Optimization of Geosynthetic Design for Asphalt Pavement Reinforcement

C. Sarbach
Afitexinov, 56 Route de Ferrossière, 38110 Saint-Didier de la Tour, France
E. Tardif
Afitexinov, 56 Route de Ferrossière, 38110 Saint-Didier de la Tour, France

ABSTRACT: The use of geogrids for pavement reinforcement has been continuously increasing over the past decades. Their main role remains to limit crack reflection and they are therefore typically used on cracked pavements before renovating the upper asphalt layers. Still, the way they work remains a debated issue and no clear guidelines currently exist for selecting this type of products in view of a specific construction project. This paper presents our current understanding of the mechanisms behind asphalt pavement reinforcement in view of the 3 functions described in the European standard for these products (EN 15381), namely stress relief, reinforcement and interlayer barrier. As a consequence, an optimal geosynthetic design can be inferred, based on the combination of a fiber-glass geogrid and a light geotextile as exemplified by the Geoter® FNG product range developed at Afitexinov. The interest of these products is discussed and illustrated in the light of recent results.

1 INTRODUCTION

The use of geosynthetics for pavement reinforcement can be traced back to as early as 1937, when a steel mesh was used to reinforced an asphalt layer over 2 km of a 10-yrs old cracked concrete pavement on route M21 in the South West of Grand Rapids (Michigan, USA) (Williams, 1954). The idea was simply to mimic reinforced concrete. Although it was observed from the beginning that placement of the steel reinforcements was quite tricky, this was replicated on several occasions in the USA in the 1940-50s, and then in Canada and the UK in the 1950-60s, confirming that the technology could delay reflective cracking in asphalt layers over cracked pavements, provided correct installation could be realized, previous treatment of large cracks was performed (crack sealing) and a thick enough asphalt layer was placed. In parallel, it was also observed very soon that the deconstruction of such reinforced pavements was very complicated and that the corrosion of steel wires could lead to the formation of potholes (Smith and Gartner, 1962).

In the 1960s, non-woven geotextiles, developed in many fields of civil engineering, mostly for the separation and/or filtration of soils and granular materials. Very rapidly, the idea popped to use them in pavements, once saturated in bitumen, as interlayers to delay reflective cracking. One of the first trial took place in 1966 in the USA (Dykes, 1980). There are indeed been earlier trials with coarsely-woven cotton layers in the 1930s, but they didn't persist as the cotton was found to eventually rot (Dykes, 1980). It was soon observed that fibers with limited thermal shrinkage at asphalt laying temperature, had to be preferred, that is essentially polyester or polypropylene. Also, a large enough quantity of tack coat had to be spread in order to correctly glue the textile to the pavement structure. Therefore, improper placement (generally meaning either lack of tack coat or excess of wrinkles and other defects) and again lack of large-cracks pretreatment, were identified to be the main reasons explaining the poor performance observed in some occurrences (Carmichael and Marienfeld, 1999). Otherwise, the technic was generally accepted to successfully delay reflection cracking and provide additional benefits due to the waterproofing of the underneath structure (Barksdale, 1991). The main mechanism for delaying crack propagation was proposed to be a stress relief effect appearing when the crack sees a soft layer (ie, the geotextile in the binder) when propagating in stiffer layers (ie, asphalt mixtures) (Lytton, 1989) .

Similar trials were also performed in Europe, with for example many proprietary solutions being developed by road contractors in France by combining nonwoven geotextiles of 120-250 g/m2 with ~1 kg/m2 polymer-modified bitumen membranes. These solutions were found to be efficient to retard reflective cracking for 1 or 2 winters versus the same overlay thickness without a fabric interlayer (Giloppe et al., 1997) and were therefore considered to be one of the best options against reflective cracking in terms of price / performance ratio by the French Airport Pavement administration (STBA, 1999). The US experience showed that the statement would hold as long as the thickness of the above asphalt overlay remains smaller than ~8-10 cm. For higher asphalt thicknesses, the benefits were not so clear as far as reflective cracking was concerned (Barksdale, 1991).

Finally, the continuous evolution of the field of geosynthetics, led to the development of geogrids in the 1970s and attempts to use them in asphalt pavements appeared naturally. They were thus an obvious successor to earlier uses of steel meshes but with an easier installation, a good potential to make deconstruction less complicated and little corrosion risk. Early trials were indeed performed in the late 1970s with polymeric or glass geogrids (Giloppe et al., 1997), but they were still perceived as emerging technologies in the late 1990s in both the USA (Holz et al., 1998) and France (Giloppe et al., 1997). Products combining geogrids and geotextiles came as an obvious evolution given the above context, and progressively became the reference solution, with a main design combining a light geotextile to a fiber-glass geogrid. The idea was to limit the risk of slipping observed with some polymeric grids (Giloppe et al., 1997), and this proved an excellent solution in order to facilitate installation in general.

