

White Paper

A NEW AND INNOVATIVE STEEL-BASED ANTI-REFLECTIVE CRACKING INTERLAYER

Worldwide, asphalt is used as material for road construction due to its excellent cost and performance. In reality however, roads can show several signs of damage such as rutting, settlements and all kinds of cracking phenomena. Reflective cracking is a type of crack caused by the reflection of a crack somewhere in a base layer through the surface, for example when concrete slabs are overlaid, during road widenings, etc. Today, different anti-cracking interface systems exist, such as SAMI's, non-woven geotextiles, geogrids (plastic, glass and carbon), combigrids and steel-reinforced nettings. The different interlayer systems all have their specific properties with advantages and disadvantages. Moreover, the performance of a specific product is not only dependent on the product properties and the root cause of the cracks but also on the correct installation of the product. Past research revealed steel to be an ideal material for an anti-reflective cracking interlayer. Steel netting as currently known is very rigid and needs to be optimally fixed by nails or a slurry seal. In addition, the relatively thick net requires an overlay thickness of at least 5 cm to prevent the reflection of the net through the asphalt surface. In this paper we present a new, innovative, steel-based anti-reflective cracking interlayer with improved installation properties compared to traditional steel netting, enabling fast and easy installation.

1 Introduction

Cracking of asphalt concrete roads is a widespread phenomenon that deteriorates the road surface and reduces driving comfort. Furthermore, cracks enable the penetration of water through the surface, leading to deterioration of the underneath structure and consequently reduction of the total lifetime of the road. Reflective cracking is a special type of cracking that originates when cracks from a base layer (rigid, semi-rigid or flexible) propagate through the surface via the asphalt overlay (Sanders 2001).



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These cracks are caused by horizontal and/or vertical movements in the cracked/jointed structure caused by a combination of environmental conditions, such as seasonal and daily temperature variations, and traffic loading (Perfetti & Sangster 1988). The renovation of such a surface by milling the top layer and replacing the asphalt is not efficient and only delays the growth of the crack by the centimetres of overlay on top of the cracks. As such, the time to see cracks at the surface is directly related to the thickness of the overlay (Vervaecke et al. 2008). To maximize overlay lifetime, anti-reflective cracking interlayers in combination with an asphalt overlay are widely used for the rehabilitation of cracked asphalt and concrete pavements.

A wide range of anti-cracking interlayers exists: SAMI's, non-woven geotextiles, geogrids (plastic, glass or carbon), combigrids and steel-reinforced netting.

The properties of the raw materials, their possible coating as well as their appearance in the geotextile (mesh dimensions, mesh shape, etc.) are diverse, which makes comparison of these products very difficult. The performance of these products has been evaluated in both laboratory and field tests, and showed a delay of the crack propagation through the surface (Norambuena-Contreras & Gonzalez-Torre 2015, Pasquini et al. 2013, Vervaecke & Maeck 2008). Moreover, proper installation of these products is also key to achieving good anti-reflective cracking behaviour.

The installation process includes all steps from preparation of the existing surface (grinding, cleaning, treatment of cracks and joints), spraying of the tack coat, to installation of the anti-reflective cracking interlayer and the asphalt. Frequently occurring problems are the installation of products with wrinkles (Figure 1), the use of an insufficient amount of tack coat for the product, surface roughness, and the incorrect type of tack coat. Some products have a high tensile strength but due to their brittle nature (e.g. glass) or temperature sensitive properties (e.g. plastic), the high strength might no longer be available after the installation process (Gonzalez-Torre et al. 2014). Therefore in some countries like Belgium, these products are combined with a protective bitumen layer (SAMI) on top of the product (SB250 3.1).



Figure1: Left: Due to tackiness, the product is damaged by traffic. Right: A wrinkle in a geogrid inducing a discontinuity in the asphalt.

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Steel is widely used in construction as reinforcement in concrete, masonry and even asphalt. The current generation steel products for road reinforcement are hexagonal meshes with reinforcement bars in the transversal direction or traditional welded steel mesh. These meshes are very rigid; to install them properly they need to be fixed by nails or preferably with a slurry seal. They are known for their excellent anti-cracking properties thanks to the high Young's modulus and good anchorage in the matrix. Some disadvantages of the current generation products are their multiple step installation process, the need for at least 5 cm overlay, and their time-intensive removal process at the end of the road life since they cannot be ground with traditional grinding machines.

Bekaert is known for its hexagonal steel mesh, commercialised under the name Mesh Track[®] or Bitufor[®] which describes the combination of the mesh with the slurry to install it. As a market leader in this segment of steel meshes, in 2012, Bekaert initiated a project to develop a new steel-based anti-cracking interlayer with improved properties that facilitate installation, good anti-cracking behaviour and easy removal at the end of the life of the road surface. In the first section of this paper, the new steel-based anti-reflective cracking layer, Fortifix[®], is presented. The second section describes some specifics of installation and recycling. In the final section, performance data are elaborated.

