POLYESTER ASPHALT REINFORCEMENT GRIDS - THE ANSWER TO REFLECTIVE CRACKING AND THE BASIS FOR SUSTAINABLE ROAD MAINTENANCE

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Abstract. Asphalt reinforcement grids made of high modulus polyester (PET) are widely used and have proven their performance in countless projects worldwide as an effective treatment against reflective cracking in asphalt overlays. The high resistance of polyester against installation damage and dynamic loading combined with an effective interlayer bonding and easy installation are key factors for the success of asphalt reinforcement. The good performance of the asphalt reinforcement on the other hand is the basis for the increase of pavement life and thus a sustainable use of resources. This paper will present the positive experience gained over the past 40 years in numerous projects worldwide; in parallel the latest research in this field will prove the effectiveness of high modulus polyester asphalt reinforcement. Combining the above information will then lead to a comparison of Embodied Carbon Dioxide for different rehabilitation methods showing the sustainability of using polyester asphalt reinforcement to extend pavement life.

Keywords: Asphalt Reinforcement, Polyester, Pavement Rehabilitation, Pavement Life, Sustainability.

INTRODUCTION

Asphalt reinforcement has been used all over the world for many years to delay or even prevent the development of reflective cracks in asphalt layers. Using asphalt reinforcement can clearly extend the pavement life and therefore increase the maintenance intervals of rehabilitated asphalt pavements.

This increase in pavement life does have the positive effect that not only the maintenance costs per year but also the amount of energy used for maintenance per year can be significantly reduced. Environmental and climatic protection is gaining an ever increasing importance, the road construction industry may therefore benefit from adopting these solutions in order to assist in tackling climate change.

Similarly the design of asphalt overlay and maintenance projects has to aim at reducing the overall embodied energy and thereby make them more sustainable. The need for sustainable designs and construction methods is now appearing more and more in corporate and social responsibility statements and could eventually become a criterion for the selection of construction methods.

1 BASICS: REFLECTIVE CRACKING AND ASPHALT REINFORCEMENT

As is well known, cracks appear in asphaltic roads due to external forces, such as traffic loads and temperature variations. The temperature influence leads to the effect that the binder content in the asphalt becomes brittle; cracking starts at 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 like traffic, leads to cracks which propagate from the bottom to the top of a pavement (bottom-up cracking).

A conventional rehabilitation of a cracked pavement involves milling off the existing top layer and installing a new asphalt wearing course. But cracks may still be present in the existing (old) asphalt layers underneath. Due to stress concentrations at the crack tips, caused by external forces from traffic and natural temperature variations, the cracks will continue to propagate rapidly to the top of the rehabilitated pavement.

Deteriorated concrete pavements are typically rehabilitated by installing new asphalt layers over the old concrete slabs. Temperature variations lead to a rapid crack propagation especially at the expansion joints to the top of the new asphalt overlay. In order to delay the propagation of cracks into the new asphalt layers an asphalt reinforcement of high modulus Polyester can be installed. The reinforcement adopts the peak stresses at the crack tip, distributes them over a larger area and thus increasing the resistance to reflective cracking.

The phenomenon of reflective cracking is a major concern for road engineers facing the problem of road maintenance and rehabilitation.

2 WHY POLYESTER REINFORCEMENT?

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. This leads to very small internal stresses between the PET fibres and the surrounding asphalt (similar to reinforced concrete). For this reason Polyester does act as a compatible material in the asphalt package. At this point it has to be mentioned that the aim of a PET-grid as asphalt reinforcement is not to reinforce asphalt in such a way as one reinforces concrete. The installation of a PET-grid as an asphalt reinforcement improves the flexibility of the structure, avoids peak-loads over a cracked existing layer into the overlay and thus delays reflective cracking.

As found by de Bondt (1999) the bonding of the material to the surrounding asphalt plays an important role in the performance of an asphalt reinforcement. If the reinforcement is not able to sufficiently adopt the high strains from the peak of a crack, the reinforcement cannot be effective. In his research, de Bondt determined an equivalent "bond stiffness" in reinforcement pull-out tests on asphalt cores taken from a trial road section. The equivalent bond stiffness of HaTelit® (Bituminous coated PET-grid) was found to be by far the best of all the commercial products investigated. De Bondt found that with flexible reinforcement grids the stresses are transmitted via direct adhesion between the reinforcement strands and the asphalt.

