Parameter to Ensure a Durable Grid-Reinforced Asphalt Pavement

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ABSTRACT: Asphalt reinforcement products manufactured using polyester fibers have successfully been applied in pavement rehabilitation for more than 40 years. Their outstanding performance has helped to increase time between maintenance, which has not only had a substantial financial cost saving but also a very positive ecological effect, in form of a reduction in the use of exhaustible resources and less construction traffic. The practice impressively shows the function of asphalt reinforcement, but the theoretical aspects of the function are not completely researched. Through the introduction of a design model for reinforced roads, we have fixed the factors of influence which are responsible for a durable effective asphalt reinforcement. Research has focused on following topics: 1) surface characteristics of the raw material and their effect on the in-situ activated tensile strength; and 2) elongation underneath the asphalt layer during dynamic loading and the influence on lifetime expectation

1 INTRODUCTION

The conventional method for the rehabilitation of cracked concrete or asphalt pavements is the installation of new asphalt layers. But a new overlay does not make the cracks disappear; they are still present in the old asphalt layers. Because bituminous bound materials are unable to withstand the high tensile stresses resulting from external forces like traffic and temperature variations, these cracks rapidly propagate into the new asphalt overlay. This phenomenon, known as reflective cracking, is one of the major problems associated with the use of asphaltic overlays.

In order to tackle the problem of reflective cracking and to therefore prolong the service life of a pavement, asphalt reinforcement grids have been used all over the world for more than 40 years, proven to be a very effective solution. The use of these products can clearly extend the pavement service life and therefore increase the maintenance intervals of rehabilitated asphalt pavements (EMPA, 2017; Yang, 2018). In addition to the longer life time of reinforced pavements also the maintenance costs per year and the amount of energy used for the maintenance will be significantly reduced.

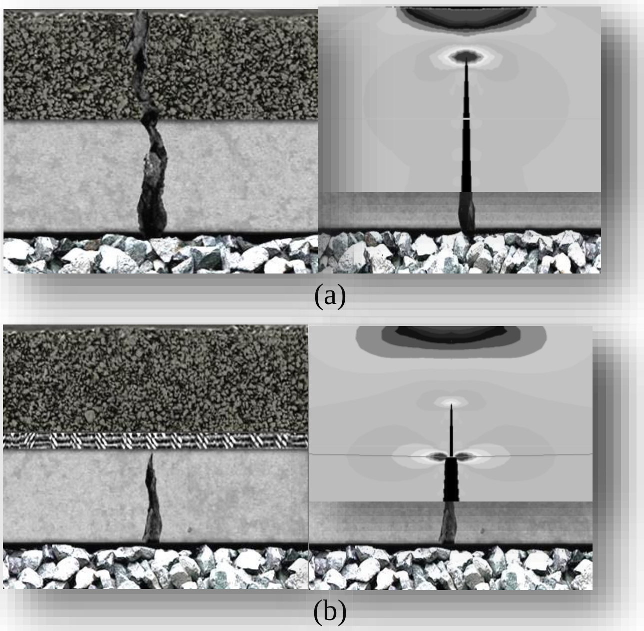
Sustainable designs and construction methods are subject to our corporate and social responsibility and can be decisive for the choice of products and rehabilitation methods in the future. Currently there are a number of different asphalt reinforcement products and systems of different raw materials (e.g. Polyester, Glass, Carbon, Polypropylene…) available in the market. It is not disputed that all these systems have a positive effect in the battle against reflective cracking (Vanelstraete and Francken, 1996; Norambuena-Contreras and Gonzalez-Torre, 2015). However, there are essential differences in the behavior and effectiveness of each system.

The objective of this paper is to present important required characteristics for the asphalt reinforcement, so that a good performance and a durable asphalt pavement rehabilitation can be achieved.

2 PAVEMENT FAILURE DUE TO REFLECTIVE CRACKING

Reflective cracking consists on the propagation of cracks from a deteriorated layer to the surface of a new overlay and is the major modes of failure in rehabilitated pavements (Elseifi, 2015). It is well known that cracks appear due to external forces, such as traffic loads and temperature variations. The temperature influence and the dynamic loading over the time leads to the binder content in the asphalt becoming brittle. Cracking starts from the top of a pavement and propagates down (top-down cracking). On the other hand, high stresses at the bottom of a pavement, from external dynamic loads, such as traffic, leads to cracks which propagate from the bottom to the top of a pavement (bottom-up cracking).

