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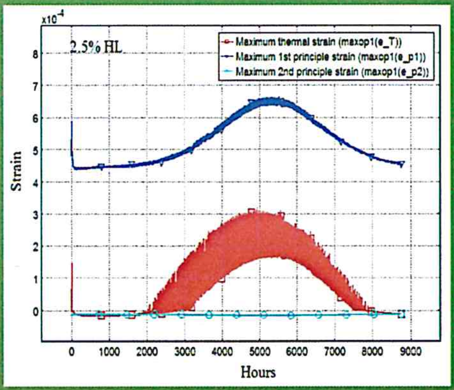

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ASPHALT REINFORCEMENT – A PROVEN ECONOMIC & ECOLOGICAL ASHPALT REHABILTIATION METHOD

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ABSTRACT

Asphalt reinforcement products manufactured using polyester fibres have successfully been applied in pavement rehabilitation for more than 45 years. Their performance has helped to increase maintenance periods, which provides a substantial financial and ecological benefit, in form of a reduced whole life costs, reduced use of finite resources and associated benefits (i.e., reduced traffic disruption).
The wider benefits of asphalt reinforcement and in particular those produced from polyester fibres are discussed. This paper identifies several key factors influencing the performance of asphalt reinforcement products and the performance of an asphalt reinforcement as a composite with asphalt and reinforcement considered together. Moreover, the sustainability benefits of asphalt reinforcement are discussed by assessing and quantifying the embodied carbon dioxide (ECO_2) of road pavement construction and maintenance processes to provide a baseline against which these processes can be measured, evaluated and compared.
A simplified comparison is presented whereby a conventional road pavement maintenance project is compared with and without asphalt reinforcement and provides a good estimate of the carbon dioxide (CO_2) savings for the rehabilitation method with asphalt reinforcement. More than 60 % of the CO_2 emissions generated during the entire construction phase are caused solely by the energy-intensive production of the asphalt mixes and the associated processes. This was the result of a detailed investigation of all CO_2 emissions in a conventional road pavement maintenance project. In comparison a CO_2 saving of 24.3 t CO_2 per rehabilitated road kilometre was identified in a project where the cracked binder is being reinforced instead of replaced. The recyclability of this asphalt reinforcement is also discussed to establish if it supports the move to a more circular economy.

Keywords: Asphalt Reinforcement, Polyester, Embodied Carbon Dioxide (ECO_2), Emission Savings, Recyclability

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. 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. Several road authorities have signed up to ambitions carbon emissions reduction plans aiming to significantly reduce emissions of both the construction and maintenance of their road network, recent commitments signed at Cop26 in Glasgow saw many countries signing up to net zero carbon emissions by 2050, (i.e. when the amount of carbon we add to the atmosphere is no more than the amount removed).

By assessing and quantifying the Embodied CO_2 of road pavement construction and maintenance processes these provide a baseline against which these ambitious 'net zero' targets can be measured and evaluated. Several manufacturers are already providing Environmental Product Declarations (EPD's) which aim to quantify the embodied CO_2 emissions of their product on a 'cradle to grave' basis which allows a full assessment of the embodied CO_2 for both the initial construction and over the full, service life of the infrastructure asset.

For a typical rehabilitation project the actual amount of embodied CO_2 of the asphalt reinforcement itself is relatively small when compared to that of a typical 50 mm asphalt layer or other energy-intensive materials like concrete or reinforced concrete steel, however the sustainability benefits it can bring about by delaying or preventing the replacement of these energy-intensive primary materials can be significant.

An additional consideration is the reuse of recycled materials and whether these support the principals or of circular economy. Recycled Asphalt plainings (RAP) are now considered for reuse in new asphalt mixes. Investigations were undertaken to determine if the incorporation of HaTelit asphalt reinforcement in a pavement would have any detrimental effect on the recyclability of that pavement at the end of service life and if residual granules of the reinforcement would affect the new recycled asphalt mix design or performance. Moreover some manufacturers have started to use recycle polymers to produce asphalt reinforcement. Recycling of single use polyester bottles effectively produces polymer granulate which can be used to produce virgin quality fibres that are incorporated into asphalt reinforcement grids. The performance benefits of polyester-based asphalt reinforcement are subsequently discussed together with embodied CO_2 of these combined solutions and how use of these material supports a 'net zero' strategy

REFLECTIVE CRACKING AND ASPHALT REINFORCEMENT

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, from external dynamic loads, such as traffic, can cause cracks which propagate from the bottom to the top of a pavement (bottom-up cracking). Additionally underlying discontinuities in the pavement subgrade/base course can also reflect up through the overlying asphalt.

