

ASPHALT REINFORCEMENT THROUGH GEOSYNTHETICS: DESIGN METHOD AND UK EXPERIENCE

Nicola Brusa¹, David Crowther², Pietro Pezzano³

¹ Regional Engineer, Southern England, Maccaferri Ltd, UK

² Technical Manager, Maccaferri Ltd, UK

³ Pavement Technical Specialist, Officine Maccaferri Spa

Maccaferri UK Ltd,
7600 The Quorum, Oxford Business Park North
Garsington Road - Oxford OX4 2JZ
T: +44 (0) 1865 770555
F: +44 (0) 1865 774550
www.maccaferri.co.uk
oxford@uk.maccaferri.com

ABSTRACT

Traffic volumes on Britain's roads have never been higher and significant increase in traffic levels over the coming years is more than a virtual certainty. These high levels of traffic loading, particularly from heavy commercial and transport vehicles, put considerable strain on the road network's overall capacity.

Over the past decade, the geotechnical industry has developed a range of geosynthetic reinforcement systems optimized for increasing the performance and durability of road pavements and also for reinforcement to reduce the asphalt thickness or to improve the traffic loading capacity.

Design methods have been development over the years and these allow designers to have a feeling for the benefit of using asphalt reinforcement geosynthetics.

This paper aims to analyze what has been done so to date, the solutions available nowadays, from the research available, design criteria, product choice and installation criteria. This paper will describe and analyze also a real case study and actual application carried out in the UK 10-15 years ago, understanding the condition and of the pavement prior to repair and after some years of refurbished pavement serviceability.

The successful case history presented at the end of the paper confirms by practical experience the soundness of the described design method and engineering solution proposed.

I. Introduction

The term "reinforcement" refers to the ability of an interlayer to better distribute the applied load over a larger area and to compensate for the lack of tensile strength within the road pavement. As in any reinforcement application, the reinforcing material should be stiffer than the material being reinforced (Rigo, 1993).

With appropriate design and correct installation, many improvements can result from reinforcing HMA overlays: increased tensile strength; increased resistance to reflective cracking and bottom-up fatigue cracking; increased shearing resistance and hence may reduce shoving and flow rutting; increased coherence in the overlay; and potential material savings and enhanced pavement performance so significant whole design life benefits.

II. Asphalt reinforcement geosynthetics

Geosynthetics such as geotextiles, geogrids and geocomposites provide the widest range of product used for asphalt reinforcement as they are able to withstand high stiffness demand, installation damage and loadings. In the past 20 years, research has brought the development of products which are able to reinforce the wearing course, thus improving the traffic design of the pavement or to reduce the overall cost of the pavement, both for new and rehabilitation pavement projects.

One of the oldest interface systems used in flexible pavement is actually steel reinforcement. This idea, which appeared in the early 1950s in the US, was based on the general concept that if HMA is strong in compression and weak in tension, then reinforcement could be used to provide needed resistance to tensile stresses, in the same manner as reinforced concrete.

In the early 1980s, a new class of steel reinforcement product, hexagonal woven wire mesh in place of welded mesh, appeared in Europe. Many of the problems encountered earlier appeared to have been solved, and satisfactory experiences with the new class of steel reinforcement were reported (Vanelstraete, et al., 2000).

III. The double twist wire mesh reinforcement

Double twist woven wire mesh reinforcement (Road Mesh®) was initially introduced to intercept the reflected cracks generated by jointed concrete pavements. Wider use of the product and further research have found the double twist steel mesh being used more widely and for a greater number of solutions. The double twist steel mesh is best suited to being used for the following applications:

- Fatigue cracking and overlays: if a new pavement or if a new overlay is installed over a fatigued/cracked pavement, cracks will propagate to the surface after a very short traffic period. The double twist steel mesh is introduced to extend the life of the overlay by absorbing the horizontal tensile stresses resulting from the existing cracks and by traffic loads.
- Road widening: when roads need to be widened, differential settlement cracks occur at the junction between the old and new pavement structures. Road Mesh® is introduced to bridge the junction to absorb the crack stresses caused by the differential settlement: the effective interlock with the asphalt aggregate matrix ensures the optimum contribution of the reinforcement; a minimum of 1 m either side of the joint is required.
- Surface rutting: under repeated heavy vehicle traffic, the asphalt surfacing is exposed to repeated shear forces which result in shear slip circles and ultimately leads to shoving. Road Mesh® is installed at the base of the overlay, for a typical minimum layer thickness of 60 mm, thus intersecting shear slip circles and ultimately reducing surface rutting.