Furthermore the reinforcement must be robust to resist the stresses and strains during installation, overlaying and compaction of the asphalt (Fig. 1 & Fig. 2). Even during installation, the reinforcement may be subjected to high load when trafficked by tracked pavers or "blacktop" trucks. Very high forces can also be applied to the individual strands of the reinforcement by aggregate movement in the hot blacktop during compaction. Polyester as a raw material exhibits very good resistance to installation damage compared to other products with stiffer, more brittle raw materials (tBU 2003).

Fig. 1: Installation and ...

Fig. 2: ... compaction of asphalt on a PET reinforcement grid

3 PROOF OF EFFECTIVENESS BY PROJECT EXPERIENCE

3.1 Project: Corso Giovanni Agnelli, Torino, Italy

In 2006 the Olympic Winter Games took place in Torino, Italy. Prior to this major event the "Corso Giovanni Agnelli", which is one of the main roads passing the Olympic stadium, was in great need of rehabilitation. The existing asphalt pavement showed severe cracking where almost every joint from underlying concrete slabs had reflected through the asphalt overlay. Therefore, the city of Torino decided to carry out a rehabilitation, which was undertaken in June 2005. Over a length of approximately 500 m a bituminous coated PET asphalt reinforcement grid was used. In order to obtain a comparison, a second area was rehabilitated without reinforcement.

In June 2005 the first section was rehabilitated using asphalt reinforcement. After milling off the existing asphalt wearing course, an asphalt levelling course was laid on the concrete slabs. HaTelit® was then installed (Fig. 3) in accordance with the manufacturer's installation guidelines, and was covered with a 40 mm layer of asphalt wearing course. Two weeks later, in July 2005, the second section was rehabilitated without reinforcement. Here a new 50 mm asphalt layer was installed directly on top of the concrete slabs after milling off the existing wearing course (Fig. 4).

Fig. 3: Installation of asphalt reinforcement

Fig. 4: Installation of 50 mm wearing course directly on concrete

Project monitoring: In May 2006 the first assessment of the road took place. The reinforced area did not show any cracking, however in the unreinforced area, the first signs of cracking were visible over the expansion joints of the concrete base (Fig. 5).

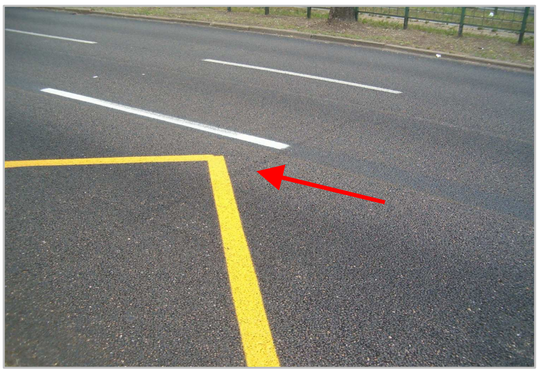


Fig. 5: First signs of cracking in the unreinforced area in May 2006

July 2009: Some 4 years after the rehabilitation, the second assessment of the road took place. At this time, the HaTelit® reinforced area still did not show any cracking (Fig. 6). In contrast, almost every expansion joint from the concrete slabs had reflected through the new overlay in the unreinforced area (Fig. 7).

Fig. 6: HaTelit® reinforced area in July 2009

Fig. 7: Unreinforced area in July 2009

August 2010: 5 years after the initial rehabilitation the reflective cracking in the unreinforced section was so severe that a full overlay replacement was required and done in August 2010. In this particular project the lifetime of the unreinforced section was only 5 years which is a good fit with the assumption in the following comparison.

Conclusion: The use of HaTelit® has prevented the propagation of reflective cracks developing from the expansion joints of the concrete slabs while the unreinforced section showed first cracks already after one year and had to be rehabilitated again after 5 years of service. This example has proven again, that HaTelit® considerably delays the propagation of reflective cracks. It also proves a life extension factor of 3 - 4, compared to an unreinforced solution, with the associated cost savings resulting in a considerable reduction in cost of asphalt pavement maintenance. Further examples for the successful use of a bituminous coated PET-grid can be found on www.huesker.com.

3.2 Project: Salgado Filho Airport, Porto Alegre, Brazil

In 2001 the existing access to an aircraft maintenance hangar (up to Boeing 777) had to be resurfaced after more than 40 years of use. The existing pavement was made of 6.0 × 3.5 m concrete slabs, 300 mm thick. The slabs were bedded on a layer of gravel. The design involved the installation of a new 50 mm asphalt layer on the existing pavement. In order to prevent the propagation of the expansion joints, between the concrete slabs into the new asphalt layer, an asphalt reinforcement was specified in order to extend the fatigue life of the rehabilitated pavement.