The role of the light geotextile is to make installation easier thanks to its ability to absorb bitumen. The geogrid provides the reinforcement and fibers with breaking strain < 5% were soon observed to behave better, as requested in the current Californian specifications (Maintenance Technical Advisory Guide, 2009). Glass-fibers are therefore a preferred choice because of their reasonable price and excellent performance in this application.

Even if there is clearly a large amount of published literature on this topic, no design guidelines currently exist to help select product as a function of the project at stakes. The most advanced specifications in the World for geosynthetics in asphalt overlays are probably the ones from California (Maintenance Technical Advisory Guide, 2009), but they are still not a design guide where product strength could be for example computed as a function of position in the pavement and traffic.

Given this context, Afitexinov developed a full range of reinforcing geosynthetics for asphalt pavements based on a combination of glassfiber geogrids with a light geotextile. The type of products and the way their performance is currently assessed is described in this paper, and examples of recent applications are also given. Our objective is to help project designers better select the needed product for each project, in the current absence of accepted design guidelines.

2 PRODUCT DESIGN

2.1 *General features*

As briefly explained in the introduction, and although many other variations still exist, the geosynthetics currently used for asphalt reinforcement mainly combine a light geotextile to a fiber-glass geogrid. The specificity of the products manufactured by Afitexinov, relies on the use of the warp-knitting technology, which allows to have both a good "cohesion" of the geogrid in itself and a strong association with the light geotextile. This is obtained thanks to the knitting thread that physically binds together the glassfibers in each strand, and at the same time binds them to the underneath textile (Figure 1). The products have thus enough internal "cohesion" to be used without further treatment; the Notex® Glass product range corresponds to this basic design, based on a 17 g/m2 polyester veil and a glass-fiber geogrid with tensile strength as needed, typically 50 or 100 kN/m in both directions (Table 1). This design will be identified as GG/veil to illustrate that it combines a fiberglass geogrid with a light veil.
Design can be refined by using a heavier geotextile (up to 140 g/m2) in the Geoter® FNG product range. This design will be identified as GG/nw to illustrate that it combines a fiberglass geogrid with a somewhat heavier non-woven geotextile.
Another refinement is yet performed on the Notex® Glass C range. It corresponds to the same design as Notex® Glass but with an additional coating in order to maximize product adhesion to asphalt mixtures (Figure 1 - Table 1). This latter design will be identified as GG/veil C to illustrate that it combines a fiberglass geogrid with a light veil, and a coating.

Figure 1. The Notex® Glass geosynthetics are obtained by warp-knitting a light geotextile and a glass-fiber geogrid. An additional coating can also be added when needed (here, with bituminous coating).

Table 1. Selected properties of the geosynthetics.

Property	Method	Units	Notex® Glass (C) 50x50/40	Notex Glass® (C) 100x100/40	Geoter® FNG 100x100/40
Nature of Geogrid	-	-	Glass-fibers	Glass-fibers	Glass-fibers
Nature of Geotextile	-	-	17 g/m^2 polyester veil	17 g/m^2 polyester veil	up to 140 g/m^2 nonwoven
Coating	-	-	Only present for the "C" grades	Only present for the "C" grades	-
Mesh size	-	mm	40 x 40	40 x 40	40 x 40
Design code			GG/veil (C)	GG/veil (C)	GG/nw
Roll size (width x length)	-	m x m	5.2 x 100 (other sizes on request)	5.2 x 100 (other sizes on request)	5.2 x 100 (other sizes on request)
Tensile Strength (Machine Direction MD)	EN ISO 10319	kN/m	50	100	100

TECHNICAL SESSIONS

Tensile Strength (Transverse Direction TD)	EN ISO 10319	kN/m	50	100	100
Elongation at Break (Machine Direction MD)	EN ISO 10319	%	3	3	3
Elongation at Break (Transverse Direction TD)	EN ISO 10319	%	3	3	3
Extra tack coat rate (residual binder)	-	g/m^2	300 (C: 300)	300 (C: 300)	Up to 900 g/m²

2.2. *Installation*

As briefly explained in the introduction and further described in the next section, installation was identified from the very beginning to be a major concern for geosynthetics in asphalt pavements. It is indeed clear that a poorly installed product is worse than no product at all (Barksdale, 1991; Holz et al., 1998; Maintenance Technical Advisory Guide, 2009), because it would then create a discontinuity in the pavement structure impeding load transmission from the top to the bottom layers. As a consequence, the upper layers would sustain loads exceeding what was foreseen in their design, in a way similar to that occurring for poorly bound asphalt layers. That is where the expertise of manufactured specialized in this application makes a whole difference.