This type of asphalt reinforcement is manufactured from double twisted steel wire mesh with transverse reinforcing rods evenly spaced throughout at approximately 16 cm centers, as shown in Table 1 and Figure 1.

Wire diameter (mm)	Transverse rod (mm)	UTS – Ultimate Tensile strength MD/CDM (kN/m)
2.40	4.40	40/50

Table 1. Mechanical characteristics of the double twist wire mesh

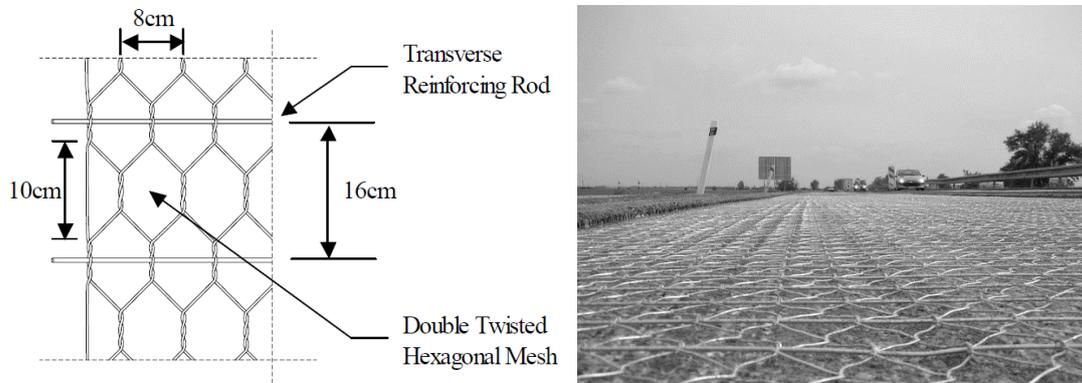


Figure 1. Geometrical characteristics of the double twist wire mesh

The hexagonal mesh size is 80 by 100 mm (nominal) as defined in EN 10223-3:2013, the wire is protected against corrosion by a zinc coating complying with EN 10244-2:2013 Class A. The mesh profile thickness varies between the 2.4 mm wire diameter up to a maximum 9.2 mm, where the transverse rod passes through the double twist. This varying height of the product strands, and distance between them, ensures that the asphalt can encapsulate the wire, without developing a weak shear zone at the product interface.

Other reinforcing materials, due to their geometry, are able to absorb crack reflection stresses, but because they are not able to integrate themselves into the aggregate matrix, they cannot contribute to reducing the rut resistance as well. Therefore good asphalt /mesh bonding is one of the main requirements for the performance of a reinforcement used in pavement applications.

The structure and shape of the reinforcement is usually a governing factor: a product with an open mesh structure allows the geosynthetic to fully interlock with the aggregate matrix, while a geotextile does not. Shear box testing carried out at Nottingham University has highlighted the importance of the geosynthetic structure with respect to bonding.

Figure 2 is the summary of Data from the Repeated Load Shear Test, and represents the interface bond test results where the shear deformations are plotted against shear stresses. If we compared the secant stiffness at a repeated shear stress of +200kPa it is clear that the GGR-E-PP+GTX, the GGR-W-GLASS+GTX and the GGR-W-GLASS+GTX samples, that are grids coupled with a fabric, had the lowest Interface Shear Stiffness.

Reinforcement	Description
GGR-E-PP	Extruded Geogrid in PP
GGR-E-PP+GTX	Extruded Geogrid in PP with nonwoven geotextile backing
GGR-W-GLASS+GTX	Woven Geogrid in Glass with nonwoven geotextile combined