As the asphalt reinforcement must always be placed between two bituminous layers, an asphalt levelling course was installed on the existing concrete pavement first. HaTelit® was installed on the levelling course, in 1.0 m wide strips, only over the expansion joints. To keep to the very tight time frame it was decided, on site, just to reinforce the heavily loaded inner part of the pavement. The outer parts, where the planes normally do not taxi, were left unreinforced. The reinforcement was covered with a 50 mm asphalt layer.

What initially was thought to be a pure practical solution, developed into an ideal demonstration of the effectiveness of Polyester asphalt reinforcement. It was now possible to compare directly, between an unreinforced, and reinforced pavement with a polyester grid. In October 2007, approx. 7 years after the rehabilitation, the first assessment of the pavement took place. The expansion joints in the unreinforced areas had already propagated to the top of the surfacing (Fig. 9). The presence of vegetation, visible in the developed cracks, led to the conclusion that these cracks had existed for some time. In contrast to this, the HaTelit® reinforced areas did not show any indications of cracking. The propagation of the expansion joints in the unreinforced areas can only be ascribed to the different temperature behaviour and the consequential horizontal stresses. As well as the temperature induced horizontal stresses the reinforced area was also exposed to the dynamic loads from the passing planes.

Fig. 8: Beginning of the taxiway

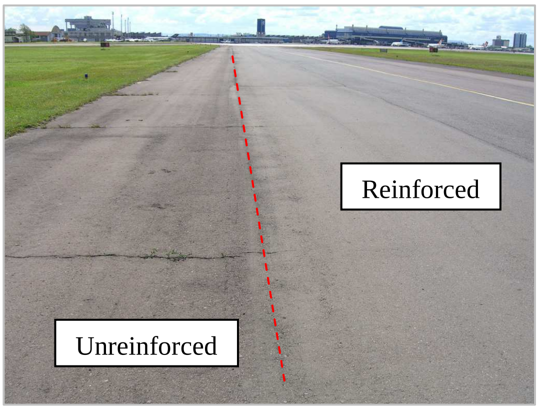


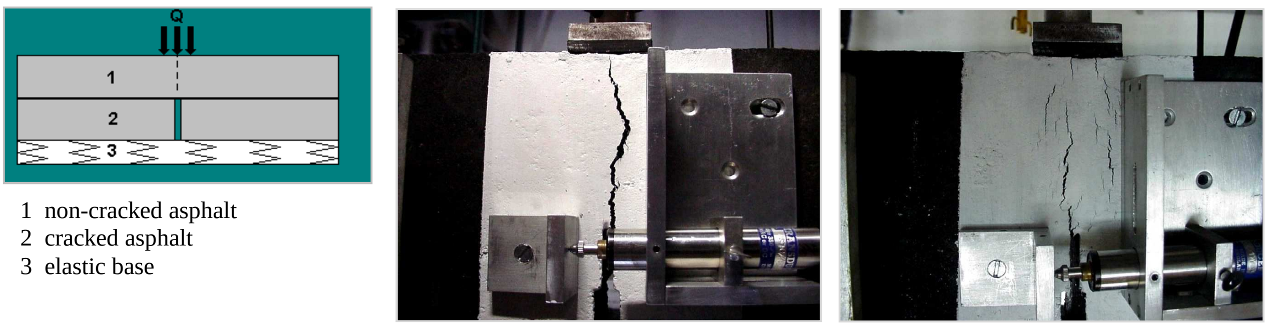
Fig. 9: Joints of the concrete slabs reflect in the area where no reinforcement was used

4 PROOF OF EFFECTIVENESS BY RESEARCH

The effectiveness of PET asphalt reinforcement is the key to sustainable rehabilitation of pavements. Parallel to the practical experience of the last 40 years with PET asphalt reinforcements, various laboratory tests and design methods exist, proving, that the lifetime extension factor is 3 - 4 times when using HaTelit®. The most significant research is presented hereafter:

4.1 Dynamic fatigue Tests (Bending and Shearing)

A full description and the results of a testing program performed at the Aeronautics Technological Institute in Sao Paulo, Brazil, were published by Montestruque in 2004. In this research program which started in 1999, an asphalt wearing course was applied over an existing crack in a detailed series of tests (Fig. 10). Both the bending mode and the shear mode were investigated under dynamic fatigue loading conditions. The results confirmed that HaTelit® considerably delays the penetration of cracks. Compared to the unreinforced samples, the HaTelit® reinforced asphalt layers were subjected to up to over 5 times the number of dynamic load cycles before a crack reached the surface. The crack pattern clearly shows that the reinforcement absorbs the high tensile forces and distributes over a larger area.