In order to delay the propagation of cracks into the new layers an asphalt reinforcement of high tenacity polyester can be installed. In providing reinforcement, the polyester grid structurally strengthens the pavement section by changing the response of the pavement to loading (Koerner, 2012). The reinforcement increases the resistance of the overlay to high tensile stresses and distributes them over a larger area, thereby reducing the peak shear stresses at the edges of the cracks in the existing old pavement (Figure 1).



(a)

(b)

Figure 1. Simulated stress distribution with FE-Method, without (a) and with reinforcement (b)

3 ASPHALT REINFORCEMENT AGAINST REFLECTIVE CRACKING

With the purpose of analyze and quantify the improvement of the crack resistance when using an asphalt reinforcement, several studies have been developed during the last decades. Following we would like to present latest research results.

3.1 *EMPA*

Research in the Switzerland about the application of asphalt interlayers for road pavements, published in 08.2017 (EMPA, 2017). The aim of the research work was to obtain information on the effectiveness of different asphalt interlayers and the corresponding service life of the pavement. Special focus was given on the time dependent development of cracks.

Both laboratory and field tests showed that asphalt reinforcement systems can delay the development of cracks, thereby extending the life of asphalt pavements. Further, it was observed that asphalt reinforcements (systems B and C) are more effective if no SAMI is used.

3.2 *University of Texas*

A study regarding geosynthetic-reinforced asphalt systems, published in 08.2018 (Yang, 2018). This research presents a study on various aspects relevant to geosynthetic-reinforced asphalts. Specifically, this thesis has been organized in three stand-alone sections: 1) Literature Review; 2) Overlay Testing; 3) Shear Fatigue Testing.

Section II 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 geosynthetics 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. Four types of reinforcement has been tested by using the same mesh size and the same coating to better see the influence of the raw material.

Table 1. Asphalt reinforcement types analyzed

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

3.2.1 *Summary and conclusions from overlay tests*

Parts of the results are presented here, for full details the reader may refer to the full publication [2]. 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 fibers are more compatible with the asphalt concrete than the glass fiber, 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 fiber 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 fibers which are more compatible with the asphalt concrete in the stiffness of the materials than the glass fiber. Except of the above mentioned research in several further case studies PET grids performed equally or better than stiff glass or carbon grids. So it is clear that there must be different factors which are influencing the efficiency of an asphalt reinforcement.

3.3 *University of Cantabria/University of Bío-Bío*

Norambuena-Contreras and Gonzales-Toores (2015) tested eight different types of geosynthetics used as anti-reflective cracking systems. The reflective cracking test results showed that the use of a geosynthetic produced a reduction on the average crack opening in all cases evaluated. Nevertheless, it was found that geosynthetics that present high tensile strength do not necessarily present a high contribution on retarding the crack propagation in asphalt pavements.

Additionally, it has been seen that the resistance to deterioration of materials that composes geosynthetics is a more decisive factor on their subsequent behavior than the material itself.

4 DECISIVE CHARACTERISTICS OF AN ASPHALT REINFORCEMENT

4.1 *Mobilization of tensile forces*

An asphalt reinforcement improves the stress-strain properties of an asphalt pavement by adding tensile strength into the asphalt system. As described in the previous chapter several studies demonstrate that polyester as raw material shows better results in preventing reflective cracking than stiffer raw materials e.g. glass.

This makes clear that other properties are influencing the mode of action of an asphalt reinforcement. Most important is the transmission of tensile forces on the contact surface. Simple tests show that much more force is needed to pull out a shoelace out of a piece of butter than pull out a steel wire which is much stiffer. A similar principle is valid for reinforced concrete. If the steel bar is smooth and not ripped, nearly no tensile force can be activated.

Most of the testing procedures, to determine the tensile strength and elongation (e.g. ISO EN 10319:2008), are undertaken in “air” and not embedded in asphalt. The performance of an asphalt reinforcement should always be determined as a composite, with asphalt and reinforcement.

Many tests have been performed in the past decades to prove the performance of asphalt reinforcement produced with high tenacity polyester fibers. The aim of such tests was to reproduce, in the best possible way, the conditions from the asphalt pavements in laboratory conditions, whilst also trying to determine the important parameters which influence the behavior of an asphalt reinforcement.

