) based on a planned life time of 32 years [15,16].

Figure 7 presents a comparison of environmental profile of Eco-PenTack maintenance system over a conventional maintenance system used intensively nowadays for PA pavement maintenance. The result shows that Eco-PenTack maintenance system has a more favorable environmental profile over the conventional system, for instance, nine of ten environmental impact categories of Eco-PenTack are about 25% lower. The less frequent replacement of asphalt PAC involves less maintenance, so less energy and raw materials for bitumen production and construction of porous asphalt is needed.

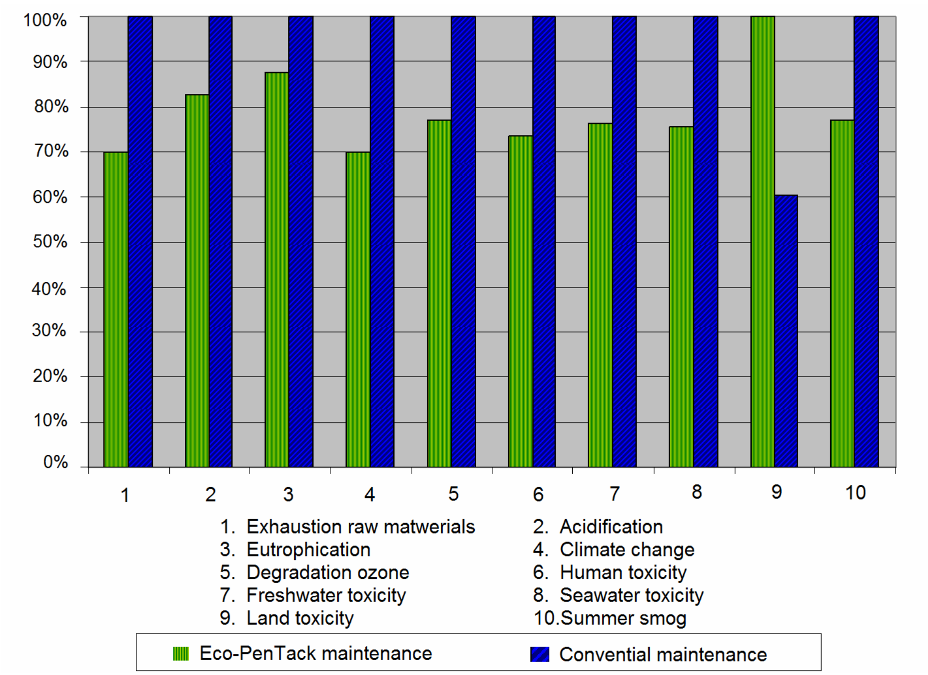


Figure 7: A comparison of environmental profile of Eco-PenTack maintenance system over a conventional maintenance system used intensively nowadays for PA pavement maintenance

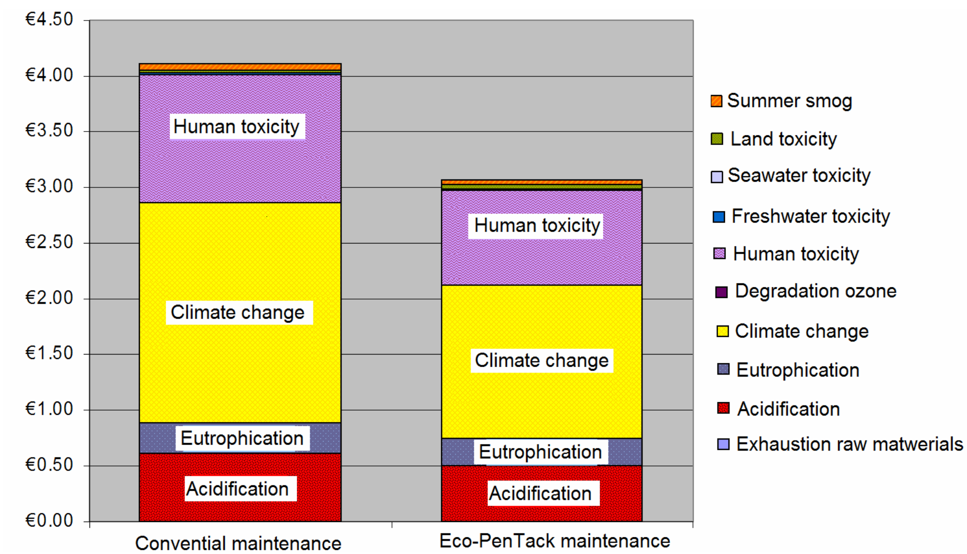


Figure 8: A comparison of environmental impact in terms of shadow costs of Eco-PenTack maintenance system with conventional maintenance system applied widely for PA pavements

Figure 8 demonstrates a comparison of total environmental impact of porous asphalt with Eco-PenTack system versus conventional system in terms of shadow costs, estimated the damage to society caused by the environmental inputs. It is clear that porous asphalt with Eco-PenTack maintenance system has an average about 25% lower environmental impact than that with conventional maintenance system. The difference is mainly due to the larger contributions of climate change and human toxicity due to a fact that the Eco-PenTack maintenance system has a lower environmental score for most environmental items. It is certain that the choice for organic vegetable additives gives an environmental improvement.

It is concluded that the Eco-PenTack maintenance of PA pavement is better than the present conventional maintenance system on all environmental issues, except land ecotoxicity.

4 CONCLUSIONS

Based on the test results and LCA calculations presented in this paper, the following conclusions can be drawn:

1. Eco-PenTack shows a clear rejuvenation effect on the aged binder out of PA pavement.
2. The Eco-PenTack treatment not only shows a rejuvenation effect on porous asphalt, but also improve the integral stability, probably due to the rejuvenation effect in combination with healing effect as suggested by the dynamic creep test results.
3. The Eco-PenTack treatment does not virtually influence functional properties of porous asphalt. The initial skid resistance and brake deceleration rate just above the limit requirement concerning the safety issue, but the skid resistance will come back shortly after open of the road to traffic. The noise emission level and drainage effect of porous asphalt is almost not affected by the treatment.
4. LCA study shows that The result shows that the Eco-PenTack maintenance system has a more favorable environmental profile over the conventional system. This is associated with the choice of organic vegetable additives, which contribute to an environmental improvement.

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