Unreinforced sample after 80,000 cycles

HaTelit® reinforced sample after 490,000 cycles

Fig. 10: Dynamic Testing at ATI (Brazil) - Bending Mode

4.2 Slagterlaan Simulation acc. to A.H. de Bondt

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 ($c_{eq,rf}$). 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 Fig. 11, for full details the reader may refer to the full publication.

The equivalent bond stiffness of HaTelit® turned out to be by far the best of all the commercial products investigated. The importance of the bituminous coating for flexible grids becomes clear. De Bondt found that in flexible grids like HaTelit® the stresses were transmitted via direct adhesion between strands and asphalt – hence the coating plays a vital part to the ultimate performance.

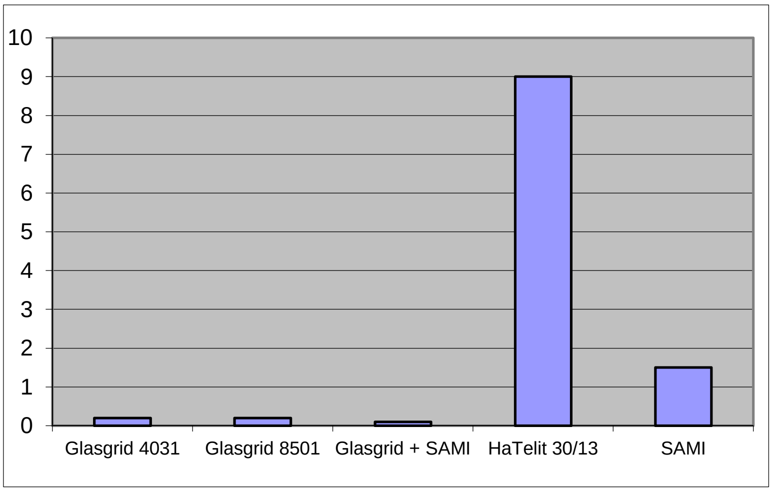


Fig. 11: Equivalent bond stiffness ($c_{eq,rf}$ in N/mm/mm²) of different commercial products

By using finite element models, de Bondt calculated the improvement factors for reinforcements based on material stiffness (EA_{rf}) and pull-out stiffness ($c_{eq,rf}$). With a product stiffness of ~900 N/mm and a pull-out stiffness ($c_{eq,rf}$) of about 9, HaTelit® achieves an improvement factor of 3.5 in de Bondt's Slagterlaan 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 and high bond stiffness can create such an improvement for the overlay life of an asphalt pavement.

5 EMBODIED ENERGY AND EMBODIED CO_2

5.1. DEFINITIONS

5.1.1. Embodied Energy (EE)

A vast field of research work is ongoing around the world to determine the embodied energy of individual products, services and construction materials. Treolar has provided the most well known definition that embodied energy is: *"The quantity of energy required by all of the activities associated with a production process, including all activities upstream to the acquisition of natural* *resources and the share of energy used in making equipment and in other supporting functions i.e. direct energy plus indirect energy*." (Treolar, 1994)

Basically, this means all the input energy required to make a material, such as a clay brick. This includes the energy to extract the clay, transport it to the brick-works, mould the brick, fire it in the kiln, transport it to the building site and put the brick into place. It also includes all the indirect energy required, i.e., all the energy required to manufacture the equipment and materials needed to manufacture a brick, e.g. trucks, kilns, mining equipment, etc. All have a proportion of their energy invested in that single brick. The embodied energy is typically expressed in MJ/kg.

5.1.2. Embodied CO_2 (ECO_2)

Similarly the embodied CO_2 of a material is a calculated value of the quantity of CO_2 derived due to the extraction, processing and transportation of the material to the site based on the typical form of energy used. This value is expressed as the mass in kg of embodied CO_2 for 1 kg of material, shown as kg CO_2 / kg. (WRAP Report, 2011)

5.1.3. Difference of Embodied Energy (EE) and Embodied CO_2 (ECO_2)

The main difference is that two products with the same amount of EE can have a different amount of ECO_2 because the energy used for production may for example have been generated from coal fired power plants with high CO_2 output while for the other product mainly renewable energy sources may have been used. For example, two factories could manufacture the same product with the same technology and efficiency, resulting in the same EE per kilogram of product produced. The total CO_2 emitted by both, however, could vary widely dependent upon the source of energy consumed by the different factories.