2 Product definition

The presented steel-based anti-cracking interlayer, Fortifix[®], differs from existing products by the half-product as well as the shape of the mesh. The new mesh has a rectangular shape and is made from flexible, high-strength steel cord. The steel cord mesh is kept in position on a plastic carrier (a low weight plastic grid or non-woven). The steel cord is galvanised and fulfils Class D material according to EN10244-2 to ensure a lifetime of the product in the application comparable to that of the road surface. Furthermore, the cord half-product is foreseen of embrittled zones at predetermined positions to make the product millable together with the asphalt.

The properties of the product compared to traditional hexagonal steel mesh and a classical glass-based geotextile are presented in Table 1. The tensile strength is determined according to ASTM D6637 Method 1 (single rib test). As can be seen from Table 1, all products differ from each other by dimensions, tensile strength and tensile stiffness. Although tensile strength is a dominant characteristic in the comparison of geosynthetics, tensile strength is less important in the final application. The dominant parameters for obtaining good anti-cracking behaviour are "stiffness" EA (material cross section A * material modulus E), the secant modulus and the adhesion with the pavement layers including the existing surface as well as the overlay (Gonzales-Torre et al. 2014 and references). Since steel has a high Young's modulus of approximately

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200 GPa, the cross-section of the reinforcement material can be reduced compared to glass products. The new mesh has an EA in the range of existing glass-based geosynthetics with a strength of 100 kN/m.

Table 1: Properties of metal and non-metal geotextiles used as anti-cracking interlayer

		Mesh properties	Mechanical properties
Existing steel mesh - Mesh Track [®]		Steel wire (2.45 mm) Hexagonal 118x80 mm Trans. wire (3x7) mm ± 1.7 kg/m ²	Strength: (40x58) kN/m EA: (22600 x 32500) kN/m
Existing glass mesh		Glass roving Square 35x35 mm Plastic coating ± 330 g/m ²	Strength: (70x100) kN/m EA: (2800 x 4000) kN/m
New steel mesh - Fortifix [®]		Steel cord (1.05 mm) Rectangular 40x30 mm Plastic grid or non-woven ± 335 g/m ²	Strength: (38x50) kN/m* EA: (3100 x 4400) kN/m

*The embrittled zones are considered as 0 kN

3 Installation

One of the key success factors in the development of the new steel-based anti-cracking interlayer is easy and simple installation. As with all road works, the preparation of the jobsite is key. The existing road surface should be prepared by milling away the required asphalt (at least the top layer), cleaning the surface by high-pressure rinsing and brushing, and treatment of the cracks and joints. Subsequently, the appropriate type of tack coat (the type depends on whether the surface is concrete or asphalt) is applied in a minimum amount of 300 g/m² (residual weight); higher amounts are needed on rough or porous surfaces. The new steel mesh is then applied in the fresh tack coat to ensure an immediate interaction between tack coat and carrier. The grid with non-woven should be pushed down with brushes to ensure adherence at the surface. Depending on climatic conditions, extra chipping might be needed to prevent sticking on the wheels.

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The product with the plastic grid as carrier can be covered with bitumen-coated chippings or a SAMI. Subsequently, the product can be covered with at least one layer of asphalt concrete of at least 3 cm. The flexible and low weight steel cord allows this product to be easily unrolled manually as well as automatically from a truck. Moreover, the weight of the steel compared to the weight of the carrier ensures flat installation on the surface, while the carrier ensures good contact with the tack coat. Some impressions of the installation process are shown in Figure 2.



Figure 2: Installation process of the new steel-based anti-cracking interlayer with non-woven on a ground concrete surface

Traditional geosynthetics made from plastic, glass or carbon are sensitive to damage induced during the installation process by both the site traffic as well as the asphaltting process (Sakou Touole & Thesseling 2013). Gonzalez-Torre et al. 2014 investigated several mechanisms to assess damage during the installation process, i.e. mechanical damage (ISO 10722:2007), real installation and installation in laboratory. Depending on the material, damages of 10% to 90% were reported in tensile strength and secant modulus. Steel was however not investigated in that research.

