Eleventh International Conference on the Bearing Capacity of Roads,
Railways and Airfields, Volume 2 – Hoff, Mork & Saba (eds)

Asphalt reinforcement: A proven economic and ecological asphalt rehabilitation method

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ABSTRACT: Asphalt reinforcement products manufactured using polyester fibres have successfully been applied in pavement rehabilitation for more than 40 years. Their outstanding performance has helped to increase maintenance periods, which provides a substantial financial cost saving but also a very positive ecological effect, in form of a reduction in the use of exhaustible resources and reduced traffic disruption.

This performance history impressively highlights the application of asphalt reinforcement.

A number of factors which influence the performance of an effective asphalt reinforcement have been identified. Recent research has focused on a couple of these influence factors which are summarized in this paper.

1. Surface characteristics of the raw material and their effect on the in-situ activated tensile strength
2. Elongation underneath the asphalt layer during dynamic loading and the influence on lifetime expectation

A cost comparison between the rehabilitation methods is given as well as a detailed description of the calculation of CO2 emissions.

Keywords: Asphalt reinforcement, Long term bonding strength, CO2 savings

1 INTRODUCTION

Asphalt reinforcement has been used worldwide for many years to delay or prevent reflective cracks in asphalt layers. Using asphalt reinforcement can clearly extend the fatigue life and therefore the maintenance intervals of rehabilitated asphalt pavements. Currently there are a number of different products and systems of different raw materials (e.g. Polyester, Glass, Polypropylene…) available in the market. It is not disputed that all these systems have a positive effect, however there are essential differences in the behaviour and effectiveness of such systems.

2 PAVEMENT FAILURE DUE TO REFLECTIVE CRACKING

Cracks appear in asphaltic pavements due to external forces, such as traffic loads and temperature variations. The temperature influence and the dynamic loading over time leads to the binder content in the asphalt becoming brittle. High stresses at the bottom of a pavement,

DOI: 10.1201/9781003222897-4

from external dynamic loads, such as traffic, can cause cracks which propagate from the bottom to the top of a pavement (bottom-up cracking). In order to delay the propagation of those cracks into the new layers an asphalt reinforcement of high tenacity Polyester can be installed. The reinforcement increases the resistance of the overlay against high tensile stresses and distributes them over a larger area, thereby reducing the risk of local overstressing which would result in cracks.

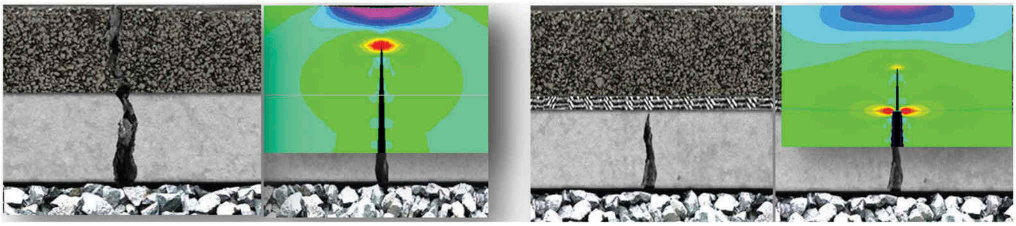

Figure 1. Simulated stress distribution with FE-Method, without (left) and with reinforcement (right) (Montestruque, 2002).

3 MOBILIZATION OF TENSILE FORCES

Typically the testing procedures, to determine the tensile strength and elongation (e.g. ISO EN 10319:2015), of Asphalt reinforcements are undertaken in "air" and not embedded in asphalt. An asphalt reinforcement improves the stress-strain properties of an asphalt pavement by adding tensile strength into the asphalt system. However, other properties (other than the in air measured reinforcement stiffness) are influencing the performance of an asphalt reinforcement and that asphalt/reinforcement interface bond is an important influence factor in transferring tensile forces into reinforcement on the contact surface. The performance of an asphalt reinforcement should ideally be determined as a composite, with asphalt and reinforcement considered together. Many tests have been performed in the past decades to demonstrate the performance of asphalt reinforcement produced with high tenacity Polyester fibres. The aim of such tests was to replicate, as close as possible, the installed in-service composite behaviour in laboratory conditions, whilst also trying to qualify the important parameters which influence the behaviour of an asphalt reinforcement.

