THE USE OF HYCORE® STEEL MAT FOR ASPHALT PAVEMENT CONSTRUCTION AND MAINTENANCE

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ABSTRACT

The use of steel interfaces of wire meshes or cross-linked rods and other geosynthetics to improve the asphalt concrete pavements is a common practice in the highway construction and maintenance since more than 20 years. However the introduction of this technology in the market is relatively recent in the world.

In this report is presented a new product denominated Hycore® made of steel strips to create a three-dimensional high stiffness interface able to be easy packed and handled. The Hycore® has been developed to overcome the inconveniences of other products, and to satisfy all the functions that are needed in one product which at same time, constitutes a simpler and more efficient technology from the economic point of view.

The Hycore® is integrated inside the aggregate structure of the asphalt concrete creating a new compound material: ***the steel reinforced asphalt concrete.*** This material is endowed with a better mechanical behavior and higher tensile strength that limits the appearance of fatigue cracks and control the reflective cracking in the maintenance activity with a substantial increment of the durability, with low maintenance requirements, contributing to the saving of natural resources (lower consumption of materials and energy).

In this report, the results of diverse static and dynamic tests over the compound material and control samples are presented. The influence of the introduction of the Hycore® in the properties of the asphalt pavement layers is analyzed as well as the application technology. The technical and economical benefits results of the employment of the new material are evaluated. Hycore® is a cost effective and straightforward technology for reinforcing new asphalt pavements and rehabilitating pavement structures. Thanks to its high stiffness and the “box effect”, Hycore® constitutes a universal interlayer for preventing all types of cracking for flexible pavements.

Keywords: asphalt, pavement, reinforcement, interlayer, reflective cracking, maintenance, steel reinforcement, thermal cracks, Hycore

1. INTRODUCTION

Over time, the original characteristics of rehabilitated or new flexible pavements lead to substantial damage inside the pavement structure due to high traffic loads and their dynamic action.

New pavements should have long service life and minimal maintenance requirements. On the other hand, existing ones should be reinforced and repaired as part of routine maintenance procedures by the most cost effective solutions available.

Today, the control of reflective cracking and reinforcement using interlayer materials are common practice in rehabilitating pavement with asphalt overlays. Hycore® wants to offer a superior alternative to the traditional, in some cases high-technology and therefore costly products in the market.

Steel is a commonly used material: its use in asphalt pavement technology for rehabilitation and for new flexible pavement construction is accepted as common practice.

Hycore® offers a new, cost effective technology and global method for asphalt pavement construction and rehabilitation. Rehabilitation using Hycore® as a technology of reinforcement and to prevent reflective cracking is an optimal method allowing asphalt layers with a low thickness.

This translates into economical and ecological benefits, increases the life span and reduces future maintenance costs. The reinforcement properties of the Hycore® allow its economic use in new flexible pavements: thinner road pavement structures and longer maintenance cycles with increased life expectancy.

2. DESCRIPTION OF THE HYCORE® ASPHALT MAT

Hycore® is a bi-directional steel reinforcement interlayer with a three-dimensional geometry made of steel strips with a special shape and joined together.

Characteristics		
High tensile strip	Tensile:	ca. 930 N/mm2
	Thickness:	1.0 mm
High tensile wire	Tensile:	1770 N/mm2
	Diameter:	3.0 mm
Surface of each single "box"	10'700 mm2	
Number of "boxes" per m2	93.4 pcs.	
Standard roll	Width:	3.50 m
	Length:	25.00 m
	other sizes on request	
Total area per roll	87.5 m2	
Weight per roll	ca. 184 kg	
Packaging size per roll	Diameter:	ca. 1'000 mm
	Length:	3'500 mm
Weight per m2	2.10 kg/m2	

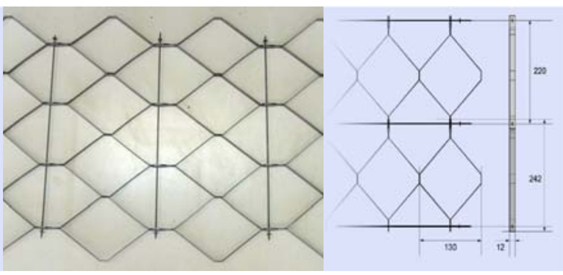

Figure 1 View and characteristics of the Hycore® Asphalt Mat.