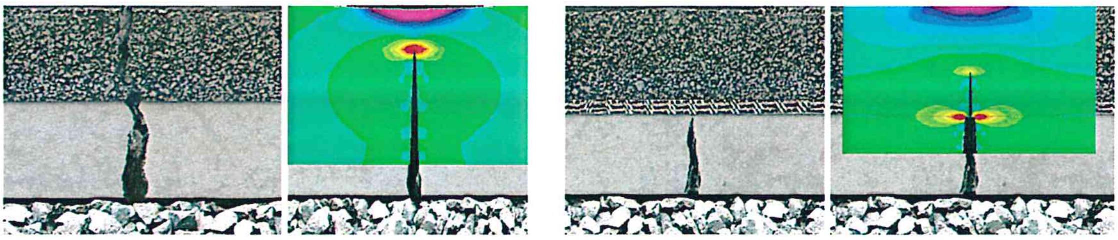

Figure 1: Simulated stress distribution with FE-Method, without (left) and with reinforcement (right)

In order to delay the propagation of cracks into the asphalt layers an asphalt reinforcement geosynthetic 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.

WHY POLYESTER REINFORCEMENT?

The wider benefits of asphalt reinforcement and in particular those produced from polyester fibres was discussed previously (Elsing & Horgan, 2019). This paper identified several key factors influencing the performance of asphalt reinforcement products and the performance of an asphalt reinforcement as a composite, with asphalt and reinforcement considered together.

- Bond Stiffness
- Bonding Strength: Mobilisation of tensile forces
- Thermal expansion coefficient
- Field testing
- Laboratory Testing
- Cyclic load and Fatigue testing

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, therefore, 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.

Bond Stiffness

De Bondt (1999) published "Anti-Reflective Cracking Design of (Reinforced) Asphaltic Overlays", which was the last phase of the 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.

It was 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. 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.

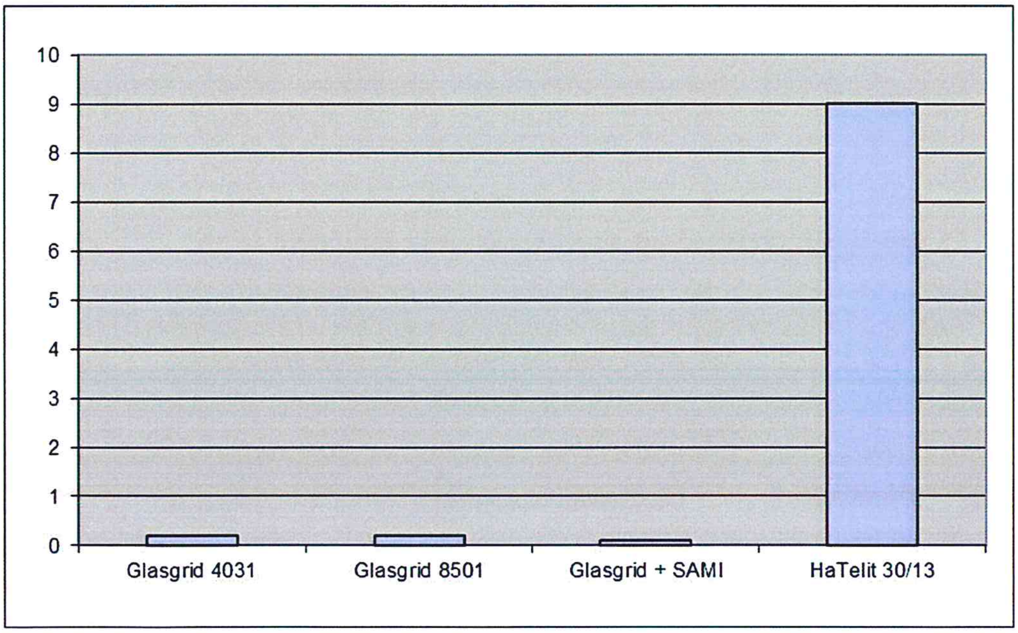

Figure 2: Equivalent bond stiffness ($c_{eq,rf}$ in N/mm/mm²) of different investigated products (De Bondt, 1999)

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, 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 an asphalt reinforcement. The combination of high reinforcement stiffness (Polyester) and high bond stiffness (Bitumen impregnation) creates a high improvement factor for the overlay life of an asphalt pavement.