3.1 *Bond stiffness*

De Bondt, 1999, published "Anti-Reflective Cracking Design of (Reinforced) Asphaltic Overlays", which was the last phase in his Ph.D. program and a 5 year research project at the Delft University of Technology. De Bondt determined the relevance and influence of different parameters on reflective cracking in asphalt overlays, and performed comparative investigations on different commercially available products in the market at that time. He found that one of the most important parameters is the bonding of the reinforcement to the asphalt, he defined as 'bond stiffness'. De Bondt determined the equivalent bond stiffness in reinforcement pull-out tests on asphalt cores taken from a trial road section. Parts of the results are presented in Figure 2`, for full details the reader may refer to the full publication. De Bondt determined that the equivalent bond stiffness of a polyester reinforcement was by far the most effective of all products investigated. The importance of the bituminous coating for flexible grids has a significant influence. De Bondt found that in flexible grids like a polyester reinforcement the stresses were transmitted via direct adhesion between strands and asphalt – hence the coating plays a vital part to the ultimate performance.

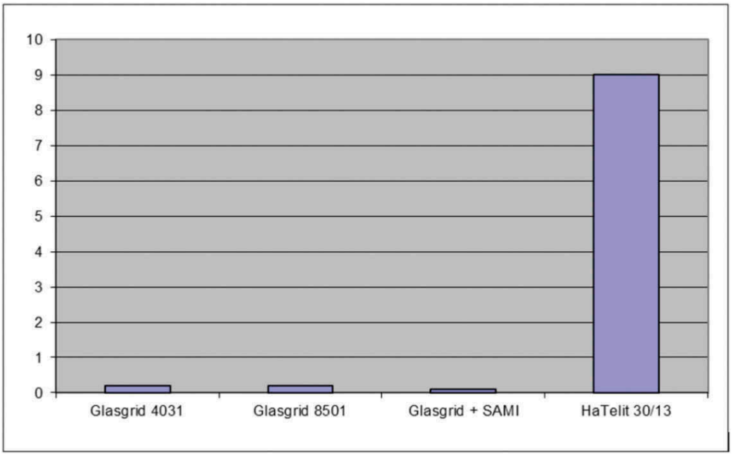

Figure 2. Equivalent bond stiffness (ceq,rf in N/mm/mm²) of different investigated products.

By using finite element models, De Bondt calculated the improvement factors for reinforcements based on material stiffness (EArf) and pull-out stiffness (ceq,rf). With a product stiffness of ~900 N/mm and a pull-out stiffness (ceq,rf) of about 9, the polyester reinforcement achieves an improvement factor of 3.5 in the simulation compared to a control section. (i.e. achieves a number of load cycles 3.5 times the number of cycles for the control section without reinforcement before reflective cracks reappear). From this research it is evident, that a good bonding of the reinforcement to the asphalt is very important for the performance of asphalt reinforcement. The combination of high reinforcement stiffness (Polyester) and high bond stiffness (Bitumen impregnation) create a high improvement factor for the overlay life of an asphalt pavement.

3.2 *Bonding strength*

To mobilize tensile forces in the reinforcement a good bonding between the asphalt layer and the integrated reinforcement is essential. Based on the German guideline ZTV Asphalt-StB 07/13 the shear force within the testing procedure according to Leutner should not be lower than 15.0 kN between the binder course and the surface layer.

Figure 3. Drill core with reinforcement (after testing).

Table 1 shows the results of drill cores tested at the University RWTH Aachen, 2018. These exemplary results show that the bonding strength is not significantly influenced by a bitumen coated Polyester grid.

Table 1. Comparison of shear forces of unreinforced drill cores and HaTelit reinforced drill cores acc. to Leutners method.

	without reinforcement		with reinforcement	
Temperature[°C]	mean value shearing force[kN]	mean value shearing distance[mm]	mean value shearing force[kN]	mean value shearing distance[mm]
20°C	26,1	3,9	24,9	3,8

3.3 *Fibre surface structure*

A Study on Geosynthetic-Reinforced Asphalt Systems, was published by Luming, 2018. This research presents a study on various aspects relevant to geosynthetic-reinforced asphalts. Section II of this thesis presents the experimental research that was conducted using overlay testing involving geosynthetic-reinforced asphalt specimens. The standard overlay test has been designed to evaluate crack propagation in asphalt concrete using a fatigue loading mechanism that induces tensile and shear stresses. The experimental study presented in Section II adopted this test to evaluate the effectiveness of the different interlayers in retarding the reflective cracking from an old asphalt into a new overlay. The asphalt specimens were tested in the standard overlay test along with geosynthetic-reinforced asphalt specimens. In addition, an image acquisition system was used to track propagation of cracks during overlay tests, see Figure 4.