In addition to the product design, with the light geotextile acting as a sponge for the tack coat, thus facilitating placement, it is very important that the correct tack coat rate is used and that the laying is performed in the fresh tack coat emulsion. The correct tack coat rate is the rate that would have been used in the absence of the geosynthetic, plus the extra rate needed to saturate the product (Table 1).

More precisely, if the tack coat in the absence of the geosynthetic is 300 g/m^2 of residual binder, then the rate must be 600 g/m^2 for GG/veil C or 800 g/m^2 for GG/veil. This makes it clear that the coating helps reduce the tack coat rate because it already partly saturates the product. Overdosing is not generally recommended since it would generate a risk of product sliding [5]. Laying in the fresh emulsion is also of critical importance, given that the high viscosity of the binder used in the tack coat makes it unlikely that it will rise by capillarity in the product once the emulsion has broken, contrary to the low viscosity fresh tack coat emulsion. The use of light brooms to force the emulsion to penetrate the geosynthetics greatly improves the phenomenon and must therefore always been performed swiftly after laying, given that the emulsion can break in less than 15 min during hot summer days. An example of perfect installation was performed on Paris Charles de Gaulle (CDG) Airport (Figure 2).

Figure 2. Laying of a reinforcement geosynthetics on runway 2 of Paris CDG airport in 2016. Picture courtesy of Colas

Validating that the product is well bound can be done using the so-called "Leutner test", corresponding to the shear bond test in prEN 12697-48 (Lesueur et al., 2020) . In addition to the extensive work that has been done on this test method, its interest also rely on the fact that specifications exist on the threshold value to be found on field specimens to insure good bonding between layers (Lesueur et al., 2020). The same procedure can be applied to cores extracted from real jobsites.