5.1.4. Sustainability

Since the 1980's *sustainability* has been used in the sense of human sustainability on planet Earth and this has resulted in the most widely quoted definition of sustainability and sustainable development, that of the Brundtland Commission of the United Nations (Wikipedia, 2012): *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations - Brundtland Commission, 1987)*

In the context of the construction industry this does mean that different construction techniques and designs for a specific project are compared for their ECO_2 as an indicator for their sustainability. As a matter of fact the ECO_2 is only one criterion beside social and economic considerations. However, the request for sustainability is now appearing more and more in corporate and social responsibility (CSR) statements on both the client's and contractor's side.

5.2. LEVEL OF DETAIL

From the above definitions one can identify a certain variation of EE and ECO_2 for individual products being used on a specific construction site. For this technical comparison, however, a simplified approach has been chosen considering only the ECO_2 for the materials used on site without considering the individual transport distances and their installation. The authors of this paper appreciate that this comparison is not in line with the typical "cradle to gate" approaches used in this field, but it has been previously shown that the following comparison is sufficiently detailed to compare the two construction techniques without compromising on the accuracy of the results.

5.3. DATA SOURCE

The ECO_2 values ("Carbon Footprint") used in the following chapters are taken from the latest ICE Inventory of Carbon & Energy V2.0 (Hammond, 2011). The University of Bath has created the ICE embodied energy & embodied carbon database which is the freely available. The aim of this work is to create an inventory of embodied energy and carbon coefficients for building materials. The data base is structured into 34 main material groups e.g. Aggregates, Aluminium, Asphalt etc.

5.4. EXAMPLES OF EMBODIED CO_2

The amount of embodied carbon dioxide per kg of material can vary significantly as can be seen in Table 1. The more processing and energy that is required to achieve the final product the higher is the ECO_2.

Especially energy intensive processes like the production of cement are producing a high amount of CO_2. Cement manufacturing releases CO_2 in the atmosphere both directly when calcium carbonate is heated, producing lime and carbon dioxide, and also indirectly through the use of energy if its production involves the emission of CO_2.

Table 1. Examples of embodied carbon dioxide (ECO2) in construction materials

Material	kg ECO_2 / kg of material	Note
Aggregate	0.0052	gravel or crushed rock
Aluminium	9.16	-
Asphalt	0.076	6% binder content
Bitumen	0.55	-
Cement	0.74	UK weighted average
Concrete 16/20	0.10	unreinforced
Reinforced Concrete RC 40/50	0.188	high strength applications / precast
PVC General	3.10	-
Polyester	1.93	derived from HDPE
Steel	1.46	average UK recycled content
Steel	2.89	Virgin steel
Source: ICE Inventory of Carbon & Energy V2.0		

6 COMPARISON OF EMBODIED ENGERGY FOR REINFORCED AND UNREINFORCED ASPHALT OVERLAYS

The report *"Sustainable Geosystems in Civil Engineering Applications"* commissioned by the Waste and Resource Action Plan (WRAP, 2010) has analysed geosystems as alternatives to standard designs used by civil engineers. Parallel to geosystems for ground engineering the report has identified that *"Reinforcement of the asphaltic or bound layers can increase the life of the surface layers, again by contributing to a strengthening of the bound layers. Such strengthening increases their ability to resist cyclic fatigue, thermal stresses during extremes of winter and summer temperatures, as well as increasing resistance to near-surface crack propagation."* (WRAP, 2010). The report clearly identifies that asphalt reinforcements can extend pavement life by limiting reflective cracking and thus providing more sustainable pavements as a consequence.

This paper aims to demonstrate the above referenced effect by comparing the ECO_2 based on the material consumption per year of lifetime of two construction techniques. One construction technique is the conventional rehabilitation of cracked overlays by milling and repaving, the second is a rehabilitation using PET asphalt reinforcement in the same process.

6.1 BASIS FOR CALCULATION

The example chosen for this comparison is a typical rehabilitation project with 5,000 m² of cracked wearing course to be replaced. Although the project size does not have any effect on the relative saving of ECO_2 it helps to give a better assessment for the saving potential.

