Polyester geogrids as asphalt reinforcement - a sustainable solution for pavement rehabilitation

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ABSTRACT: The conventional method for 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 that result 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, a reinforcement grid made of high modulus polyester has proven to be a very effective solution. Geosynthetics as asphalt reinforcement have consistently shown outstanding results in addressing the issue of crack initiation and propagation, eliminating the damage caused by water intrusion that ultimately leads to the failure of the pavement structure. The increased pavement life achieved by the use of this technology not only prevents excessive disruption to traffic flow and local business, but it also demonstrates strong environmental and economic benefits. Through basic theory and practical experiences this paper will demonstrate the success and extended pavement life that can be achieved in both highway and airfield applications. Special attention is given to a comparison of Embodied Carbon Dioxide for different rehabilitation methods showing the sustainability of using polyester asphalt reinforcement to extend pavement life.

1 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.

2 CREATING AN ASPHALT REINFORCEMENT OVER ALMOST 40 YEARS

The idea of a reinforcing fabric for asphalt road construction first emerged in the early 1970s (Figure 1). The first experiences with geogrids were in the construction of earthworks and foundations, so the idea to use them in asphalt pavements was a logical next step.

The initial intention was that the embedded Geotextile layer was able to pick up the tensile stresses in the asphalt and prevent cracks from forming. However, it was soon realized that this principle did not work, but the product proved very useful at delaying the formation of reflection cracks in resurfaced roadways.

Even then polyester, abbreviated as PET, was a preferred raw material because of the compatibility of its mechanical properties with the behavior of asphalt. Since then many products made from different raw materials have been developed.

Figure 1. One of the first attempts to use a geogrid in asphalt pavement at the early 1970s

3 BASICS: REFLECTIVE CRACKING AND ASPHALT REINFORCEMENT

It is well known that cracks appear due to external forces, such as traffic loads and temperature variations. The temperature influence leads to the binder content in the asphalt becoming 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, such as, traffic, lead to cracks that 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 course, but cracks are still present in the existing (old) asphalt layers. As a result of stress concentrations at the crack tips caused by external forces from traffic and natural temperature variations, the cracks will 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 comprised of high tenacity polyester can be installed. 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. The reinforcement also provides a normal load to the crack surfaces, thereby increasing the aggregate interlock (shear resistance) between both crack surfaces and thus increasing the resistance to reflective cracking.

High modulus polyester (PET) 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 fibers and the surrounding asphalt (similar to reinforced concrete). For this reason Polyester does not act as an extrinsic material in the asphalt package, however at this point it should 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 asphalt reinforcement improves the flexibility of the structure and avoids peak-loads over a cracked existing layer into the overlay and through this mechanism reflective cracking is delayed.

As found by De Bondt (De Bondt 1999) the bonding of the material to the surrounding asphalt plays a critical 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 a bituminous coated PET-grid was found to be, by far, the best of all the commercial products investigated.

Furthermore, asphalt reinforcement must resist as much damage as possible from the stresses and strains applied during installation and overlaying / compaction of the asphalt. Very high forces can also be applied to the individual strands of the reinforcement by aggregate movement in the hot blacktop during compaction.

4 PRACTICAL EXPERIENCES

4.1 *Municipal Road Rosenstrasse, Ochtrup (Germany)*

The following project shall give an example of the successful use of asphalt reinforcement in roads. The project is located in the Northwest German town of Ochtrup. The road is a highly trafficked road. The majority of vehicles are trucks, because the road is one of the main connections to the nearby border of the Netherlands. Before rehabilitation, the road exhibited severe alligator cracking, longitudinal and transverse cracking in large scale. The original design called for milling, approximately 50 mm of the surface followed by installation of a new 50 mm asphalt surface course. Due to the problematic condition of the existing base, the expected lifetime of the new surface was only 2 years (Figure 2).

The more durable (but also much more expensive) solution would have been to remove the cracked binder and base course. An alternative to this solution was the installation of a Polyester Geogrid as asphalt reinforcement over the cracked binder course, where the thickness of the new wearing course would remain 50 mm. Therefore, the economical advantage had to be proven by a longer lifetime, which should be the main goal in most of these applications. The layers would have the same thickness, therefore the economical advantage results from the longer lifetime of the surface over the old cracked area.

After milling off the 50 mm surface course the asphalt reinforcement grid was installed, and covered again with a 50 mm 0/11 AC asphalt layer. The whole project was finished in the summer of 1996.