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

temperature [°C]	without reinforcement		with reinforcement	
	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

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 2). This leads to very small internal stresses between the PET fibres and the surrounding asphalt (similar to reinforced concrete) and minimizes/avoids the phenomenon of progressing de-bonding and as result of repeated daily and seasonal thermal cycles. For this reason Polyester does not act as an extrinsic material in the reinforced asphalt layer

Table 2: 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

Field Tests: Federal Materials Testing Institute (EMPA 2017)

The aim of the research work was to obtain information on the effectiveness of different asphalt interlayers (Figure 4) and the corresponding service life of the pavement. Surface characteristics of the raw material and their effect on the in-situ activated tensile strength were assessed. Both laboratory and field tests were undertaken to assess the performance of different products and focus was given on the time dependent development of cracks and an accelerated loading cycles in the field to determine the number of pavement loading cycle until the development of reflective cracking.

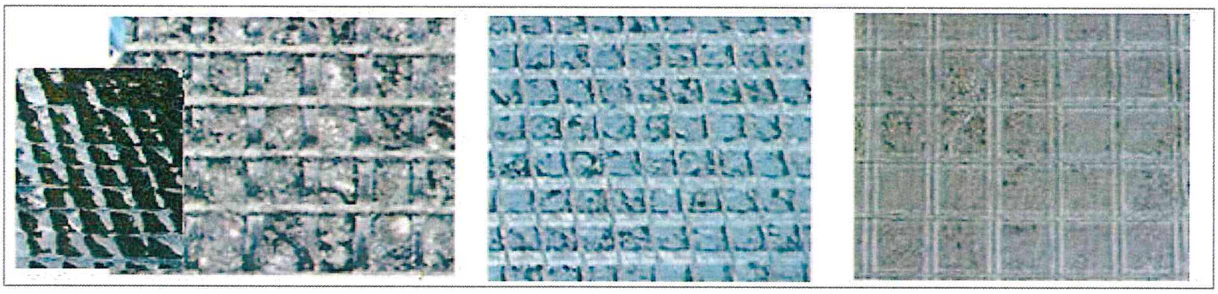

Figure 4: Grid A: Glass fibre grid + SAMI; Grid B: Glass and carbon fibre grid; Grid C: Polyester Grid

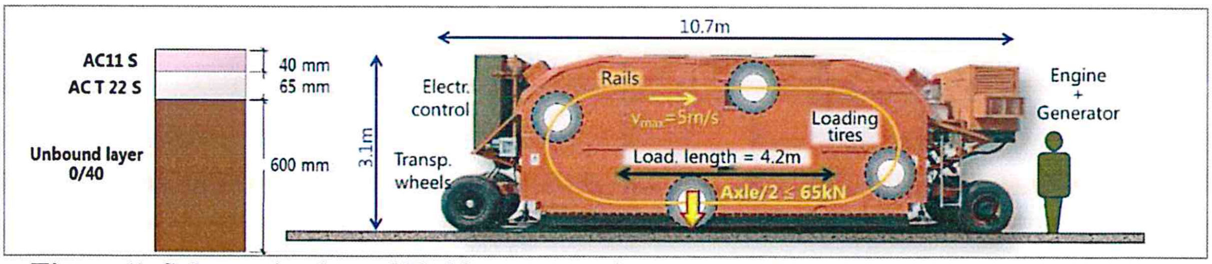

Figure 5: Schematic view of Field test set and pavement thickness

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 (stress absorbing membrane interlayer) is used.

Laboratory Testing: University of Texas

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. 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, see Figure 6