GGR-W-STEEL	Double Twist Steel Mesh
GGR-W-GLASS	Woven Fiber Glass Geogrid

Table 2. Legend related to Figure 2

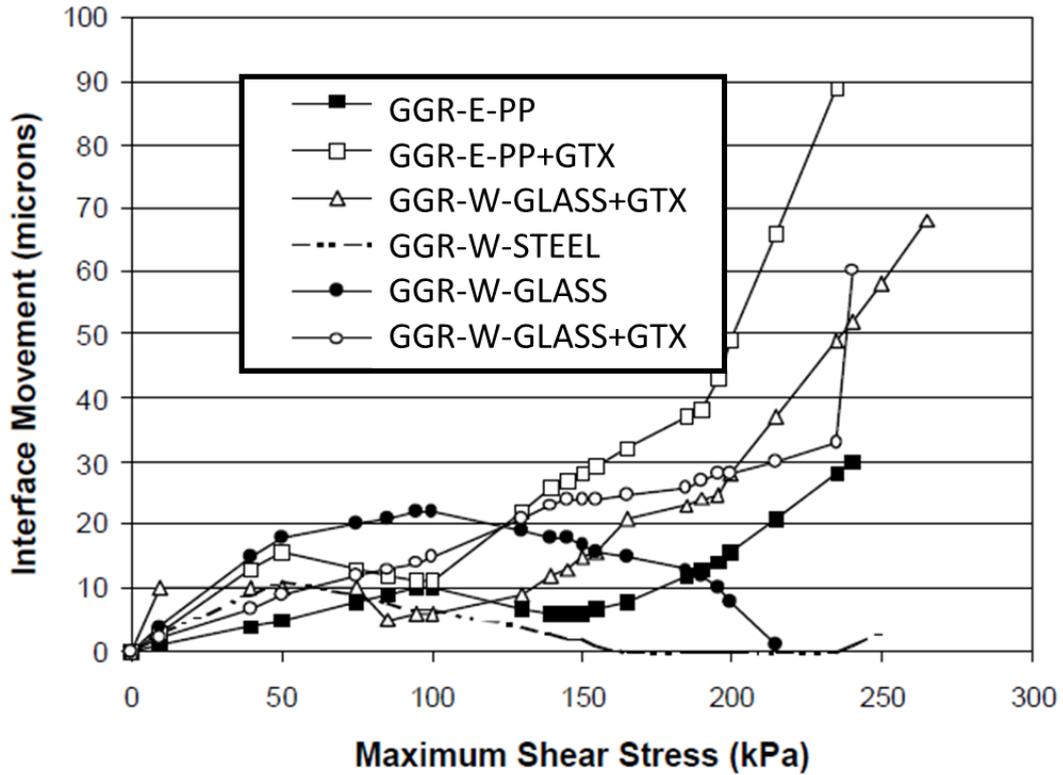


Figure 2. Shear box test on various geosynthetics to assess the bonding properties

It is easy also to appreciate that the stiffer the reinforcement, the higher value of tensile strength is developed thus the higher will be the benefit. Both raw materials and type of geosynthetics influence the stress-strain behavior of the asphalt reinforcement geosynthetics as shown in figure 3, where the material stiffness decreases from left to right.