Figure 4. Test set up for shear fatigue test.

Four types of reinforcement were tested. Each reinforcement had the same mesh size and the same coating to eliminate a couple of potential variables and to provide a better understanding of the influence of the raw material. Polyester (PET), Glass fiber and Polyvinyl alcohol (PVA) were tested.

Table 2. Tested asphalt reinforcement from different raw materials.

	Reinforcement 1	Reinforcement 2	Reinforcement 3	Reinforcement 4
Raw material	PVA	PET	Glass	Glass
Tensile-strength[kN/m]	50	50	50	100

Results and conclusions from this tests.

Parts of the results are presented here, for full details the reader may refer to the full publication, Luming, 2018. With the opening and closing of the simulated existing crack, the cross-crack initiates and propagates from the tip of the simulated crack towards the top surface of the asphalt concrete. Overall, the reinforced asphalt specimens showed better fatigue performance than the unreinforced asphalt concrete. The PVA and PET fibres are more compatible with the asphalt concrete than the glass fibre, thus they can better interact with the asphalt specimen at later fatigue life. The normalized load of the PVA reinforcement at the end of phase 4 was the highest, indicating the best performance of this material in enhancing the shear resistance of the asphalt concrete over fatigue life. The PET reinforcement shows second best results, close to them of PVA. The performance of the glass fibre reinforced specimens was not as good as the polymer reinforced specimens in terms of retarding the load decline. This could be attributed to the varied compatibility of the reinforcement with the asphalt concrete. PVA and PET consist of polymer fibres which are more compatible with the asphalt concrete in the stiffness of the materials than the glass fibre.

4 ELONGATION INFLUENCING THE LIFETIME

4.1 *Function of fatique*

The textbook definition of fatigue theory states that fatigue cracking initiates at the bottom of the flexible layer due to repeated and excessive loading, and it is associated with the tensile strains at the bottom of the HMA layer (Huang, 1993). The fatigue cracking in cracked pavements can be significantly delayed, by reducing the tensile strains at the bottom of a flexible asphalt layer (Figure 5).

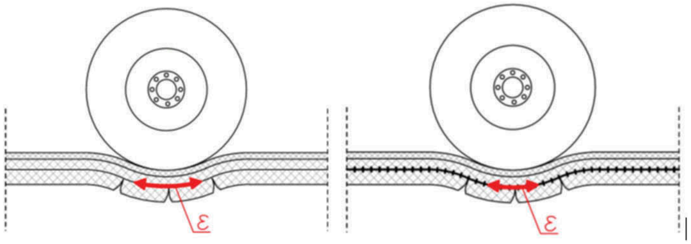

Figure 5. Schematic view of the fatigue cracking mechanism in pavement cross section without and with reinforcement.

According to the function of fatigue:

$$N_f = k_1 (1/\varepsilon_t)^{k_2}$$

N_f = allowable load repetitions of a pavement (until failure occurs)
k_1 = coefficient of fatigue
k_2 = exponent of the fatigue function
ε_t = elongation on the bottom of the asphalt layer [%]

From specialist literature the value mentioned for the coefficient factor of fatigue k1 is 2.0 × 10-12. For k_2, the exponent of fatigue function, is 5.0. At a vertical deformation of 0.5mm during a loading cycle an elongation of 0.0001% is measured below the asphalt layer. A small reduction in the elongation below the asphalt layer already has significant effects on the allowable loading cycles. Detailed figure are presented in Table 3.

Table 3. Calculated loading cycles until failure occurs.

Reduction of elongation	Elongation[$\mathcal{E}_t$]	Loading cycles[N_f]	Improvement Factor
Reference	$\mathcal{E}$=0,000100%	2.00×10^8	-
-5%	$\mathcal{E}$=0,000095%	2.99×10^8	1.5
-10%	$\mathcal{E}$=0,000090%	3.99×10^8	2.0
-20%	$\mathcal{E}$=0,000080%	6.10×10^8	3.0

4.2 *Effects of an asphalt reinforcement on the function of fatigue*

In a diploma thesis by Höptner, 2010, the benefits of asphalt reinforcement in road rehabilitation by using a modified rutting simulator have been investigated. The aim of this research was to analyze the influence of an asphalt reinforcement on reducing the deformation in pavements. The setup has been prepared according to realistic pavement design. The pre-cracked specimens have been located on an elastic rubber foundation which simulates the base course (Figure 6). The force has been applied by a rubber wheel. For the test set up a standard asphalt design has been chosen, with a 60mm binder course (AC 16 B S) and a 40mm surface course (SMA 8 S). The specimen was prepared in a roller sector compactor. In the first step the binder layer (including the simulated crack) was prepared.