The high-strength transverse steel roods allow the steel mat to be rolled up and simplify the handling and placement on the construction site.

Hycore® is compatible with all known asphalt concrete materials. It provides internal interlocking with the mineral aggregate of the composite material, producing the so-called “box effect”.

Hycore® is thermally stable and physically durable and can therefore withstand the rigors of paving operations. No creep deformation or chemical break-down are exhibited by Hycore® which might affect short and long term performance.

The Hycore® was developed by 3S Geotecnia y Tecnología, S. L. (Spain) to Fortatech A. G. (A Swiss company member of the Brugg Group) which manufactures and distributes the mat.

3. HYCORE®: NEW ANSWER TO REFLECTIVE CRACKING

To extend the life span of existing pavements, the normal option is to apply an asphalt concrete overlay. The life span of asphalt concrete overlays covering old asphalt pavement is limited: the crack pattern of the old pavement migrates through the new asphalt overlay to the surface; as a result, thick overlays are used to increase the life span, often with moderately successful results.

The best solution is to incorporate an interlayer to delay reflective cracking. The use of high stiffness interlayer Hycore®, will prevent fatigue cracking in the overlay and act as a special interlayer to stop the migration of the crack pattern from the old pavement to the surface of the new asphalt overlay.

The shear and tensile forces generated in the new overlay are absorbed by Hycore® steel mat at very low strain (elongation) and transferred horizontally in all directions due to the anchorage of the steel mat within the aggregate structure of the asphalt concrete (box effect).

Reflective cracking process is stopped because the unit strain of the steel mat is lower than the value necessary to open a crack in the bottom face of the asphalt concrete overlay. The energy from the cracks of the old pavement is transferred to the steel mat.

4. EFFECTIVE AND SAFE REINFORCEMENT INTERLAYER

The ability of the asphalt concrete to withstand tensile stresses is limited and its life span is determined by this factor. The reinforcement effect of Hycore® is clear. Thanks to its high stiffness in comparison with the asphalt concrete (1:23), the steel mat absorbs the tensile forces at very low horizontal strains (Figure 2) stopping the formation of fatigue cracks with a pronounced effect in the life of the pavement (> 35 times).

The use of this high stiffness Hycore® interlayer improves the mechanical properties of the Compound System, increases its dynamic modulus of elasticity and the magnitude of the tensile forces that can be supported in the bottom part of the reinforced asphalt pavement layers at low strain values.

When Hycore® is applied inside asphalt concrete layers, a new material is obtained: a Compound System (asphalt concrete + Hycore®) with a modified fatigue mechanism, ***the steel reinforced asphalt concrete***.

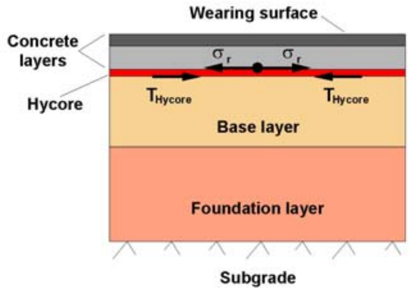

Figure 2 Scheme of the Hycore® Asphalt Mat used as reinforcement interlayer.

5. STATIC FLEXURAL TESTS

The modification of the properties of the Asphalt Concrete with the introduction of Hycore® reinforcement was evaluated during the development of the product in a relative way by with the help of three point flexural tests over rectangular beams. Two types of bending tests were carried out: three point flexural tests and bidirectional ring supported flexural tests.

5.1 Test samples

The samples consist of Asphalt Concrete slabs 305x305x50 mm size, reinforced with laboratory scale (70x80 mm) Hycore® Asphalt Mat. Unreinforced samples were tested to obtain reference values.