Figure 2. Surface after milling

4.1.1 *Project update: June 2002*

Six years after the repairs were carried out, the District's Chief Executive was asked for a condition report on the “Rosenstrasse”. In his answer, he commented as follows: "I'm happy to inform you that the repairs have fully stood the test of time. The use of the asphalt reinforcement system under the 0/11 asphalt layer has meant that, to this day, no cracks have appeared in the asphalt-concrete surface. This method was chosen at the time to avoid the necessity of the additional work required for the binder and base course."

4.1.2 *Project update: September 2009; Assessment by TÜV Rheinland*

The TÜV Rheinland is a leader in independent assessment services. In 2009, the TÜV Rheinland was commissioned to document the cracking and assess the condition of “Rosenstrasse” along the portion of the road that was repaired in 1996.

The appraisal compared the current condition with the condition that existed before repairs were carried out. This comparison allowed conclusions to be drawn about the effectiveness of the asphalt reinforcement system for delaying the occurrence of cracks propagated from the lower asphalt layers.

On August 24th 2009, a visual inspection was done in accordance with Working Paper No. 9 (by the German FGSV; Research Association for Transportation in Germany). The TÜV used the image documentation of the construction measures used in May 1996 as the basis for its assessment. The District's Chief Executive responsible at that time provided additional necessary information.

4.1.3 *Result*

After 13 years of use, the cracking condition value (ZWRIS) for the section of the road repaired with the Polyester grid in 1996 was determined to be excellent. The visual inspection of the road surface revealed almost no damage with the exception of two areas. The damage in these areas, however, was due to subsequent repair work on the drainage system. A few lateral cracks were discovered at one point on the outer edge of the road. Small cracks along the road surface were also found at a few other points on the outer edges (Figure 3).

The photos documenting the condition of the site in 1996 (Figure 4) show that the distance between the reinforcement system and the road edge was always around 150 - 300 mm. TÜV Rheinland also confirmed: "The entire remaining road area is free of cracks."

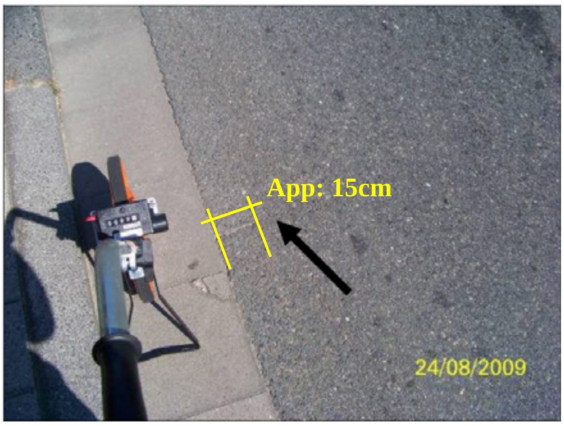

Figure 3. Lateral crack at the edge

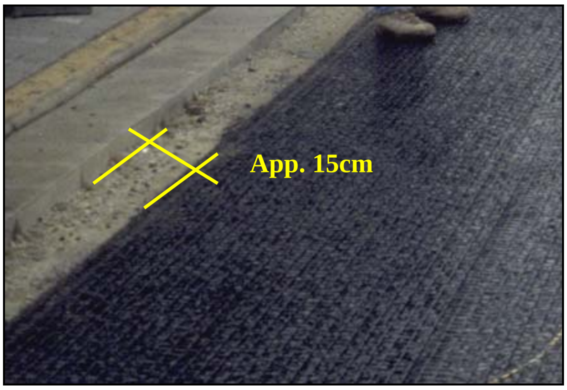

Figure 4. Fitted reinforcement (detail)

The condition assessment by TÜV Rheinland revealed that the “Rosenstrasse” in the city of Ochtrup has, in spite of constant heavy traffic, remained in good condition to this day. The deployment of the asphalt reinforcement system to effect repairs has completely stood the test of time. This measure has shown that a Polyester asphalt reinforcement can keep the condition of rehabilitated roads at a high level over extended periods of time.

4.2 *Salgado Filho Airport, Porto Alegre (Brazil)*

In 2001 the existing access to an aircraft maintenance hangar (used by aircraft as large as the Boeing 777, with a weight over 250 tons) had to be resurfaced after more than 40 years of use. The existing pavement was made of 5.0 × 3.5 m concrete slabs, 250 mm thick. The slabs were resting on a layer of gravel.

The rehabilitation design involved the installation of an asphalt leveling layer first. In order to prevent the propagation of the expansion joints from the concrete slabs into the new surface, an asphalt reinforcement made of high modulus polyester was to be installed. A 50 mm asphalt surface course was installed on top of the polyester reinforcement.