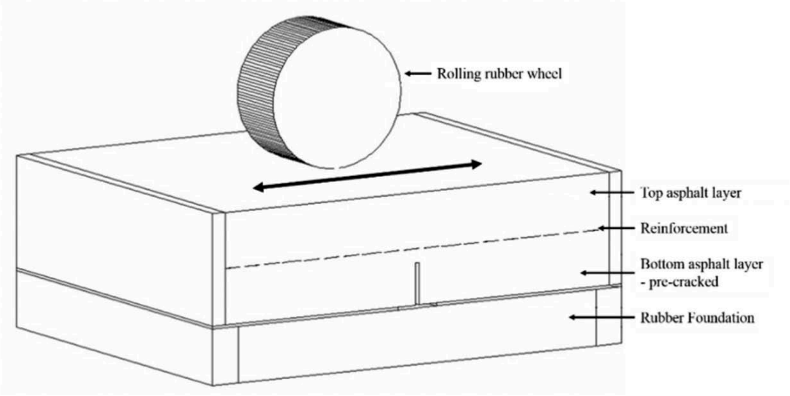

Figure 6. Test set-up cyclic loading test (schematic).

After preparing the binder course (including a simulated crack) specimens with and without reinforcement were produced. The reinforced specimen was impregnated with a bituminous emulsion (C67B4-OB) in accordance with the installation guideline of the producer of the asphalt reinforcement (Figure 7).

A force of 700N has been applied onto the specimen by a rolling rubber wheel, which is equivalent to a 10 t axle load. Two identical asphalt specimens have been produced, with, and without polyester reinforcement. The deformation from loading cycle 50.000 to the end of the testing at

Figure 7. Pre cracked specimen with asphalt reinforcement.

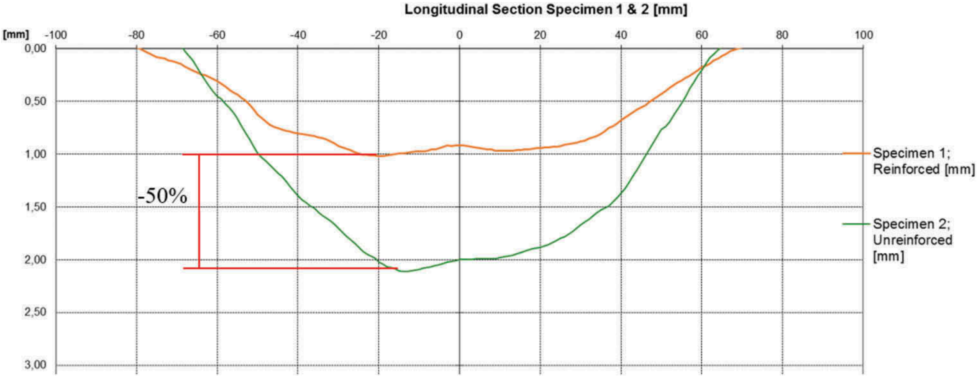

Figure 8. Deformation with and without Polyester reinforcement of an asphalt specimen between 50.000 and 60.000 loading cycles.

60.000 loading cycles was, without reinforcement, 2.1mm. The measured deformation with reinforcement, only was 1.0mm. This results in a reduction of 50% in deformation. (Figure 8).