Figure 3 Details of the test sample preparation**.**

The samples were prepared by standard procedures of heating, mixing and compaction (Figure 3). The heated steel frame and the heated steel mat are laid in the defined position in the compaction installation. The sample of the steel mat is laid in the bottom of the frame covered with oiled filter paper. The asphalt concrete mixture is added at a controlled temperature, spread uniformly and then compacted using a standard vibrating platform following the standard protocols.

5.2 Three point flexural test

For these tests a Flexural Testing Machine (FTM) was designed and produced which allows accommodate test samples up to 305 mm width. Two strain gages were fixed to the steel mat to evaluate the tensile forces generated in the steel strips during the test.

Figure 4 Testing machine and test installation for Three Point Flexural Test

A set of reinforced and non reinforced samples was tested in the FTM. The main parameters of the tests are the follows:

- *Type Asphalt Concrete mixture*	*S-20*
- *Content of Bitumen:*	*4%*
- *Test temperature:*	*24ºC*
- *Load application velocity:*	*5 mm/min*
- *Distance between supports::*	*250 mm*

The behavior of the samples along the test confirms the expectances in the effect of the new steel mat. The A.C. samples present a typical crack in the center of the sample growing vertically up to the failure (Figure 5).

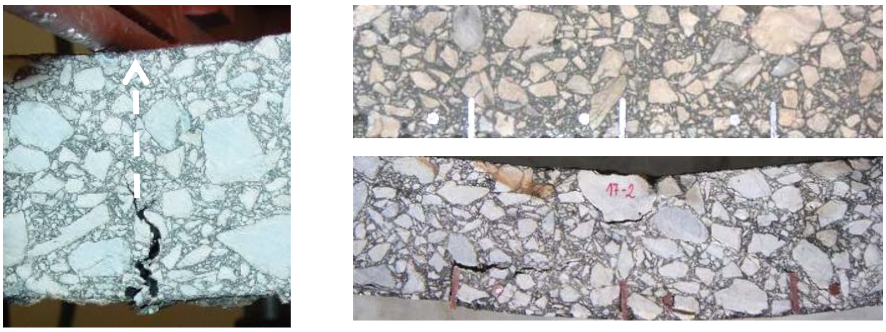

Figure 5 Left: Typical vertical crack in the A.C. slab. Right: Perfect integration between the two materials. No vertical cracks arise with the introduction of the Hycore® steel mat.

On the other hands, the samples reinforced with Hycore® support higher loads and no vertical cracks arise inclusive for big vertical displacements 8 times higher than the ones for the cracking of the A.C. control samples. At big displacements the failure occurs by shearing and compression forces generated inside the A. C. mass. The results show a marked influence in the flexural strength of the samples reinforced with Hycore®.

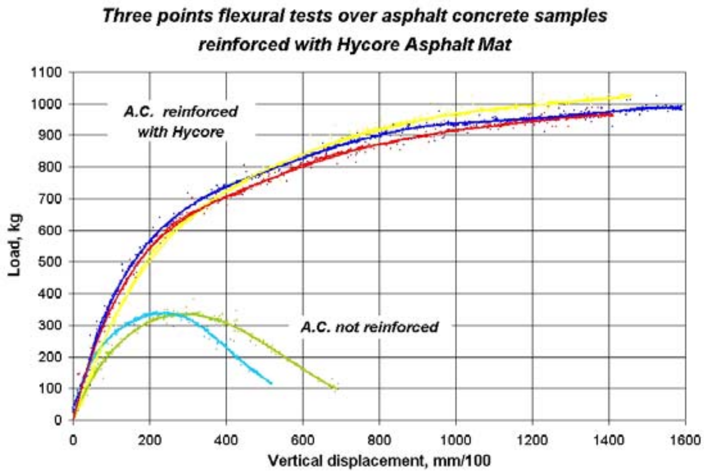

Figure 6 Test results over samples reinforced with Hycore® and control samples.