4.2 *Bond stiffness*

In 1999 de Bondt 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.

He found that one of the most important parameters is the bonding of the reinforcement to the asphalt, defined as bond stiffness (ceq,rf). 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 (Bondt, 1999).

The equivalent bond stiffness of a polyester reinforcement proved to be by far the most effective of all products investigated. The importance of the bituminous coating for flexible grids becomes clear. 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.

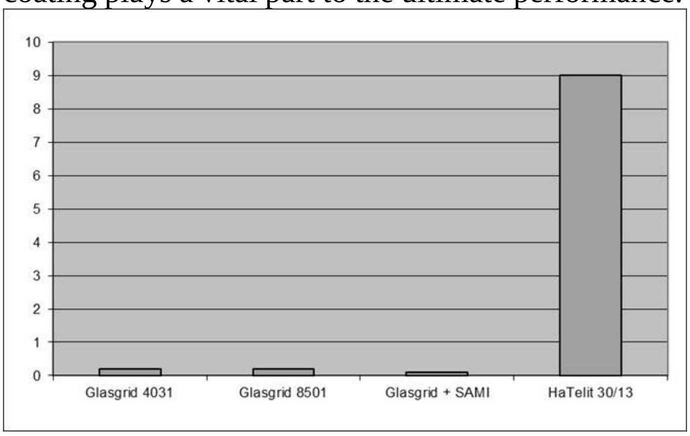


Figure 2. Equivalent bond stiffness (ceq,rf in $N/mm/mm^2$) of different investigated products

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 de Bondt's simulation.

From this it becomes clear, that a good bonding of the reinforcement to the asphalt is very important for the effectiveness of asphalt reinforcement. Only the combination of high reinforcement stiffness (Polyester) and high bond stiffness (Bitumen impregnation) can create such an improvement for the overlay life of an asphalt pavement.

4.3 *Bond strength*

To mobilize tensile forces in the reinforcement a good bonding between the asphalt layer and the integrated reinforcement is essential. If the grid is not able to sufficiently adopt the high strains from the peak of a crack, the reinforcement cannot be effective.

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. Table 2 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 > 60 % bitumen coated polyester grid.

Table 2. Comparison of shear forces of unreinforced drill cores and HaTelit reinforced drill cores acc. to Leutners method.

Temperature	Without Reinforcement (mean values)		With Reinforcement (mean values)	
	Shearing force (kN)	Shearing distance (mm)	Shearing force (kN)	Shearing distance (mm)
20°C	26.1	3.9	24.9	3.8

4.4 *Long term bonding strength*

In order to provide an example of long term bonding strength using polyester asphalt reinforcement grid, the project Rosenstrasse located in the Northwest German town of Ochtrup is presented. The Rosentrasse is a highly trafficked road, being one of the main connections to the nearby border of the Netherlands. Before its rehabilitation in 1996 the road revealed severe alligator cracking, longitudinal and transverse cracking in large scale.

The designed solution was to take up the cracked wearing, binder and base course and reinstall those layers. The alternative solution was the installation of a high modulus polyester grid as asphalt reinforcement over the cracked binder course, in which the thickness of the new wearing course should remain 50 mm.

Because of an extraordinarily economical advantage this alternative solution had been chosen. After milling off the 50mm surface course a PET grid as asphalt reinforcement was installed, and covered again with a 50mm 0/11 AC asphalt layer. The whole project was finished in summer 1996. Directly from the beginning on this construction project has been investigated intensively and results has been presented on different conferences e.g. (Elsing and Schröer, 2005).

In 2009 the TÜV Rheinland LGA Bautechnik GmbH was commissioned to record the cracking and assess the condition of “Rosenstrasse” along the length repaired in 1996. The final report stated that after 13 years of intensive traffic the road is in an excellent condition and no cracks are visible.

In context of a masters-thesis in 2013 the “Rosenstrasse” again have been evaluated (Quiel, 2013). Drill cores have been taken and the interlayer bond acc. to Leutner had been checked. Between the asphalt bearing course - Polyester reinforcement - and upper asphalt layer a maximum shear force of 24 kN was measured. After evaluating the whole data record of the “Rosenstraße” it was found, that the condition, after a lifetime of 17 years, was still very good.