5 ECONOMICAL AND ECOLOGICAL ASSESSMENT

5.1 *Executed project – district road "Rosenstraße", Ochtrup, Germany*

The Rosenstrasse in Ochtrup leads directly to the border crossing to the Netherlands and is therefore characterised by an extremely high volume of trucks. More technical details of the project can be found in (Elsing and Schröer 2005). The project started already in 1996 and from the very beginning on, the project was scientifically monitored and independently evaluated (TÜV Rheinland, LGA Bautechnik, 2009). The Rosenstrasse was repaired over its entire carriageway width due to substance damage in the form of net cracks. Both the binder course and the base course were also extremely cracked and in very poor condition. The service life for a full lining was assumed to be 15 years. For financial and time reasons, it was decided not to mill out the base and binder courses and to lay the asphalt reinforcement directly onto the binder course after milling off the surface course. This was to prevent the existing cracks from quickly penetrating into the new surface course and thus extend the rehabilitation interval. During execution, the asphalt reinforcement was laid according to the installation instructions and then covered with 5 cm asphalt concrete 0/11. The assumptions made at that time were verified and the durability of the road was evaluated. After 15 years the road was in excellent condition. No cracks were found along the entire length. The adhesive bond according to Leutner was still 24 kN (Quiel, 2013). After 15 years, the road condition can be regarded as equivalent to a full rehabilitation with changing all existing cracked asphalt layers. Until today, after 23 years, the road is in perfect condition and no rehabilitation had to be carried out. In this way, sustainable renovation costs could be avoided. The use of asphalt reinforcement has proven to be a successful rehabilitation measure in its entirety.

5.2 *Cost comparison of this project*

Lying on the conservative side, only the costs of maintaining the cracked binder course were considered in this rehabilitation project. In the case of the asphalt reinforced version, the material costs of the reinforcement and the costs of installing the reinforcement are incurred. The cost of milling the binder course, the material costs of the new binder course and its paving and compaction are saved. The direct cost savings for the selected reinforced version were > 34% in 1996.

5.3 *Cost comparison in general*

A current comprehensive analysis of the costs of various rehabilitation methods was carried out on the basis of a bachelor thesis (Claußen, 2019). This included the pricing of a fictitious construction site in the Wismar (East part of Germany) area. The rehabilitation method of replacing the binder course and surface course was compared with the method of replacing the surface course using an asphalt layer, as described in the example above. In the conventional variant, 4 cm of surface course and 6 cm of binder course are to be milled out and placed again. In the reinforced version, only the surface is milled off and the asphalt reinforcement is laid on top of the existing cracked binder. The costs for the conventional variant are € 144,591.3 for 5000 m² and € 84,711.3 for the reinforced variant. Also on the basis of this example a saving of 41% of the costs can be determined.

International experience shows that the percentage of the direct cost savings are also in the range of 35% - 40%, although the prices for building materials, transport and labour vary considerably. More roads could therefore be rehabilitated for the same investment.

5.4 *CO_2 savings*

The CO_2 emissions were idendified on the basis of a concrete road maintenance measure. A detailed description of the calculation of CO_2 emissions is given in (Brzuska, 2019). The result shows that more than 60 % of the CO_2 emissions were caused solely by the production of asphalt mixes and the associated processes. The reason for the high CO_2 emissions during the production of asphalt mix is the high energy consumption. A simplified transfer of the results of this construction measure to the Rosenstrasse construction measure mentioned above gives a good estimate of the CO_2 savings for this renovation option. Here, 6 cm of binder course was retained and the asphalt reinforcement was laid on top of it. Comparison: Conventional method - replacement of binder course and surface course - with the method - laying asphalt reinforcement on the binder course. Conservatively, only the CO_2 emissions resulting from the saving of the mix for the binder course are taken into account. The CO_2 emissions resulting from the production of the base course from (Brzuska, 2019), were also assumed to be on the conservative side for the production of the binder course. CO_2 emissions caused by the arrival and departure of employees, the transport of construction machinery, the extraction and transport of asphalt granulate required for the production of mixes were not taken into account. This alone results in a CO_2 saving of 24.3 t CO_2 per rehabilitated road kilometer. Another aspect that contributes significantly to CO_2 savings is the reduction of construction time. This means that the road can also be opened to traffic earlier, leading to a reduction in traffic jams caused by the construction site. In North Rhine-Westphalia for example, 50 % of all traffic jams are caused by construction sites.

6 SUMMARY

The use of asphalt reinforcement has proven to be a successful rehabilitation measure in its entirety. Placing the reinforcement directly on the cracked binder instead of replacing all asphalt layers is a highly cost-effective and environmentally friendly solution. Less CO_2 is caused and due to the faster construction time, traffic jams are reduced which additionally saves CO_2.

The use of asphalt reinforcements reduces the rehabilitation intervals significantly. In order to reach the longest possible service life of the pavement the reinforcement needs to be robust against mechanical damage during installation and compaction of the asphalt and the later dynamical loading. Additionally the reinforcement must have a direct mobilization of tensile forces in the asphalt system, and should not reduce the bonding strength between the asphalt layers. As described in the paper polymer raw materials such as PET and PVA show an extreme high mobilization of tensile forces and combined with a bitumen coating the bonding strength is nearly undisturbed and this together ensures a maximum long service life.

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