The followings comments can be done:

- Due to the "Box Effect" and the high stiffness of Hycore® it benefits the properties of the A. C. at low deformations in the usual working interval.
- The steeper slope of the graphics indicates an increment in the modulus of elasticity of the reinforced material (Compound System) regarding the non reinforced asphalt concrete.
- The reinforced samples increase the load supported to a vertical displacement 5 to 6 times higher than the vertical displacement for the A.C. cracking. A global increment of the flexural strength 3 times higher than the AC Mixture without reinforcement is obtained.
- The reinforcement limit depends on the tensile strength of the steel mat and the shear and compression strength of the concrete. It is the most important change introduced by the Hycore® which gets a change in the critical working conditions of the asphalt concrete pavements from tensile strain and cracking in the bottom face of the layer, to the compression of the asphalt concrete in the upper part of the layer reinforcement with steel mat.
- No cracks were observed in the surface of the sample and not growing of the vertical cracks was registered during these tests.

The results of the static flexural tests were used to develop the final shape and configuration of the steel mat. These results have not used to describe the behaviour of the material inside the asphalt pavement structure.

6. REFLECTIVE CRACKING TEST (RCT)

The main objective of the Reflective Cracking Test is determine the relative benefit obtained with the introduction of the Hycore® steel mat in the crack development and crack growing rate through an asphalt pavement overlay under simulated dynamic road traffic with regards to the non reinforced control samples.

The principle of the test procedure is similar to others reflective crack tests published but adapted to the characteristics of the Hycore® and to the available dynamic testing machines.

Asphalt concrete slabs made up of two layers were produced in field conditions. The bottom layer simulates the old pavement and the upper layer simulates the overlay. Between the two layers the material to be tested is lied. The cracking of the old pavement is simulated with a vertical cut in the bottom face of the inferior layer.

The test slabs are placed over a layer of virgin rubber to simulate the vertical elastic deflection by the reaction of the old pavement. A Young Module of 70 MPa of the virgin rubber used was determined in the laboratory. This module corresponds to a subgrade type E1, according to the Spanish Standard “6.1 IC Secciones de Firme”.

The generation of the reflective cracking is obtained by the application of a vertical sinusoidal load wave over the asphalt concrete slab.

The temperature of the test remains constant for all tests to eliminate the influence of this parameter in the stiffness of the asphalt concrete an in the test results.

6.1 Test conditions

The tests were carried out under load control condition using a vertical load wave with a sinusoidal form to simulate the traffic action. The load wave has the following characteristics:

- Loading interval: 2 – 42 kN (compression over the sample)
- Load wave amplitude: 40 kN
- Maximum load pressure: 1 MPa
- Frequency: 5 Hz

The load pressure applied in the surface of the test samples was varied from 0,07 MPa to a maximum of 1,04 MPa (in the Spanish Standards the maximum load pressure allowed over the pavement surface is 0,93 MPa).

To measure the velocity of the crack propagation from the tip of the artificial crack to the surface of the new layer, the crack opening (between two fixed points in the lateral face of the sample) at the level of the tip of the artificial crack regarding to the number of load cycles was automatically registered.

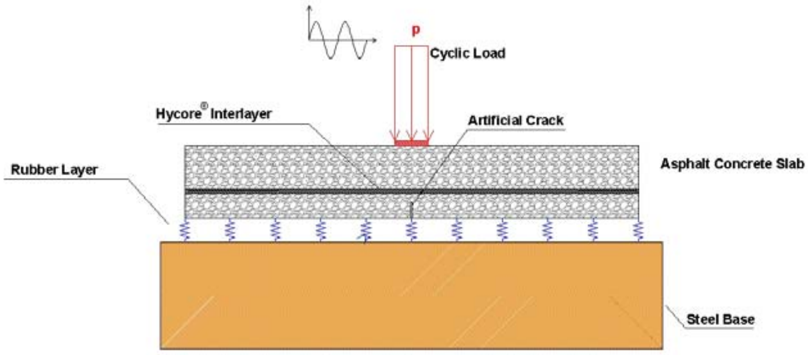

Figure 7 Scheme of the test installation for RCT.

The stiffness of the slab was also registered by the instant elastic strain of the bottom fiber of the asphalt concrete.

Figure 8 View of the Instron dynamic test machine used to load application in the RCT.

The number of load cycles to the failure of the sample is detected by the increment in the magnitude of the elastic strain wave, which is a sign of the degradation of the stiffness of the slab due to the growing of the cracks.