The > 60 % bitumen coating of the polyester reinforcement seems to be the key factor to ensure not just a short term bonding strength but also a long term bonding strength.

4.5 *Thermal expansion coefficient*

High modulus polyester is a flexible raw material with a maximum tensile strain less than 12%. The coefficients of thermal expansion of polyester and asphalt (bitumen) are very similar (Table 3). This leads to very small internal stresses between the PET fibers and the surrounding asphalt (similar to reinforced concrete). For this reason Polyester does not act as an extrinsic material in the asphalt package. The installation of a PET-grid as asphalt reinforcement improves the flexibility of the structure and avoids peak-loads over a cracked existing layer into the overlay, therefore it delays reflective cracking.

Table 3. Comparison of the thermal expansion coefficient

Material combination	Thermal expansion coefficient	Ratio
Concrete/ Steel	1.3×10^{-5} / 1.0×10^{-5}	~ 1 : 1
Asphalt/ Polyester	6.0×10^{-4} / 1.6×10^{-4}	~ 1 : 4
Asphalt/ Fiberglass	6.0×10^{-4} / 4.5×10^{-6}	~ 1 : 130

5 FUNCTION OF FATIGUE

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 3).

According to the function of fatigue:

$$Nf = k_1\,(1/\varepsilon_t)^{k_2} \qquad (1)$$

where Nf = allowable load repetitions of a pavement (until failure occurs); k1 = coefficient of fatigue; k2 = exponent of the fatigue function; and εt = elongation on the bottom of the asphalt layer [%].

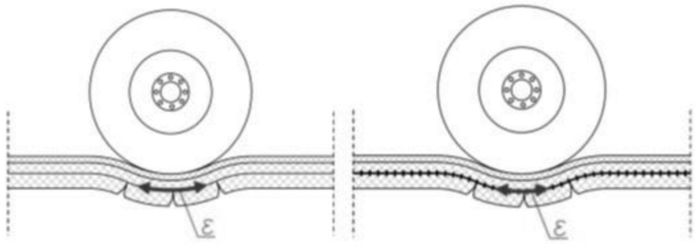


Figure 3. Schematic of fatigue cracking mechanism in pavement cross section without and with reinforcement.

From specialist literature the value mentioned for the coefficient factor of fatigue k_1 is $2.0x10^{-12}$. 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 4.

Table 4 Calculated loading cycles until failure occurs

Reduction of elongation	Elongation [ε_t]	Loading cycles [N_f]	Improvement Factor
Reference	ε= 0,000100%	2.00×10^8	-
-5%	ε= 0,000095%	2.99×10^8	1.5
-10%	ε= 0,000090%	3.99×10^8	2.0
-20%	ε= 0,000080%	6.10×10^8	3.0

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

In a diploma thesis by Höptner [9] 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 4). The force has been applied by a rubber wheel.

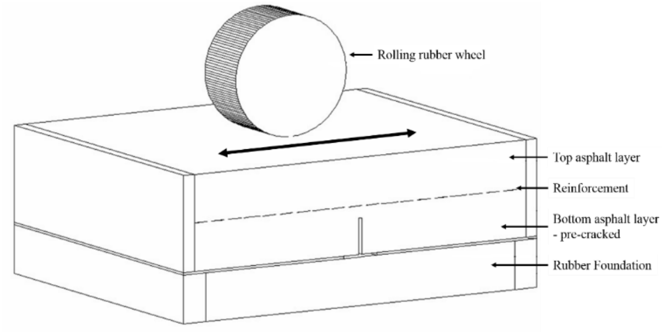


Figure 4. Test set-up cyclic loading test (schematic)

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. 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 5).

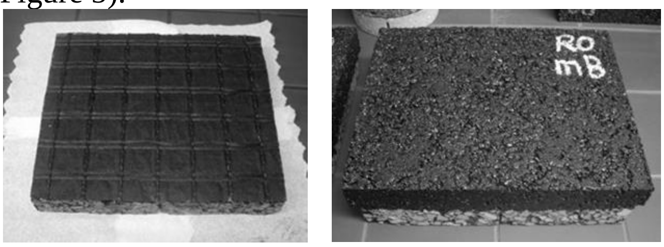


Figure 5. Pre cracked specimen with asphalt reinforcement

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 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 6).