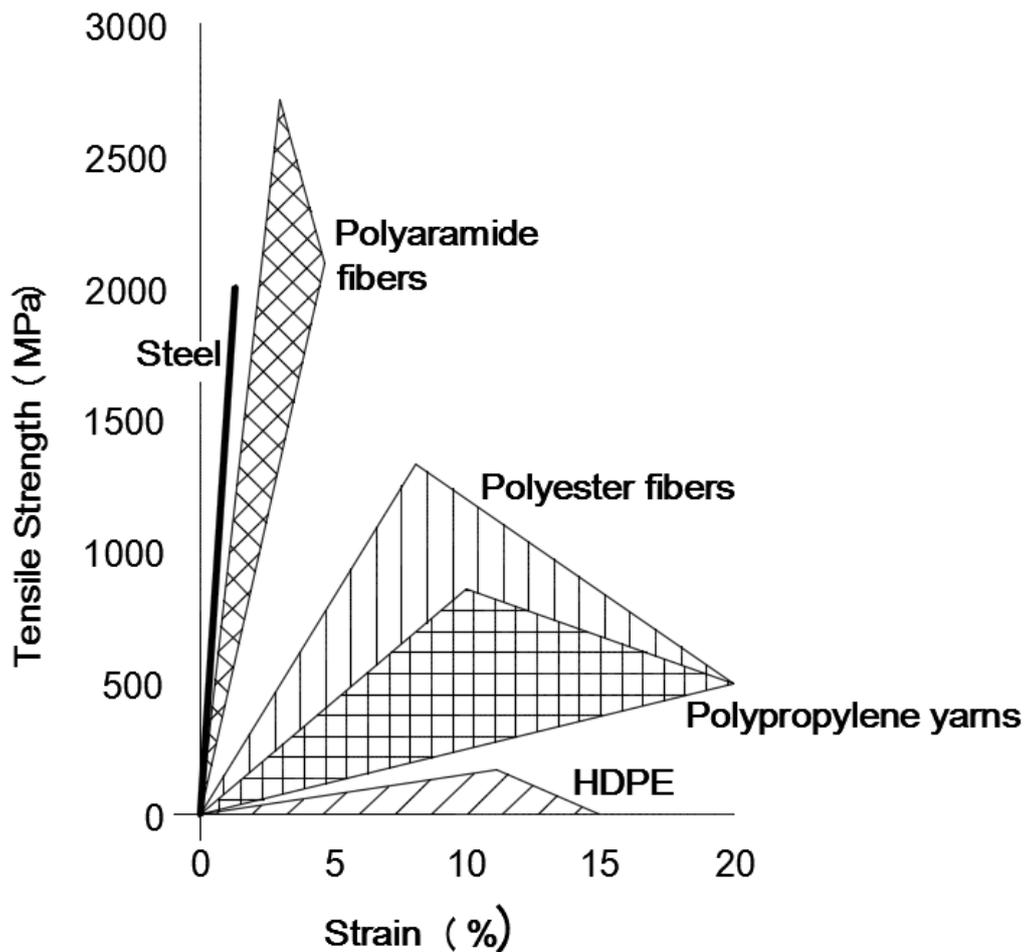


Figure 3. Stress strain curve for various geosynthetics and geocomposite raw materials

IV. Design methodology

The mechanism of asphalt reinforcement is known and has been studied extensively, however asphalt reinforcement techniques are currently not thoroughly covered in any standard or method statement in most parts of the world. No standardized design method is currently used to calculate the real benefit of a reinforcement in the asphalt layers, resulting in approximation based on past experience for the extended design life, or a higher margin of safety without varying the design life.

The design methodology proposed for asphalt pavement reinforcement in this paper, is an empirical mechanistic process and is based on the research commissioned by the UK Highways Agency (now Highway England), which resulted in a design software for reinforced overlays. The proposed method and software called OLCRACK is suitable for use in overlay design and which uses a linear elastic crack fatigue model derived from research and modelling at Nottingham University in the UK.

This methodology has been extensively trialled and is capable of replicating test results from both semi-continuously supported beam tests and the pavement test facility. The resulting predications are of the same order as those from the CAPA finite element programme, developed at Delft University. OLCRACK offers the flexibility required to cope with the highly complex problem posed by reflective cracking and the effectiveness of reinforced asphalt in extending the life of the pavement.

Two principle tests were conducted, comparing glass fiber, polymer grids and double twist wire mesh with an unreinforced control sample. Covering most of the

commercially available asphalt reinforcement products available at the time and currently available in the UK market (Figure 4).