Table 2. Basis for calculation

Project size	5,000 m²	
Asphalt thickness to be replaced	40 mm	
Density of asphalt	2,500 kg/m³ (compacted)	
Bituminous emulsion (70%)	0.3 kg/m² (unreinforced)	
Bituminous emulsion (70%)	1.0 kg/m² (reinforced)	Note (1)
HaTelit® asphalt reinforcement	0.3 kg/m² (made of PET)	
Improvement factor – reinforced to unreinforced asphalt	3 [-]	Note (2)
Design life (unreinforced):	4 years	Note (3)

Note (1): Required amount of bituminous emulsion for HaTelit® asphalt reinforcement over milled surfaces acc. to manufacturer's recommendations.
Note (2): The improvement factor of 3 for the life time of reinforced asphalt as compared to unreinforced asphalt has been selected on the lower side of the potential range of 3 - 4 to account other potential failure mechanisms which make rehabilitation necessary but are not related with reflective cracking.
Note (3): The design life of the unreinforced asphalt overlay has been chosen as 4 years since a typical crack propagation rate of approx. 10 mm / year would result in cracks reaching the surface of the new overlay after 4 years. The crack propagation rate of approx. 10 mm / year is of course project specific and could vary.

6.2 COMPARITIVE CALCULATION OF THE EMBODIED CO_2 FOR REINFORCED AND UNREINFORCED ASPHALT OVERLAYS

Table 3. Comparative calculation of embodied carbon dioxide

	Material consumption		kg embodied CO_2 per kg of material	embodied CO_2 in kg/m²	
				unreinforced	HaTelit® reinforced
Asphalt (~25 kg/cm)	100	kg/m²	0.076	7.60	7.60
Bituminous emulsion (70%, 0.3 kg/m²)	0.21	kg/m²	0.55	0.12	-
Bituminous emulsion (70%, 1.0 kg/m²)	0.70	kg/m²	0.55	-	0.39
HaTelit® asphalt reinforcement	0.30	kg/m²	1.93	-	0.58
Total embodied CO_2 for rehabilitation	kg/m²			7.72	8.57
Improvement factor	[-]			1	3
Design life (improved)	years			4	12
Total embodied CO_2 per year design life	**kg / m² / year**			**1.93**	**0.71**
ECO_2 saving per m² and year of design life					**63 %**
Total Project CO_2 saving					**73,200 kg**

In the above comparison it can be seen that a conventional (unreinforced) rehabilitation method results in 7.72 kg embodied CO_2 per m² for the materials used. The alternative design using a PET asphalt reinforcement results in 8.57 kg embodied CO_2 per m² due to the additional asphalt reinforcement and a higher amount of bituminous emulsion. The comparison of the ECO_2 for the rehabilitation project then has to be put into relation with the design life. The design life for the unreinforced overlay is set to 4 years until first cracking is likely to have reached the surface again. The reinforced overlay on the other side would last at least 3 times longer, i.e. 12 years.

The result is a saving of 63 % of ECO_2 per m² and year of design life for the HaTelit® reinforced overlay as compared to the unreinforced overlay. For a project of 5,000 m² to be repaved this would mean a total ECO_2 saving of 73,200 kg based on the significantly improved design life of 12 years.

CONCLUSIONS

This paper has shown that the use of an asphalt reinforcement made of high modulus polyester is an ideal method to delay or even prevent reflective cracking. The high resistance of polyester against installation damage and dynamic loading combined with an effective interlayer bonding and easy installation are key factors for the success of asphalt reinforcement. The project experience and research presented proves that the pavement life can be increased by a factor of 3 - 4 by using HaTelit® asphalt reinforcement.

Using this information combined with the amount of embodied carbon dioxide (ECO_2) of construction materials used for a typical pavement rehabilitation project, a comparison has been made between a reinforced and an unreinforced solution. The comparison clearly shows the significant savings of 63 % ECO_2 per year of design life of the reinforced as compared to the unreinforced overlay. This substantial saving is achieved by extending the pavement life and thus reducing the need for maintenance and the corresponding ECO_2.

Similarly to the saving of embodied carbon dioxide a significant cost saving per year of design life is achieved. This again shows that saving the environment and saving costs go very well hand in hand.

This paper has shown that asphalt reinforcement made of high modulus polyester does provide an efficient solution to save resources by extending pavement life and thus creating sustainable pavements.

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