Steel half product, i.e. rectangular and round wire from the traditional steel product, was tested for damage during installation. The material was placed on an asphalt layer, subsequently fresh asphalt was installed by a paver and the fresh layer was compacted. Before the complete cooling of the fresh asphalt, the steel wires were removed from the asphalt (Figure 3). Virgin as well as material which underwent the installation process were tensile tested according to EN ISO 6892-1:2010. The normalised values of tensile strength, Young's modulus and secant stiffness at 0.2% are presented in Figure 3. There is no visible decrease in the mechanical properties of the steel during asphalt installation. Steel is not sensitive to mechanical damage by stone aggregates and is thermally stable at temperatures up to 700 degrees Celsius. Although the new steel product has a lower tensile strength than some glass products,

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the full strength and stiffness properties of the steel can be used in the application. As such, steel can be assessed as ideal material for asphalt reinforcement. Moreover, due to its stability during asphaltting, it can be applied on both a smooth or rough/milled surface.

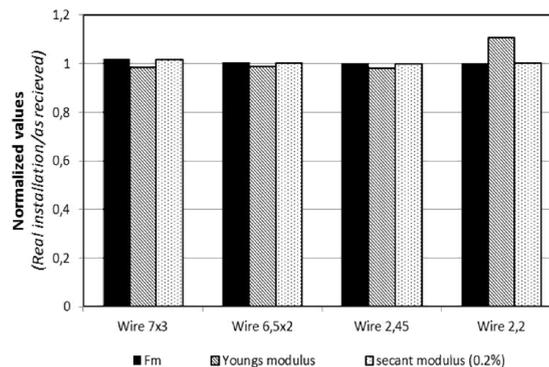


Figure 3: Left: White paint indicates steel pieces installed under 4 cm of asphalt. Right: Normalised values for Fm, Young's modulus and secant modulus at 0.2% from different steel half products.

4 Recycling

Although asphalt is already an old and traditional building material, having been in use since 1870, the material is very sustainable since it can be re-used to a very high degree. Traditionally asphalt is removed by milling the different layers of asphalt. The reclaimed asphalt is mixed with fresh material and percentages from 5% to 100% of re-used asphalt can be realised.

The use of interlayer systems brings extra complexity to asphalt recycling, in both grinding as well as re-use of the material. When asphalt with interlayer systems needs to be removed, special care must be taken with the grinding process by adapting the speed of milling as well as the depth, in order to efficiently break the material in the case of glass and carbon. For plastic, the milling drum needs to be cleaned from time to time since the plastic gets entangled on the drum. On the other hand, the reclaimed asphalt contains contamination of the interlayer grid; this material needs to be treated by sieving it and mixing it with other reclaimed asphalt in order to reduce the percentage of contamination. Alternatively, the material needs to be used as waste.

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Figure 4: Left: Milling drum after grinding 100 m² asphalt reinforced with new steel grid. Right: Traditional breaking installation for asphalt foreseen with magnets.

Steel on the other hand cannot be removed by the traditional asphalt grinding process. When asphalt with a hexagonal steel mesh needs to be removed, first the top layers above the steel need to be ground and then the steel is removed by scratching or pulling off the mesh. The grinding process is performed at a speed of approximately 12 m/min while the removal of the steel is done at 1 m²/min. Although the reclaimed asphalt and steel can both be re-used, the additional time needed for the removal of the steel has also an important cost impact.

As stated in section one, the steel cord of the grid is foreseen of embrittled spots at regular locations. These embrittled spots cause the material to break at these spots during the grinding process by traditional milling machines. Note however that also here the speed and depth of milling needs to be fine-tuned to efficiently grind the material and remove it from the drum. The left picture in Figure 4 shows the drum after grinding 100 m² of asphalt with the new steel-based grid. It can be noted that there is still some material on the drum; to reduce this entanglement both the speed and depth of milling need to be adapted for efficient milling and material evacuation. The ground asphalt contains steel which can easily be removed from the asphalt by magnets. These magnets are provided as standard on breaking installations to remove nails and other metallic objects from the asphalt. The asphalt can be re-used 100% and the reclaimed steel can be re-used as new base material in steel mills. The new steel-based grid is a sustainable anti-cracking interlayer which ensures the full lifecycle of both the asphalt and the interlayer.

5 Performance

No standard test is available for the evaluation of the performance of anti-cracking interlayers in the asphalt application. Several research groups have developed their own system to simulate a certain fracture mechanism. Note that since reflective cracking is a fatigue mechanism, cyclic testing is very important. Apart from this, the dimensions of the test specimens compared to the dimensions of the products can have an important impact on the performance and have to be taken

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into consideration during the interpretation of test results. In the early 1990s, BRRC developed a horizontal plate test to simulate crack formation by thermal movement (De Visschere & Vanelstraete 2010). This test was found to be relevant and shows a good differentiation between different products and how they are installed. In 2009-2010, this test was optimised for a research project funded by the Flemish government (Vanelstraete et al. 2011).