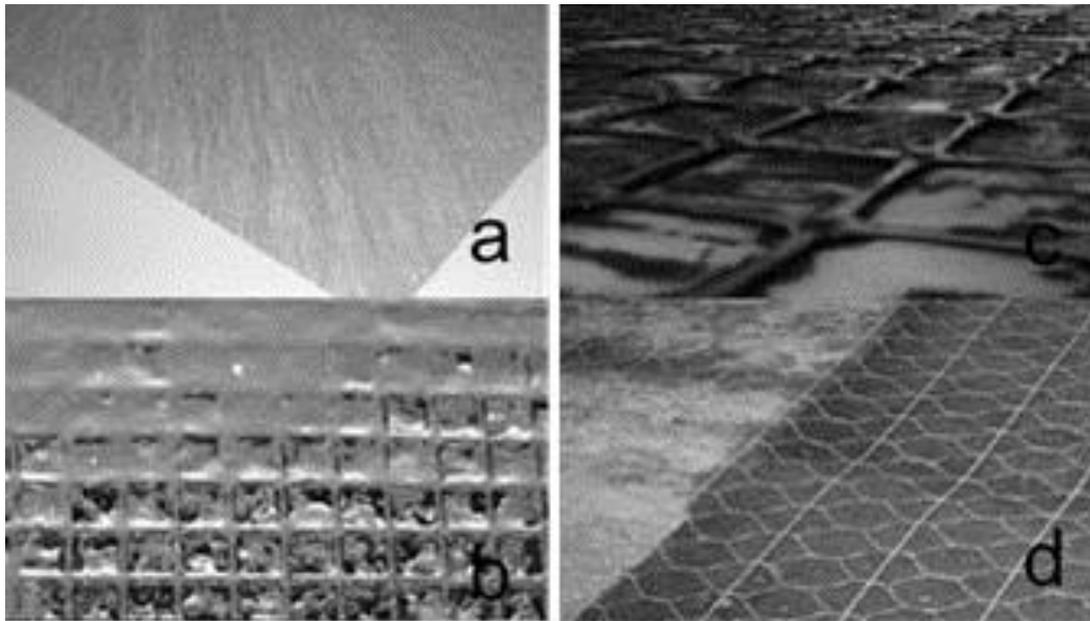


Figure 4. Asphalt reinforcement product: a) Nonwoven geotextile b) Glass fibre geogrid c) Extruded geogrid d) Double twist steel mesh

The Nottingham Pavement Test Facility was used to demonstrate the behaviour of reinforced pavements under wheel load traffic conditions: the thickness of the asphalt was designed to generate a level of strain under wheel loading which would result in cracks developing relatively quickly. Various reinforcing grids were fixed within the asphalt according to specification. The semi-continuously supported beam test replicates the distribution of stress cracking through pavements. The tests have highlighted a linear relationship between the stiffness of the reinforcement and the benefit which is expected.

The second factor was the bonding between the reinforcement and the asphalt. Reinforcements with very good bonding such as geogrids outperformed respect to geotextiles or even geogrids with geotextile combined.

The results showed that reinforcement can significantly enhance the resistance of asphalt to crack propagation, with the double twist wire steel mesh being particularly effective, offering a life enhancement factor of up to 3.

From the results, in controlling ruts, the double twist steel mesh performed in a similar manner to the polymer grid, offering an improvement factor of approximately 2. Glass grids had very little impact on rut formation. The findings from both tests, conducted under the aegis of Nottingham Asphalt Research Consortium (NARC), chaired by Professor Brown, Head of Faculty at the University, offer firm evidence to support the use of Road Mesh® in preference to other types of grids (Thom, 2000).

The design input requires the definition of the elastic moduli of the layers in the existing pavements and in the overlay, and the traffic. The output is a fatigue life for the unreinforced and reinforced pavement. It is important to note that this empirical model is mechanistic and based on specific reinforced asphalt research data, and therefore will not generate the same fatigue life results calculated by using other linear elastic empirical models. However, if the life of the critical layer is calculated by other means, then this life can be treated as equivalent to the unreinforced fatigue life value

calculated by our model, and the benefit of the reinforcement applied using the same improvement factor value.