6.2 Test samples

The Reflective Cracking Test (RCT) was designed to accommodate the asphalt concrete test specimens using Hycore® Asphalt Mat produced in the factory at 1:1 scale.

To get representative samples using Hycore® at actual scale, there were used pieces of steel mat of 4 rhombuses wide by 4 rhombuses length; it means 520 mm width by 880 mm length. In reinforced slabs, the Hycore® interlayer was placed over an initial layer of 5 cm of asphalt concrete.

According to the size of the Hycore® reinforcement the samples for testing have the following dimensions: 55 cm width and 92 cm length. Asphalt concrete slabs for testing purposes were designed of two layers of asphalt concrete (5 cm + 10 cm).

For such sample size, it was necessary to produce them in outdoor location with the help of standard construction machinery for asphalt pavement operations

Standardized asphalt concrete for surface layers (S-12 according to the Spanish Standard) was used.

6.3 Comparison of RCT results over Hycore® reinforced samples and non reinforced control samples

For the control samples was observed that, at the beginning of the test, a crack arises in the bottom face of the overlay due to the action of the load pulse. This crack appears at the tip of the vertical cut carried out previously in the inferior layer which simulates a crack in the old pavement.

The cracks reflected in the asphalt concrete overlay grow progressively, with the increment of the number of load applications to an approximately constant rate.

Starting from certain number of load cycles the failure of the test sample is indicated by an abrupt increment of the propagation speed. Finally, when the crack appears in the surface, the test slab is divided in two sections.

For the Hycore reinforced samples, at the beginning of the test, a crack arises in the bottom face of the overlay due to the action of the load pulse, as occurred before with the control samples.

The crack reflected in the asphalt concrete overlay reinforced with Hycore® grows progressively to get the upper face of the steel mat. Once the crack gets the Hycore® the evolution of the crack practically stops. The number of load cycles increases but the evolution rate of the condition of the sample is very slow. The sample at 50.000 cycles remains in the same condition as was observed at the cycle 5.000.

The sample RR-N was submitted up to 278.000 load cycles without failure by reflective cracking and the test was stopped because apparently the crack growth to the surface and the sample shows a curvature of the surface due to the settlement of the beam inside the asphalt concrete due to plastic deformations. The main crack and the other cracks by plastic deformation interconnected and there was not possible to follow the trace of the main crack in the lateral face.

When the load beam was released there was not observed cracks in the surface of the sample. To check the condition of the asphalt concrete inside of the slab at the end of the test, a central section of the sample was separated, and the slab was cut in 6 parts perpendicular to the position of the load beam.

Figure 9 Sample reinforced with Hycore® at the end of the test, 278.000 cycles. No cracks or damage were observed inside of the asphalt concrete overlay.

In the following graphics the reflective cracking test results obtained over samples reinforced with Hycore® and over control samples are presented together. Samples named RR are samples reinforced with Hycore® and RS are control samples.

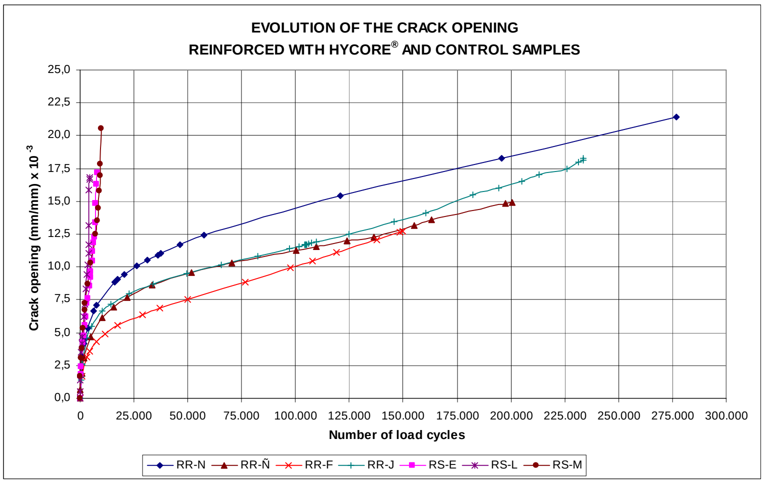

Figure 10 Evolution of the crack opening. Comparison between samples reinforced with Hycore® and control samples without reinforcement.