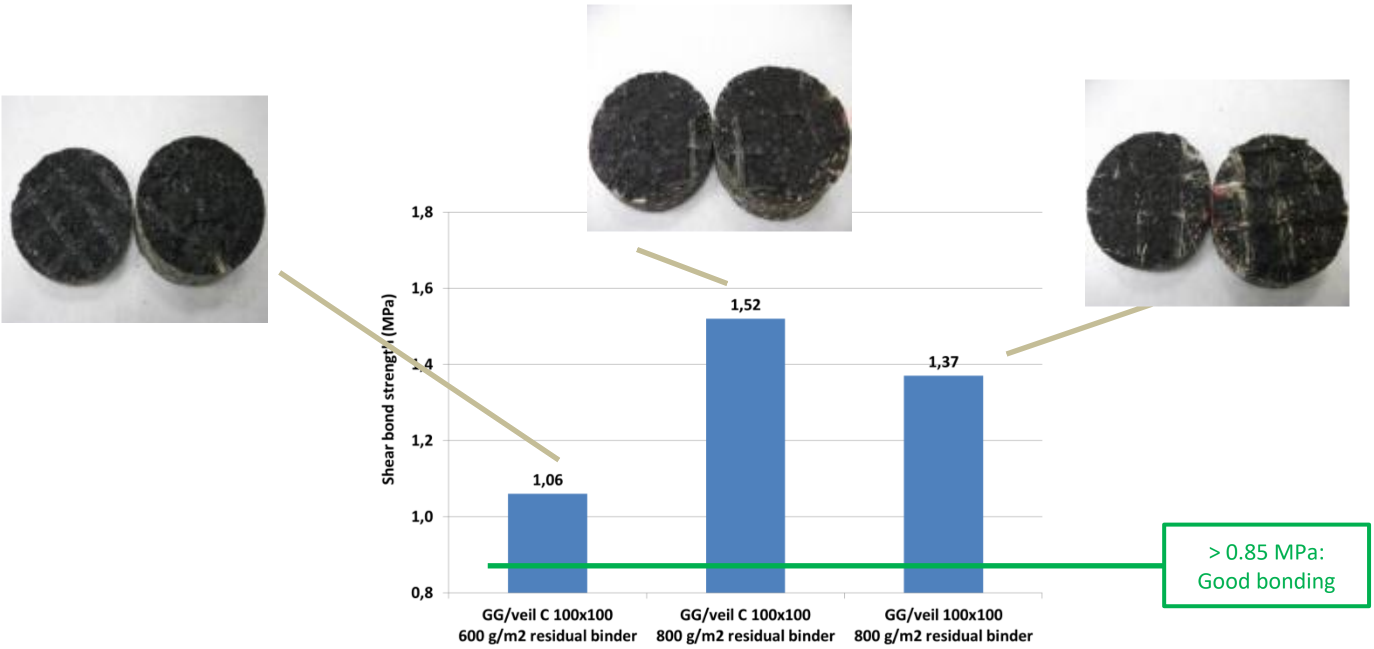

Figure 3. Shear bond strengths (prEN 12697-48) of various combinations of products (see Table 1) and tack coat rates between two layers of AC 10. The picture illustrates the broken interface. The threshold corresponds to the minimal value specified for surface/binder courses in Swiss or German jobsites (Lesueur et al., 2020).

The combined effect of product design on one side and tack coat rate on the other side is illustrated in Figure 3. The test was first performed on GG/veil C 100x100 with tack coat rate of 600 g/m^2. A usual dotation for a tack coat between two layers of BBSG would be 300 g/m^2; in parallel, this geosynthetic needs an extra tack coat of 300 g/m^2 (Table 1), hence the chosen dotation. The observed value for bond strength was 1.06 MPa, a value much higher than the current Swiss threshold for reception of surface/binder courses (0.85 MPa - Figure 3). The picture of the broken interface shows that strands of the product are still glued on both sides,

meaning that the crack propagated inside the product. In other words, the textile didn't create a weak spot. Indeed, former works showed that much lower values of bond strength, associated for example with too-low a tack coat rate, would generate a broken surface where the geosynthetic would be found only on one side of the sample.
Increasing the tack coat rate to 800 g/m^2 made the interface even stronger (1.5 MPa - Figure 3). Therefore, a small excess of tack coat with this product was beneficial.
Switching to GG/veil, without coating hence the need for the higher extra dotation of 500 g/m^2 (Table 1), maintained the bond strength at a pretty high level of 1.37 MPa compared to the coated version with its recommended extra dotation (Figure 3). Clearly, adapting the tack coat dotation for this kind of product, allows compensating for the absence of coating.
As a conclusion, the combination of an astute product design, with the light veil enhancing emulsion capillary diffusion, to the correct tack coat dotation and the right placement method, ensures to obtain bond strength well above the existing specifications. Coating is not necessary to ensure proper bonding as it can be compensated for by a proper tack coat dotation.
In addition, it is also very important to position the geosynthetic below at least 6 cm of asphalt mixture. This limits the shear strength on the geosynthetic and also the risk of bleeding given the high binder content at the interface.

3 PRODUCT PERFORMANCE

3.1 *Principles*

The use of geosynthetics in asphalt pavements is described in EN 15381 (CEN, 2008). This standard covers all products currently being used, including steel meshes even if they are not, strictly speaking, geosynthetics. The standard lists 3 possible functions that the geosynthetics can impart:

1. Stress relief,
2. Reinforcement,
3. Interlayer barrier.

The stress relief effect was already described in the introduction, as a mechanism for retarding crack propagation when it encounters a soft layer (Lytton, 1989). It is believed to be the main reason why non-woven geotextiles can reduce reflective cracking as described earlier. It has indeed been shown that it is also present with GG/veil types of products (Lesueur et al., 2020). Thus, using a heavier nonwoven (ie GG/nw vs GG/veil) should maximize this effect.
Reinforcement relates to the ability of geogrids and corresponding geosynthetics, to delay reflective cracking thanks to their high strength. This will of course be linked to the strength of the fiberglass geogrid, as validated by crack propagation tests (Freire et al, 2020).
Interlayer barrier describes the fact that the bitumen saturation of geosynthetics can waterproof the underneath structure. The current standard sets a bitumen demand of 0.9 l/m2 of residual binder as the minimum rate needed to obtain this function (CEN, 2008).
If the possible roles of the geosynthetics are well described, current specifications lack guidelines in order to better choose the products for a given project. For example, the needed strength to obtain reinforcement is not given in the standard, when project designers would need to know what strength to use for a given product at a given position in the pavement in a given context (climate, traffic).
Still, the above elements make it clear that a design of the GG/nw type, allows maximizing all beneficial effects foreseen in the standard.