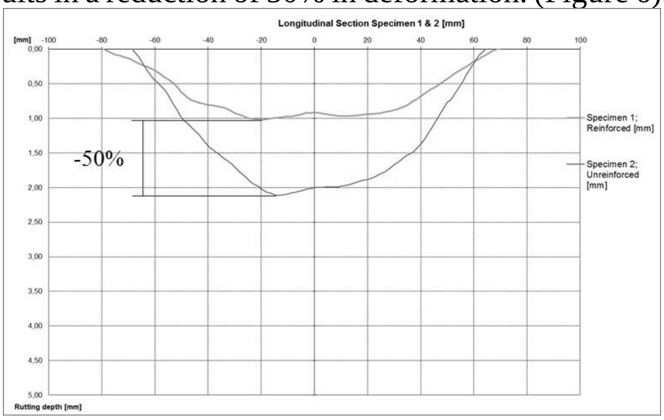


Figure 6: Deformation with and without polyester reinforcement of an asphalt specimen between 50.000 and 60.000 loading cycles.

6 CONCLUSION

Reflective cracking occurs in cracked pavements rehabilitated with a simple asphalt overlay. To retard this phenomenon many researches have demonstrated that the use of asphalt reinforcement grid shows great benefits in the road rehabilitation. However, despite the positive experience obtained over the world for more than 40 years, the asphalt reinforcement has not been sufficiently taken into account in the design of asphalt pavements. With this paper further steps have been done to come closer to a design method, introducing important parameters which should be taken into account for a good pavement performance and a durable reinforced rehabilitation. Nevertheless more research has to be done to verify the results by further empirical testing and developing a numerical model. The presented latest research indicate bituminous coated polyester reinforcement seems to be ideal as asphalt reinforcement against reflective cracking in asphalt overlays, resulting in an extension of the service life of a rehabilitated pavement.

REFERENCES

De Bondt, A.H., "*Anti-Reflective Cracking Design of (Reinforced) Asphaltic Overlays*", Ph.D.-thesis, Delft, Netherlands, 1999.

Elseifi, M. 2015. Presentation 2: Mitigation strategies for reflective cracking in pavements. *TRB Webinar* – Mechanisms and Mitigation Strategies for Reflective Cracking in Rehabilitated Pavements.

Elsing, A.; Schröer, S. 2005. Experience from more than 30 years of asphalt reinforcement with polyester grids, *15th International Road Federation World Meeting*, Bangkok.

EMPA. 2017. *Einsatz von Asphaltbewehrungen im Erhaltungsmanagement von Trag- und Deckschichten*, Application of Asphalt interlayers for road pavements, Eidgenössische Materialprüfungsanstalt (EMPA).

Höptner, A. 2010. "*Nachweis der Wirksamkeit von Asphaltbewehrungsgittern zur Verhinderung von Reflexionsrissen*", Diplom Thesis, Dresden University of Applied Sciences, Dresden.

Huang, Yang H. 1993. "*Pavement Analysis and Design*", Prentice Hall", New Jersey.

Koerner, R. M. 2012. Designing with Geosynthetics. Xlibris Corporation.

Norambuena-Contreras, J., Gonzalez-Torre, I. 2015. Influence of geosynthetic type on retarding cracking in asphalt pavements. *Construction and Building Materials*, 78: 421-429.

Quiel, M. 2013. Einsatz von Asphalteinlagen im Asphaltstrassenbau. Master Thesis, Münster University of Applied Sciences, Münster.

RWTH Aachen University. 2018. CERTIFICATE No.: 1808991, Testing of the layer bond of drill cores with and without reinforcement, Aachen, Germany, 08.2018.

TÜV Rheinland LGA Bautechnik. 2009. Test report BBV 0913526, Zustandserfassung und –bewertung der Rosenstraße in Ochtrup und Erstellung eines Vergleichs des Zustands der Fahrbahn vor und nach der Sanierung mit einem Asphaltgitter 1996. Weimar, Germany, 24.08.2009.

Vanelstraete, A., Francken L., 1996. Laboratory testing and numerical modelling of overlay systems on cement concrete slabs. *Proceedings of the Third International RILEM Conference*, Maastricht, Netherlands.

Yang, Luming. 2018. *A Study on Geosynthetic-Reinforced Asphalt Systems*, Master Thesis, University of Texas, Austin.