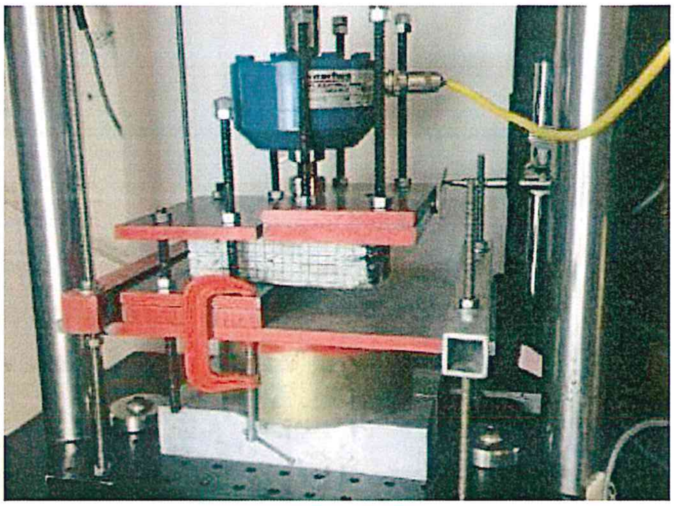

Figure 6: Test set up for shear fatigue test

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 fibre and Polyvinylalcohol (PVA) were tested.

Table 3: 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

Summary and Conclusions from Overlay 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.

Laboratory Testing: 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 7).

According to the function of fatigue: $Nf = k_1 \, (1/\varepsilon_t)^{k2}$

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

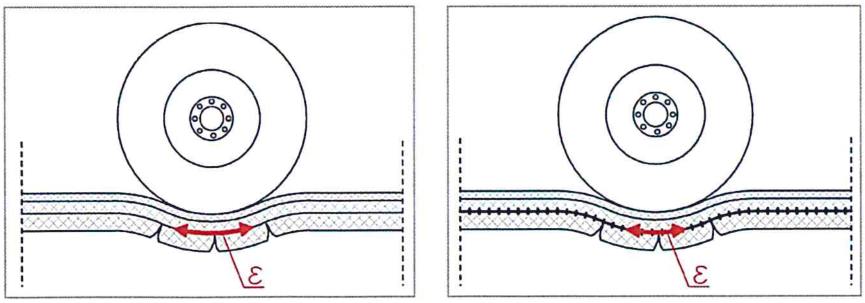

Figure 7: Schematic view of the fatigue cracking mechanism in pavement cross section without and with reinforcement

From specialist literature the value mentioned for the coefficient factor of fatigue k_1 is 2.0×10^{-12}. For k_2, the exponent of fatigue function is 5.0. At a vertical deformation of 0.5 mm 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 figures 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 x 10^8	-
-5%	ε= 0,000095%	2.99 x 10^8	1.5
-10%	ε= 0,000090%	3.99 x 10^8	2.0
-20%	ε= 0,000080%	6.10 x 10^8	3.0

Laboratory Testing: Cyclic loading and Deformation

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 analyse 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 8). 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

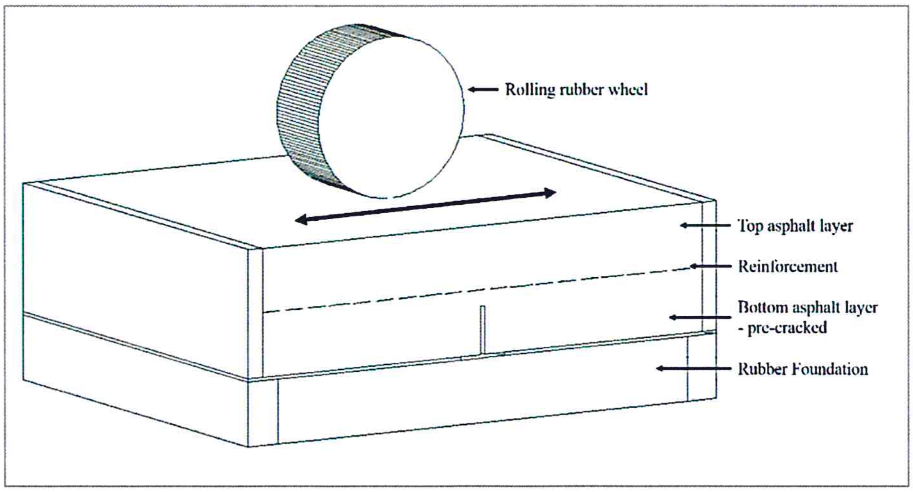

Figure 8: Test set-up cyclic loading test (schematic)

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 9).