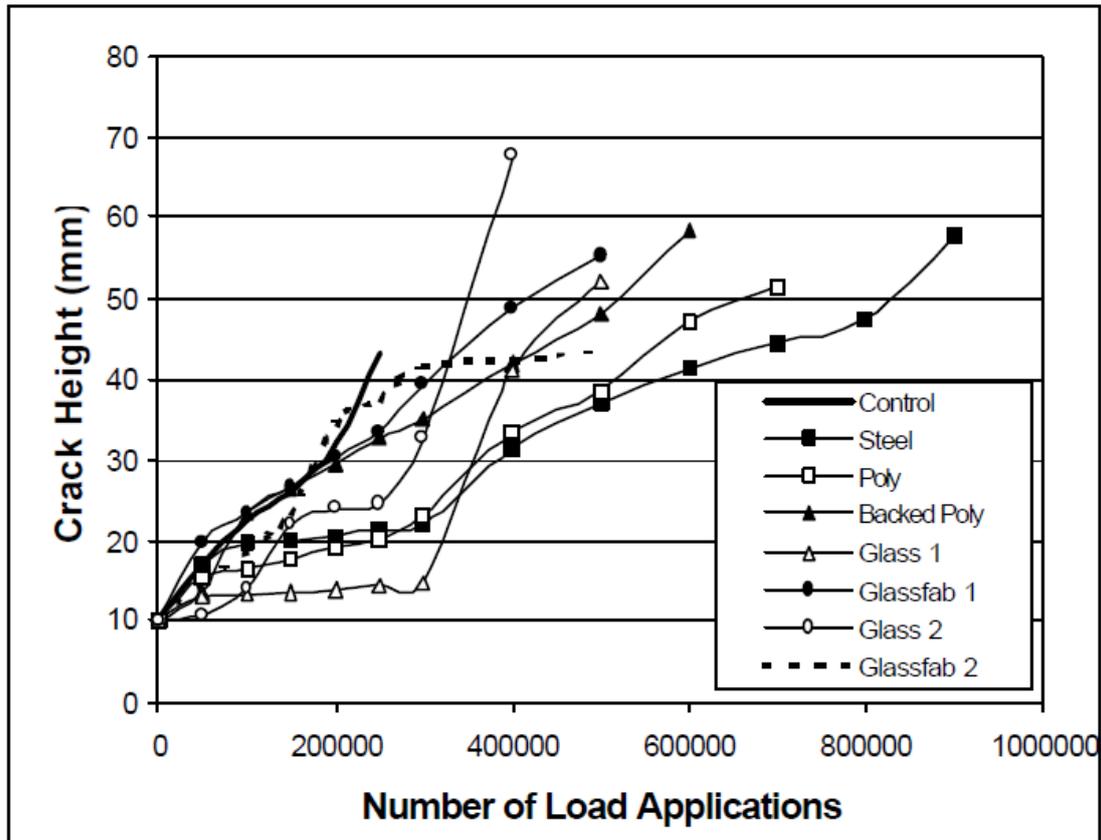


Figure 5. Crack propagation for different types of reinforcement

If we assume for example an hypothetical pavement structure, considering the traffic volume for an M or A-road (highways, major interurban freeways and major rural roads) with following data:

- 50mm HMA ($E=3000\text{MPa}$; $\nu=0.35$)
- 150mm graded crushed stone ($E=450\text{MPa}$; $\nu=0.35$)
- 250mm cemented natural gravel ($E=1500\text{MPa}$; $\nu=0.35$)
- 100MPa subgrade ($\nu=0.35$)

We are able to identify using the OLCRACK the benefit of placing a geosynthetic reinforcement at the bottom of the asphalt layer. The increment of traffic load and thus design life of the pavement could follow for example the Table 3.

Reinforcement type	Description	Strength (kN/m)	Traffic (Millions)
GTX-nw	Nonwoven geotextile	20	0.7
GGR-w (Glass)	Woven Geogrid Fiber Glass	50	1.1
GGR-E	Extruded Geogrid	40	1.2
GGR-W (Glass)	Woven	100	1.5

	Geogrid Fiber Glass		
GGR-W-STEEL	Double Twist Steel Mesh	40	2.3

Table 3. Results considering different asphalt reinforcement

Looking at the microstrain at the bottom of the asphalt layer plotted against the design traffic, the benefit of the asphalt reinforcement is evident, reducing the strain on the asphalt (Figure 6) as the geosynthetic reinforcement is developing tensile strength (Figure 7).

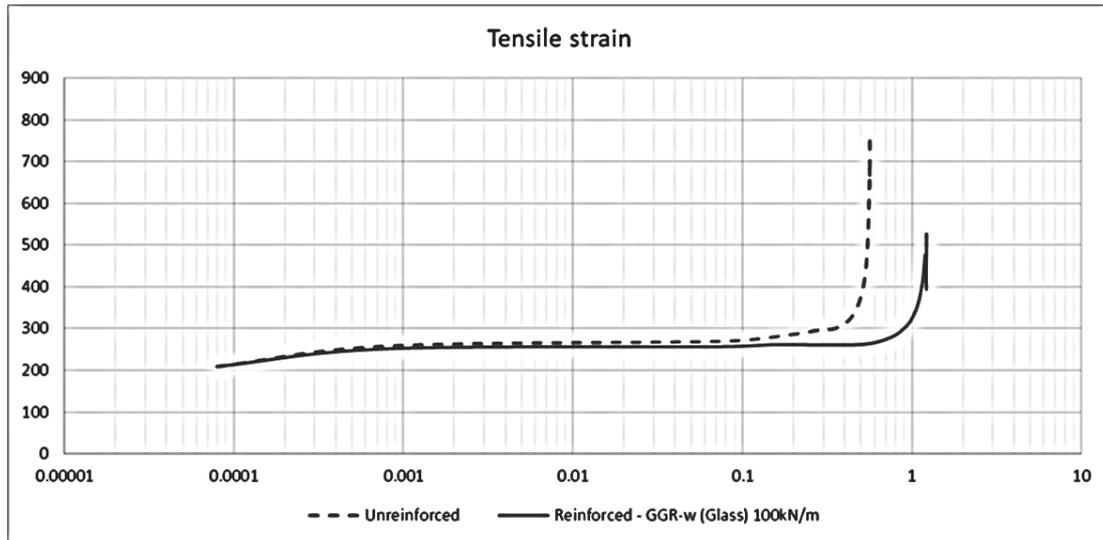


Figure 7. Typical tensile strain variation between unreinforced and reinforced structure (in this case is considering a fiber glass reinforcement)