Quantification of Performance

An example of the effect of these type of products on crack propagation in bituminous structures is illustrated in the tensile-bending test available at Cerema in Autun (Lesueur et al., 2020). It consists in preparing a 110 x 80 mm2 beams with a thickness depending on the system to be tested. The solution being tested is applied on top of a vertically-notched 15 mm thick sulphur-asphalt base (mimicking concrete). Another 6 cm of a standard AC 10 are laid on top of the anti-cracking system and crack propagation is measured thru the overall thickness of system plus the AC 10. The samples are tested at 5°C with the superposition of a continuous horizontal crack-opening at 0.01 mm/min to a cyclical vertical loading with 0.2 mm amplitude at 1 Hz. Crack propagation is recorded by strain gauges, allowing plotting a curve of crack length vs time (Figure 4).

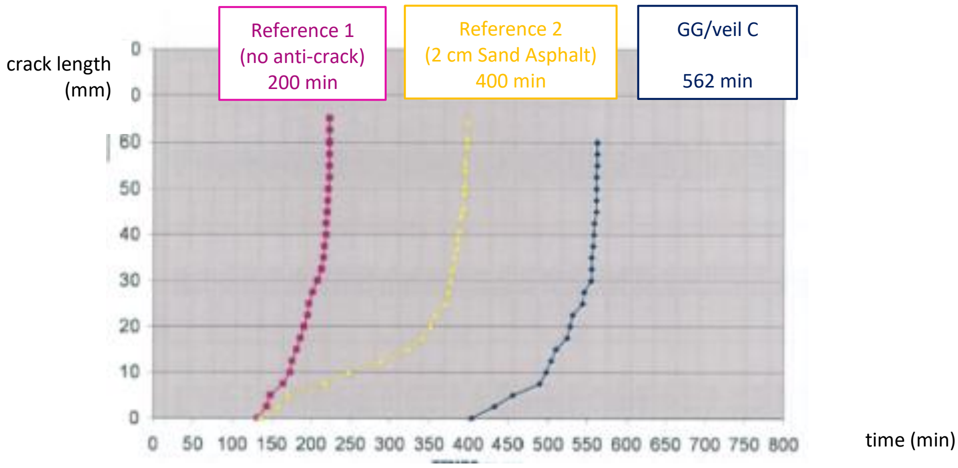

Figure 4. Tensile-bending test results comparing crack propagation in two reference systems and in the presence of a reinforcement geosynthetic (here GG/veil C)

As references, two solutions are generally compared in the French context (Figure 4):

- Propagation only thru the AC (ref. 1 - Figure 4),
- Propagation thru 2 cm sand-bitumen mixture, a common solution (Giloppe et al., 1997) to retard crack propagation (ref. 2 - Figure 4).

When performing the test with a GG/veil C geosynthetic (Figure 4), it clearly appeared that the tested geosynthetics acted as a strong barrier to crack propagation, as illustrated by a time to failure of 562 min, to be compared with 400 min with the sand-bitumen mixture (ref. 2) and 200 min without system (ref. 1).

A closer look at Figure 4 illustrates the mechanisms at stakes (Lesueur et al., 2020):

- Crack initiation started at ~130 min for both references, whereas it was delayed to ~400 min in the presence of the geosynthetics. This clearly shows that the stress-relief effect is present even for reinforcing geosynthetics, which is not so surprising when observing that they indeed constitute a soft layer (Freire et al., 2018).
- Once crack initiated, its propagation thru the geosynthetics was very slow for 100 min, corresponding to an upward propagation of ~1 cm. At this distance, the crack as clearly propagated thru the thickness of the system (geosynthetic plus tack coat) since it measured less than ~1 mm. This therefore illustrated that the product was working thru a crack-bridging mechanism, maintaining both sides of the crack in close contact. For another ~2 cm upwards, from times ~500 to ~550 min, the crack-bridging mechanism was still present as shown by a slower crack speed vs ref. 1. However, crack speed was faster than before, probably as a consequence of the progressive breaking of the geosynthetic.

TECHNICAL SESSIONS

- After this stage, very fast rapid crack propagation was found until the end.

Therefore, this test not only highlights the potential of the presented geosynthetics to retard reflective-cracking, it also illustrates the two mechanisms behind the performance: stress-relief and crack-bridging. Again, optimizing product design based on these principles, allows then maximizing performance: for a given geogrid strength, preferring a heavier non-woven should improve the stress-relief function yet maintaining the same crack-bridging ability.