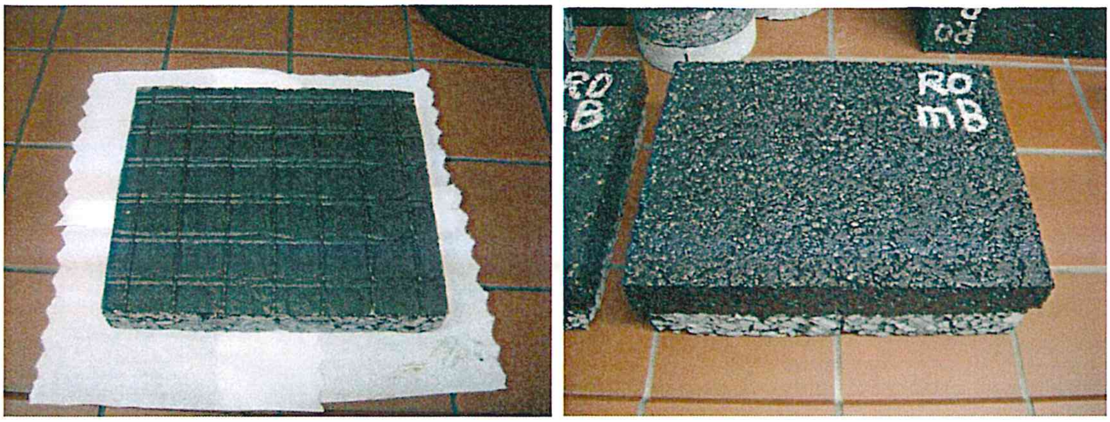

Figure 9: Pre cracked specimen with asphalt reinforcement

A force of 700N has been applied onto the specimen by a rolling rubber wheel, which is equivalent to a 10 tonne 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 10).

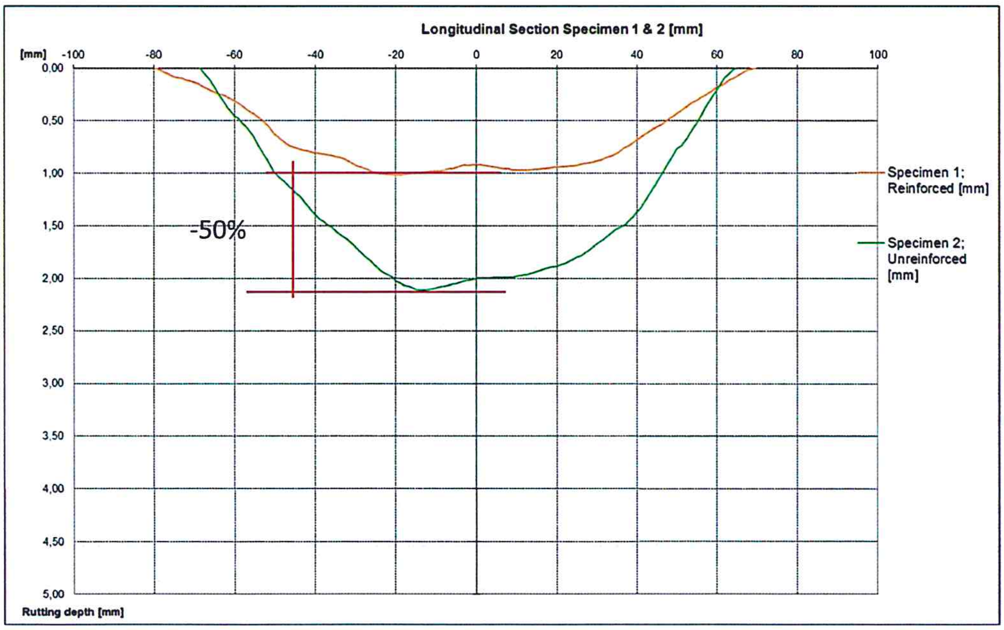

Figure 10: Deformation with and without Polyester reinforcement of an asphalt specimen between 50.000 and 60.000 loading cycles

Laboratory Testing: Cyclic loading and crack propagation

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[i].

In this research program which started in 1999, an asphalt wearing course was applied over an existing crack in a detailed series of tests (Figure 11).