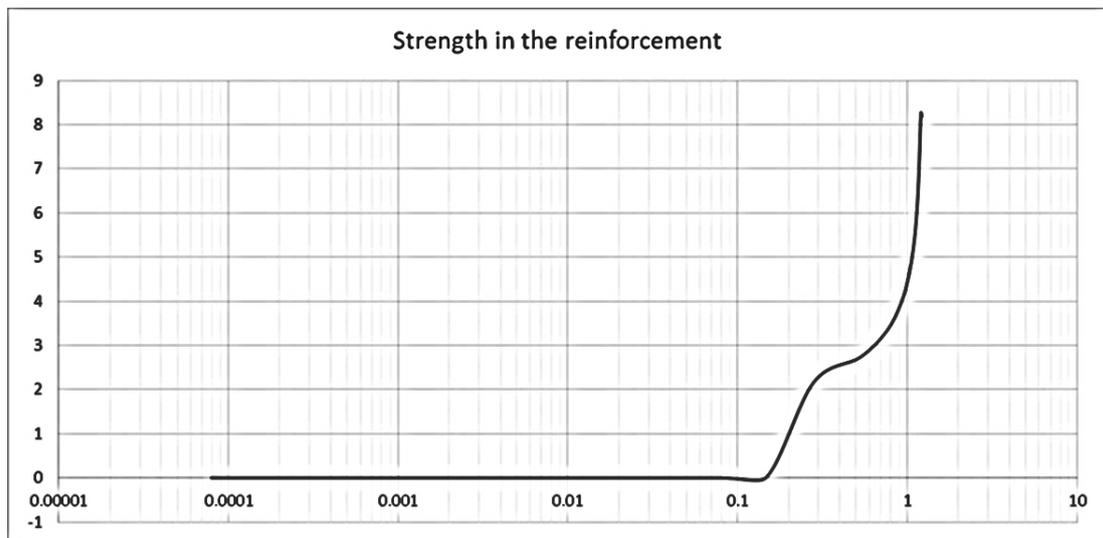


Figure 8. Tensile strength in the reinforcement plotted against traffic loading

Utilizing a finite element analysis approach, Coni and Bianco (2000) showed the effectiveness of steel reinforcement to significantly reduce reflection cracking. Others, (such as Vanelstraete et al. 2000), showed the effectiveness of steel reinforcement in reducing the slab rocking; Vanelstraete and Francken (2000) showed that steel reinforcement is effective in reducing the reflection of cracks; while Veys (1996)

reported the superior performance of steel mesh reinforcement in delaying the appearance of the reflective cracking when compared to other interlayer materials.

V. The UK experience and conclusion

The performance of Road Mesh® in asphalt pavements has been thoroughly investigated in the last 15 years through a number of research projects carried out by Universities around the world, finalized with development of an empirical design methodology for reinforced pavements, validation of FEM numerical results with tests and field data and eventually evaluation of the working life enhancement of a reinforced pavement. Table 4 shows an overview of the main parameters adopted by researchers for FE modelling.

University	FE code	Materials Behaviour ⁽¹⁾	Modelled portion (mm)
Nottingham	Capa-2D	VE	400x200x90
Cagliari	Ansys	EP	960x960x770
Virginia Tech.	Abaqus 5.8	VE	560x38000
Catania	Supersap	E	5940x5845x3040
Parma	Abaqus 6.4	VE	500x500x230
Palermo	Ansys	EP	640x830x640

⁽¹⁾ VE=viscoelastic, EP=elastoplastic, E=elastic

Table 4. Details of the adopted FE models

The main results of the research are:

- Nottingham, UK: the fatigue life of a reinforced pavement improves by a factor up to 3
- Cagliari, Italy: the reinforcement increases the pavement life by a factor between 3 and 12
- Virginia Tech., USA: the crack initiation factor is improved by a factor between 1.15 and 3.6
- Catania, Italy: the crack initiation factor improvement varies between 1.36 and 1.52
- Parma, Italy: the surface cracking is reduced of 65%
- Palermo, Italy: stresses due to shear actions (rutting) are reduced by 50%

The large amount of data collected from the worldwide research and field project experiences, have proven that the double twist steel wire mesh, originally developed to inhibit reflective cracking in the asphalt layers, can be designed to effectively enhance the working life of the whole pavement, and may in some application performing better than other geosynthetics asphalt reinforcement.