The results of the graphic shows the rapid growing of the crack opening in the control samples with the failure of the sample at a relative low number of load cycles (less than 10.000) while the samples reinforced with Hycore® support up to 278.000 cycles without the failure by the reflective cracking. All reinforced samples present an excellent behavior against the propagation of the cracks from the bottom layer throughout the upper layer.

The amplitude of the strain wave indicates the instantaneous elastic elongation of the bottom fiber of the upper asphalt pavement layer which is an indicator of the flexural stiffness of the pavement section and its ability to withstand the action of the traffic.

As the number of load cycles increase, the flexural stiffness of the A. C. layer without reinforcement decrease very fast and the amplitude of the strain wave increase with a rapid increment of the strain value.

The flexural stiffness of the samples reinforced with Hycore® decrease very low with the number of applications of the load cycles and remains enough to withstand the effect of the loads without cracking of the asphalt concrete due to reflection of the bottom old cracks.

The unit elongation of the bottom fiber reinforced with Hycore® remains for all the samples below 500 microstrains (0,0005 mm/mm) after 150.000 load cycles.

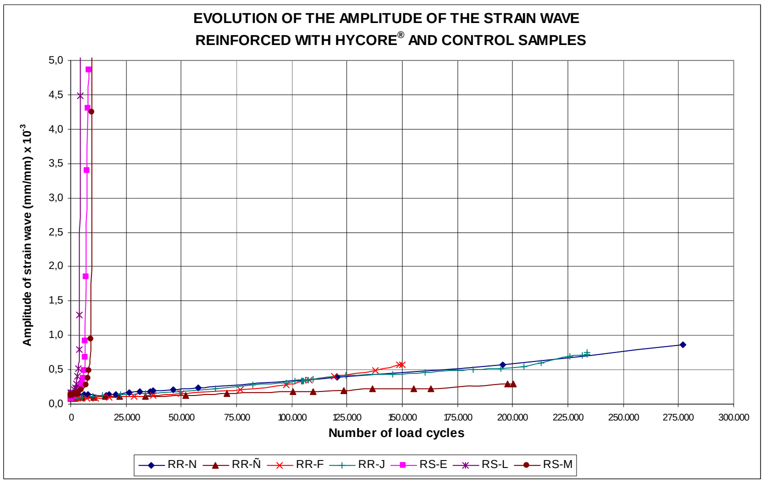

Figure 11 Evolution of the elastic strain wave in the bottom face of the slabs. Comparison between reinforced samples with Hycore® and control samples.

However the samples reinforced with Hycore® remains the flexural stiffness for a high number of load cycles (more than 25 times over the failure of control samples) without the brake down of the flexural stiffness of the pavement layer.

7. CONCLUSIONS

As result of the reflective cracking test run over a set of control samples and samples reinforced with Hycore® the following conclusions can be outlined:

- The introduction of the Hycore® Asphalt Mat in the maintenance of old cracked flexible pavements have a marked influence in the behavior of the overlay to control the reflective cracking process.
- After the tests, can be concluded that the Hycore® stops the migration of the cracks from the old pavement to the surface of the new layer.

- The relative increment in the life expectancy by the introduction of the Hycore® Asphalt Mat in the asphalt concrete overlay of old pavements is more than 25 times regarding the same solution without reinforcement.
- The Hycore® Asphalt Mat also works as an effective reinforcement interlayer, due to the maintenance of the initial flexural stiffness along a high number of load applications. The marked reinforcement effect arises due to the long term behavior and the increment of the life span.
- The maintenance of the flexural strength of the layer reinforced with Hycore® Asphalt Mat after a very high number load application allows the thickness reduction of the overlay mainly for thick asphalt concrete reinforcement layers.
- Hycore® enhances the behavior of the asphalt overlay and prolongs significantly the service life of the pavement, controlling the reflective cracking, delaying the rutting and allowing a thickness reduction in the overlay thanks to the increment in the life span.

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