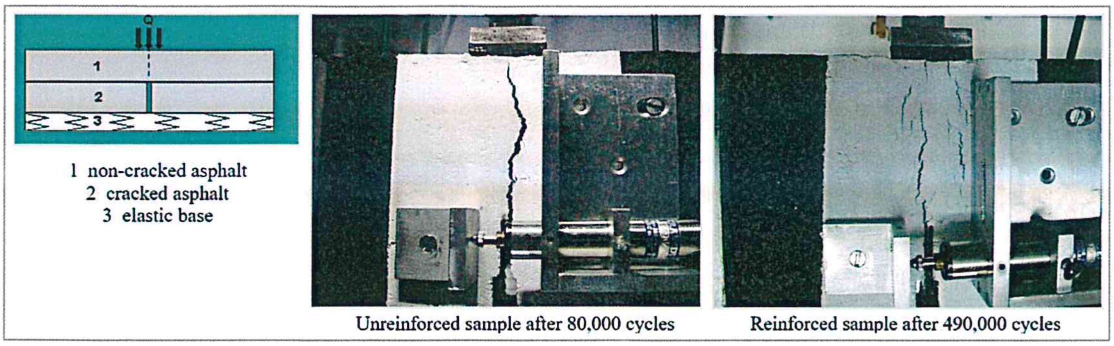

Figure 11: Dynamic Testing at ATI (Brazil) - Bending Mode

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.

EMBODIED ENERGY (EE) AND EMBODIED CO_2 (ECO_2)

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." (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. Recent commitments signed at Cop26 in Glasgow saw many countries signing up to net zero carbon emissions by 2050. By assessing and quantifying the embodied energy (EE) and embodied carbon dioxide (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 grave" 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.

Data source

The ECO_2 values ("Carbon Footprint") used in the following chapters are taken from the latest Inventory of Carbon & Energy (ICE) V2.0. 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 (i.e. Aggregates, Aluminium, Asphalt, etc.).

Examples of embodied CO_2

The amount of embodied carbon dioxide per kg of material can vary significantly as can be seen in Table 5. The more processing and energy that is required to achieve the final product the higher is the ECO_2.

Table 5: Examples of embodied carbon dioxide (ECO_2) in construction materials (cradle to gate)

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	-
HDPE	1.93	-
Steel	1.46	average UK recycled content
Steel	2.89	Virgin steel

Source: ICE Inventory of Carbon & Energy V2.0

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.

On the basis of a specific Environmental Product Declaration (EPD) the embodied CO_2 for HaTelit C 40/17 eco asphalt reinforcement, made of recycled PET, has been assessed and externally verified as 1.05 kg ECO_2/m^2 of material (3.88 kg ECO_2/kg of material). This assessment is based on a cradle to grave approach and thus exceeds the system boundaries for the examples presented in in Table 5.

COMPARISON OF EMBODIED CARBON DIOXIDE 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.

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 6: Basis for calculation

Job 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 (a)
HaTelit asphalt reinforcement	0.27 kg/m² (made of recycled PET)
Improvement factor - reinforced to unreinforced asphalt	3 [-] Note (b)
Design life (unreinforced):	4 years Note (c)

Notes:

(a) Required amount of bituminous emulsion for HaTelit asphalt reinforcement over
milled surfaces acc. to manufacturer's recommendations.

(b) 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 makes rehabilitation necessary but are not related with reflective cracking.

(c) 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.

Comparative calculation of the embodied CO_2 for reinforced and unreinforced asphalt overlays

In the comparison in Table 7 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 9.04 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 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.

Table 7: Comparative calculation of embodied carbon dioxide (ECO_2)

	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 C 40/17 eco asphalt reinforcement	0.27	kg / m²	3.88	-	1.05
Total embodied CO_2 for rehabilitation	kg / m²			7.72	9.04
Improvement factor	[-]			1	3
Design life (improved)	years			4	12
Total embodied CO_2 per year design life	kg / m² / year			1.93	0.75
CO_2 saving per m² and year of design life					61 %
Total CO_2 saving for improved design life					70,800 kg

The result is a saving of 61 % 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 70,800 kg based on the significantly improved design life of 12 years.

Environmental Product Declaration (EPD)

Many conscientious manufacturers provide EPDs for their products and thus provide a basis for project owners to assess all potential environmental impacts of a product, system or solution during its entire life cycle (cradle to grave). Such EPDs are independently assessed and verified as per ISO 14025 and EN 15804. On this basis individual products, systems or construction methods can be compared for their environmental impact during initial construction and over the full service life of the infrastructure asset as shown above.

Recyclability of HaTelit Asphalt reinforcement

Many researches has demonstrated that the use of asphalt reinforcement show great benefits in road rehabilitation. Until now there has not been a real design method to predict the loads until the fatigue Milling trials were carried out by Huesker in conjunction with "Mischwerk Schwelm" (in 2004) and RWTH Aachen (in 2008) to demonstrate that a polyester grid (HaTelit) can be milled as normal and that the millings can be recycled.