The horizontal plate test is performed on samples of 600 x 175 x 140 mm³. The samples consist of a 70 mm thick concrete base layer with a rough surface finishing (brushed) and an artificial notch (7 mm) in the middle. The anti-cracking interlayer is installed according to the manufacturer's recommendations and is covered by 40 mm of asphalt. The samples are conditioned for 12 hours at -10 degrees Celsius, the bolts are tensioned and the test is started. During the test the notch is opened and closed by 1 mm at a very slow rate by the thermal expansion of steel bars holding the sample. The maximum force is recorded and the crack propagation is followed as a function of the number of cycles and the total testing time.

Table 2: Results of the horizontal plate test performed on different investigated anti-cracking interlayer systems

	F _{max} (kN)	Crack initiation		End of test		Remarks
		cycles	time (h)	cycles	time (h)	
Reference	8	1	2	5	10	Crack
New steel grid (38x50) kN/m	9	Na	Na	Na	130	No cracks
	8.7	35	126	35	126	Delamination
Glass mesh (70x100) kN	9.5	15	42	24	90	Crack
	9.6	8	32	11	48	Delamination + crack
	9.3	28	108	28	108	Delamination

Since this test is a fatigue test, all border conditions (sample preparation, bitumen) can significantly impact the result. Not only the new steel-based product was tested but also a reference and a competitive glass grid (presented in Table 1). The samples were all prepared the same way, on the same concrete slabs, with the same type and amount of tack coat (300 g/m² residual), overlaid with 4 cm asphalt concrete.

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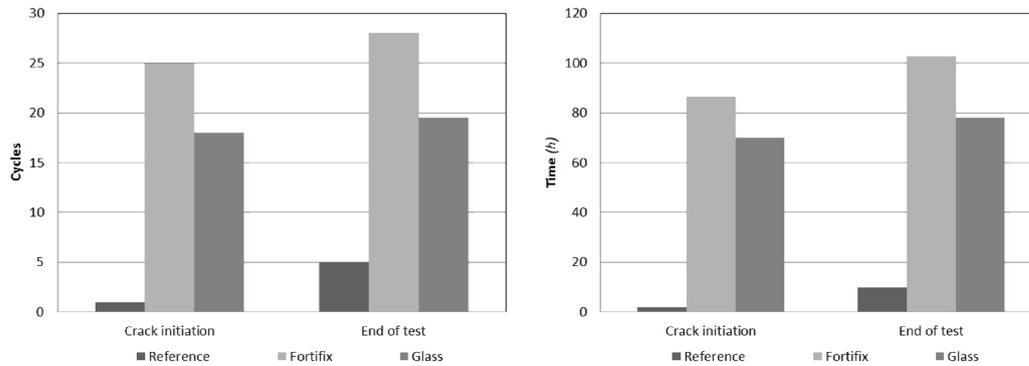


Figure 5: Left: Averaged results of the different anti-cracking systems expressed in number of cycles. Right: Averaged results of the different anti-cracking systems expressed in time

The results of the horizontal plate test are presented in Table 2 and a summary of the averaged data can be found in Figure 5. In general, one can conclude that an anti-cracking interlayer increases the maximum force take-up by the asphalt samples and delays the occurrence of the first crack in the asphalt. Comparing the performance of the new steel product and the glass grid with the same amount of tack coat, both the crack initiation and the crack propagation are superior for the steel-based product. This is a striking result since both products have a similar EA and the steel product has only half the tensile strength of the glass grid. The reason for the performance difference can be found in the improved anchorage of the steel in the asphalt. The round cords are optimally anchored in the asphalt and work as a real reinforcement, while the flat glass is only adhering to the asphalt via the coating. A detailed picture of this anchored steel in the asphalt and loose glass is shown in Figure 6. This hypothesis is also demonstrated by the failure mechanism of the glass product which is preferential delamination.



Figure 6: Left: Glass grid after being tested in horizontal plate test; the glass can be peeled off completely. Right: Steel cords anchored into the asphalt overlay.

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Conclusions

A new steel grid, Fortifix[®], made from steel cords with embrittled spots, has been presented in this article along with its specific advantages compared to traditional geosynthetics and existing hexagonal steel meshes. First of all, the flexible steel cords enable fast and easy installation of the anti-cracking interlayer. The steel is stable during the installation process and its properties are not reduced due to mechanical or thermal interaction with the asphalt. Furthermore, the embrittled spots make sure the grid can be ground together with the asphalt. The magnetic properties of steel ensure a perfect separation of steel and asphalt enabling 100% recycling of both materials. Finally, the anti-cracking properties clearly outperform other glass-based anti-cracking interlayers with a similar EA and a higher tensile strength.

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