In the last 10 years more than 600,000sqm of Road Mesh® has been installed as asphalt reinforcement within the UK.

A successful case study is now presented.

- A4114 Abingdon Road Maintenance Scheme

Abingdon Road is a main arterial road, heavily trafficked by up to 20,000 vehicles per day (cars, busses, HGV) heading south from Oxford city centre to the Southern By-Pass. Regular maintenance of the worst areas has been necessary, but in most cases

the benefit has been short lived. Therefore Oxfordshire County Council finally contemplated a major reconstruction to a substantial length of the road. The decision was taken to start work during 2003. Full pavement reconstruction was determined to be necessary, but the presence at shallow depth of utility mains services and the Norman Causeway Scheduled Monument limited the depth of reconstruction to 450mm. The existing low strength subgrade could not be improved by replacement. Therefore a solution involving Road Mesh® was developed to provide a minimum 15 year design life. The woven wire Road Mesh® was placed deep in the bituminous layers to give maximum structural benefit. The area chosen was from Step Ground Bridge to Norreys Avenue. Almost 2km of carriageway reconstructed in phases over 3 consecutive years. All phases were completed on time and on budget, achieving a high quality construction with only modest disruption to road users and frontages. The OLCRACK analysis evaluates the fatigue point as that load at which top down and bottom up propagated cracks meet, and calculates design life to this point in time. This is compared with the reinforced structure design life calculated above.



Figure 9. Abingdon Road before the installation of the asphalt reinforcement showing fatigue cracking

Figure 10. Abingdon Road today

In 2016, after almost 13 years from the first trial the significant structural benefit obtained on this site (with severe constraints on pavement depth), by positioning Road Mesh® deep in the pavement layers, has been conclusively demonstrated. The pavement behavior of the HMA confirming the good standing of the solution.

VI. Reference

BROWN S. F., THOM N. H. and SANDERS P. J. (2001) - "A study of grid reinforced asphalt to combat reflection cracking" - *J. Assoc. Paving Technologists*. Vol.70, pp. 543-571.

CAFISO S., DI GRAZIANO A. (2003) - "Evaluation of flexible reinforced pavement performance by NDT" - *82nd Annual Transportation Research Board (TRB)*. National Research Council, Washington DC

CONI M., and BIANCO P. M. (2000) - "Steel reinforcement influence on the dynamic behaviour of bituminous pavement" - *Proceedings of the 4th International RILEM Conference – Reflective Cracking in Pavements*. E & FN Spon, pp. 3-12.

MONTEPARA A., TEBALDI G. and COSTA A., (2005) - "Performance evaluation of a surface pavement steel reinforcement" - *Proceedings of the 5th International Conference on Road & Airfield Pavement Technology (ICPT)*. Seoul, Korea

MOSTAFA E., AL-QADI I. (2004) – “Effectiveness of Steel Reinforcing Nettings in Combating Fatigue Cracking in New Pavement Systems” - *83rd Annual Transportation Research Board (TRB)*. National Research Council, Washington DC.

TESORIERE G., TICALI D. (2004) – “Verifica sperimentale delle pavimentazioni rinforzate con rete metallica” - *Rivista Le Strade* n° 11/2004

THOM N.H. (2000) – “A simplified computer model for grid reinforced asphalt overlays” - *4th International RILEM Conference – Reflective Cracking in Pavements*. Ottawa, Canada, pp. 37-46.

VICARI M. (2007) – “Reinforcement with double twist steel wire mesh: modelling and laboratory experiences to evaluate the design life improvement of asphalt pavements” - *4th International SIIV Congress* – Palermo, Italy.

ZANNONI E., PEZZANO P. (2015) – “Asphalt reinforcement through geosynthetics” - *11th Conference on Asphalt Pavements for Southern Africa (CAPSA 2015)*. Sun City, South Africa