Investigation of the milling characteristics

A trial length was laid in May 2004 on land at the asphalt mixing plant at Mischwerk Schwelm in Schwelm in Germany to determine the milling characteristics and recyclability of HaTelit-reinforced roads. The construction of the trial length was as follows: A 0.6 kg/m² coating of bitumen emulsion (U70K) was sprayed on to an existing asphalt base and a layer of high-modulus polyester reinforcement installed. The reinforcement was then overlaid with a 40mm thick asphalt surface course. The trial length was removed after about 6 weeks. The milling depth was 50mm; to ensure that in milled below the asphalt reinforcement layer. The milling was carried out using a small milling machine (Wirtgen W 500) with a drum width of 0.50 m.
During the removal process, it was observed that the reinforcement grid had no detrimental effect on the speed accuracy of the milling operation. Likewise, it was found that only short lengths of fibre residue were present in the millings.

Figure 12: Residual fibres in the millings; few fibres remained on the milling drum

As part of tests on the asphalt, the effect of asphalt reinforcement fibres in the asphalt material on its recyclability was investigated. Marshall asphalt test specimens were made from the asphalt binder layer material with and without asphalt reinforcement fibres and their Marshall stability and flow value was determined.
The reference sample was equivalent to the asphalt binder course laid on the test bed. The variant with asphalt reinforcement fibres was made up to have the same aggregate

grading and binder content as the reference sample. This was achieved by the controlled addition of the appropriate quantity of uncontaminated aggregate and binder to the recovered asphalt. The aggregate and binder used were from the same batches of aggregate and binder as were used for making the asphalt binder mix. The Asphalt reinforcement fibre content was the major difference between the two variants and the purpose of the tests was to determine the effect of these fibres. There were only relatively small differences with respect to bulk density and void content between the Marshall test specimens used for the tests. The values for Marshall stability and flow were virtually identical. The results for the Marshall test parameters are shown in Table 8.

Table 8: Marshall test results

Marshall Stability	
Reference sample	8.4 kN
With Reinforcement fibres	8.5 kN
Marshall Flow	
Reference sample	3.6mm
With Reinforcement fibres	4.3mm

CONCLUSION

No unified design approach exists for the inclusion of asphalt reinforcement in pavements, however, many researchers have demonstrated that the use of asphalt reinforcement show benefits in road rehabilitation in extending pavement service life, this paper highlights a number of factors that are important for their success. This increase in service life has a number of financial and social economic benefits. The increased uptake of these asphalt reinforcement products, in particular those produced from recycled polyester, will help support the move towards a more circular economy and achieve net zero carbon emissions in the future.

REFERNECES

BS EN 10319:2015, "*Geosynthetics – Wide-width Tensile Test*", International Organization for Standardization

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

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

Elsing, A., Horgan, G., (2019) "Determining key influence factors of a durable asphalt reinforcement", 18th Annual International Conference on Highways, Airports Pavement Engineering, Infrastructures & Asphalt Technology, Liverpool

Hammond, G.; Jones, C. (2011), *"ICE Inventory of Carbon and Energy V 2.0"*, Sustainable Energy Research Team (SERT), Department of Mechanical Engineering, University of Bath, UK

Höptner, Aaron; (2010) "*Nachweis der Wirksamkeit von Asphaltbewehrungsgittern zur Verhinderung von Reflexionsrissen*", Diplom Thesis, Dresden, 2010

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

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

Treloar G.J. (1994), "Embodied Energy Analysis of the Construction of Office Buildings", Master of Architecture Thesis, Deakin University, Geelong, Australia

Sustainability. (2011, August 16). In Wikipedia, The Free Encyclopedia. Retrieved 05:43, August 17, 2011, from http://en.wikipedia.org/w/index.php?title=Sustainability&oldid=445226512

United Nations General Assembly (1987). "*Report of the World Commission on Environment and Development: Our Common Future"*, Transmitted to the General Assembly as an Annex to document A/42/427 - Development and International Co-operation: Environment; Our Common Future.

WRAP Waste and Resource Action Plan (2010), "Sustainable Geosystems in Civil Engineering Applications", UK

Quiel, M. (2013) „*Einsatz von Asphalteinlagen im Asphaltstrassenbau.*" Master Thesis, Münster University of Applied Sciences, Münster.

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