Because it was not possible to block the access for an extended period of time, the rehabilitation work had to be finished in just one night. In order to stay within this very tight time frame, it was decided to only reinforce the heavily loaded inner portion of the pavement. The outer portions, which are not typically subjected to the heavy loading of aircraft traffic, were left unreinforced.

What initially was thought to be a purely practical solution developed into an ideal demonstration of the effectiveness of an asphalt reinforcement grid. By only reinforcing a portion of the pavement and leaving the remainder unreinforced, a direct side-by-side comparison of the performance of the reinforced and unreinforced sections was possible.

In October 2007, approximately 7 years after the rehabilitation, the first assessment of the pavement took place. At that time the designer, the technical manager of the airport, and an employee of the reinforcement manufacturer were present.

The expansion joints in the concrete beneath the unreinforced pavement areas had already propagated to the top of the surfacing. The vegetation, visible in the developed cracks, led to the conclusion that these cracks had existed for some time. In contrast, the PET-grid reinforced areas did not show any indications of cracking (Figures 5 and 6). Because the unreinforced section was not subjected to aircraft traffic, the propagation of the expansion joints in these areas can be conclusively attributed to the horizontal stresses that resulted from changes in temperature. The areas reinforced with the polyester grid were subjected to both temperature-induced and aircraft traffic-induced stresses.

For further details the reader is referred to a paper prepared by Monser and Montestruque (Monser et al. 2010).

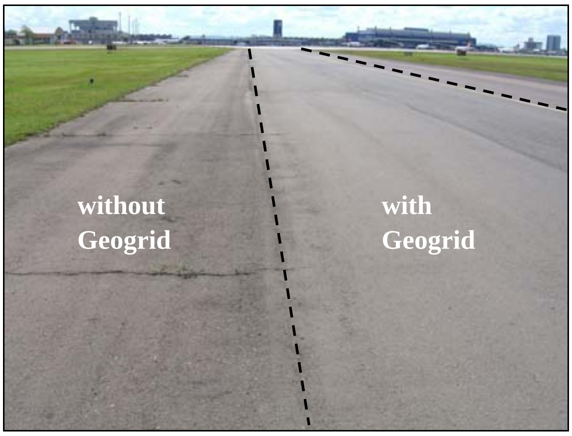

Figure 5. Overview of the studied section: view from the dockyards to the terminal

Figure 6. Joints of the concrete slabs reflect in the area where no reinforcement was used

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 (1994) 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".

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, 2010).

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: "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 (ECO_2) 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 ENERGY 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)*
Asphalt reinforcement	0.3 kg/m² (made of PET)
Improvement factor (reinforced to unreinforced asphalt)	3 (-)**
Design life (unreinforced):	4 years***

* Required amount of bituminous emulsion for HaTelit® asphalt reinforcement over milled surfaces acc. to manufacturer's recommendations.

** 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 (Montestruque et al. 2004).

*** 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 *Comparative calculation*

A comparative calculation of the embodied CO2 for reinforced and unreinforced asphalt overlays is presented on Table 3.

Table 3. Comparative calculation of embodied carbon dioxide

	Material consumption (kg/m²)	kg embodied CO_2 per kg of material	embodied CO_2 in kg/m²	
			unreinforced	reinforced
Asphalt (~25 kg/cm)	100	0.076	7.60	7.60
Bituminous emulsion (70%, 0.3 kg/m²)	0.21	0.55	0.12	-
Bituminous emulsion (70%, 1.0 kg/m²)	0.70	0.55	-	0.39
Asphalt reinforcement	0.30	1.93	-	0.58
Total embodied CO_2 for rehabilitation (kg/m²)			7.72	8.57
Improvement factor (-)			1	3
Design life (improved)			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 (kg)				73,200

In the above comparison it can be seen that a conventional (unreinforced) rehabilitation method results in 7.72 kg embodied CO2 per m² for the materials used. The alternative design using a PET asphalt reinforcement results in 8.57 kg embodied CO2 per m² due to the additional asphalt reinforcement and a higher amount of bituminous emulsion. The comparison of the ECO2 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 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.

7 CONCLUSIONS

Reflective cracking occurs in rehabilitated asphalt pavements. High tenacity Polyester as raw material is often chosen because of the high compatibility of its mechanical behaviour to the modulus of asphalt and its good behavior under dynamic loads. A bituminous coated Polyester asphalt reinforcement grid can show excellent results in delaying reflective cracking. This has been shown by numerous practical examples from the past several years.

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 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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