4 CONCLUSIONS

Geosynthetics for bituminous pavement reinforcement are generally combining a glass-fiber geogrid to a light geotextile. These products are known to be well suited for use in pavements given that their installation and performance is optimized and therefore allows mobilizing the potential functions described in the corresponding European standard (CEN, 2008).

Based on the proper testing, it can be shown that a coating is not strictly needed in order to maximize bond strength. Excellent performance can be obtained using non-coated products, provided the tack coat rate is adapted. An in-situ coating is thus achieved using the tack coat.

Given that these materials work by a combination of stress-relief and crack-bridging, it appears that, for a given geogrid strength, using a somewhat heavier non-woven than the current light veil, should maximize the former effect while maintaining the second unchanged.

Other ways to assess performance are also sometimes proposed, like the potential to reduce fatigue damage (Lesueur et al., 2020), but this shouldn´t affect the principles of product optimization described in this paper.

Finally, it is worth noting that the recyclability of the layers containing this type of geosynthetic has been documented (Lesueur et al., 2020),showing that current means (milling, formulation) can be maintained in the presence of such materials. Therefore, reinforcement geosynthetics based on fiber-glass geogrids combined with a light non-woven geotextile constitute a proven solution to increase pavement life at a reasonable cost, yet maintaining the structure recyclable.

REFERENCES

Williams, E.G. (1954) Application of wire mesh reinforcement to asphaltic concrete pavement overlays, Highway Materials Res. Lab. report, Lexington (KY, USA)

Smith, L.L. and Gartner, W. (1962) Welded wire fabric reinforcement for asphaltic concrete, Highway Res. Board Bulletin 322.

Dykes, J. W. (1980) The use of fabric interlayers to retard reflective cracking, Proc. Assoc. Asphalt Paving Technol. 39, 354-368.

Carmichael III R. F. and Marienfeld M. L. (1999) Synthesis and literature review of nonwoven paving fabrics performance in overlays, Transportation Res. Record 1687, 112-124

Barksdale, R. D. (1991)Fabrics in asphalt overlays and pavement maintenance, National Cooperative Highway Research Program - Synthesis of Highway Practice 171, Transportation Res. Board (Washington DC, USA)

Lytton, R. L. (1989) Use of geotextiles for reinforcement and strain relief in asphalt concrete, Geotextiles and Geomembranes 8(3), 217-237

Giloppe, D. , Laurent, G. and Millat, P. (1997) Systèmes limitant la remontée des fissures transversales de retrait hydraulique, Note d'information Chaussées et Dépendance 93, Setra (Paris, France), 1997 (in French)

Service Technique des Bases Aériennes (STBA), Techniques anti-remontées des fissures - Guide d'emploi en chaussées aéronautiques, STBA (Paris, France), 1999 (in French)Aderhold J, Davydov V Yu, Fedler F, Klausing H, Mistele D, Rotter T, Semchinova O, Stemmer J and Graul J 2001 *J. Cryst. Growth* **222** 701

TECHNICAL SESSIONS

Holz, R. D., Christopher, B.R. and Berg, R.R. (1998)Geosynthetic design and construction guidelines,Publication No. FHWA HI-95-038, National Highway Inst., Federal Highway Admin. (Washington DC, USA)

Maintenance Technical Advisory Guide, Chapter 12: Interlayers", in Volume I; Flexible Pavement Preservation, 2nd Ed., California Dept. Transportation (Caltrans) Division of Maintenance, 2009

Lesueur, D., Leguernevel, G. and Riot, M. (2020) On the performance of geogrids for asphalt pavement reinforcement: Laboratory evaluation and selected case studies, Proc. 7th Eurasphalt and Eurobitume Congress, Madrid, paper 331

European Standardization Committee (CEN), EN 15381 : Geotextiles and geotextile-related products. Characteristics required for use in pavements and asphalt overlays", CEN (Brussels, Belgium), 2008

Freire, R., Di Benedetto, H., Sauzéat, C., Pouget, S. and Lesueur, D. (2020) Crack propagation of bituminous mixtures reinforced by geogrids using digital image correlation, Proc. 7th Eurasphalt and Eurobitume Congress, Madrid

Freire, R., Benedetto, H. Di., Sauzéat, C., Pouget, S. and Lesueur, D. (2018) Linear Viscoelastic Behaviour of Geogrids Interface within Bituminous Mixtures, KSCE J. Civ. Eng. 22(6), 2082-2088