Maintenance and Rehabilitation

ON THE PERFORMANCE OF GEOGRIDS FOR ASPHALT PAVEMENT REINFORCEMENT: LABORATORY EVALUATION AND SELECTED CASE STUDIES

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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, evaluating their performance is not a simple task because most available testing methods are still at an early development stage with sometimes limited field validation. As a consequence, no clear guidelines currently exists for selecting this type of products in preparation of a construction project. This paper presents the laboratory results gathered so far on fiber-glass reinforced geocomposites in view of their use in real jobsites. Fatigue testing and the potential to delay crack reflection as measured with the Cerema Autun device, are presented and discussed in the light of recent jobsites on Paris Charles de Gaulle Airport and French highway A7. In addition, the correct positioning of the geogrids on the asphalt support was further evaluated using the Leutner test. This clarifies the conditions under which the placement of these materials will be optimized. From this work, a clearer picture tends to emerge on how to specify these very specific products in order to maximize their benefit for extending pavement life time.

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1. INTRODUCTION

Geosynthetics are defined as a product used in civil engineering, "at least one of whose components is made from a synthetic or natural polymer material, in the form of a sheet, a strip or a three-dimensional structure" [1]. It is therefore a generic term encompassing many other products such as geotextiles, geogrids, geocells, geomembranes, geosynthetic clay liners... [1].

The modern use of geosynthetics for pavement reinforcement can be traced back to as early as 1937, when a steel mesh was used to reinforce 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) [2]. 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, especially in Texas and Kentucky [3]. Similar trials were then performed 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 [4].

In the 1960s, geosynthetics started their continuous growth, and the main member of the family, ie 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 trials took place in 1966 in the USA [5]. 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 [5]. 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 [6]. Otherwise, the technic was generally accepted to successfully delay reflection cracking and provide additional benefits due to the waterproofing of the underneath structure [7]. The main mechanism for delaying crack propagation was proposed to be a stress relief effect appearing when the crack approaches a soft layer (ie, the geotextile in the binder) when propagating in stiffer layers (ie, asphalt mixtures) [8].

Similar trials were also performed in Europe, with for example many proprietary solutions being developed by road contractors in France by combining non-woven geotextiles of 120-250 g/m^2 with ~1 kg/m^2 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 [9] 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 [10]. The US experience showed that the efficiency would hold as long as the thickness of the above asphalt overlay remained smaller than ~8-10 cm. For higher asphalt thicknesses, the benefits were not so clear as far as reflective cracking was concerned [7].

Finally, the 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 [7;11] or glass geogrids [7;12], but they were still perceived as emerging technologies in the late 1990s in both the USA [13] and France [10]. 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 [7], 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 [14]. Glass-fibers are therefore a preferred choice because of their reasonable price and excellent performance in this application [15].

Even if there is clearly a large amount of published literature on this topic, no design guidelines currently exist in Europe 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 [14], 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 glass-fiber 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. PRODUCTS

2.1. Product design

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; one product range corresponds to this basic design, based on a 17 g/m^2 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 non-woven geotextile (up to 140 g/m^2) in another product range, described here as GG/NW.
Yet another refinement is performed on a third product range. It corresponds to the same GGG/veil design but with an additional coating in order to facilitate product adhesion to asphalt mixtures (Figure 1 - Table 1). It will be referred to as GG/veil C.

Figure 1: The geosynthetics described in this paper are obtained by warp-knitting a 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 tested geosynthetics.

Property	Method	Units	GG/veil (C) 50x50/40	GG/veil (C) 100x100/40
Nature of Geogrid	-	-	Glass fibers	Glass fibers
Nature of Geotextile	-	-	17 g/m^2 polyester veil	17 g/m^2 polyester veil
Coating	-	-	Only present for the "C" grades	Only present for the "C" grades
Mesh size	-	mm	40 x 40	40 x 40
Roll size (width x length)	-	m x m	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
Tensile Strength (Transverse Direction TD)	EN ISO 10319	kN/m	50	100
Elongation at Break (Machine Direction MD)	EN ISO 10319	%	3	3
Elongation at Break (Transverse Direction TD)	EN ISO 10319	%	3	3
Extra tack coat rate (residual binder)	-	g/m^2	500 (C: 300)	500 (C: 300)

Note that the warp-knitting technology makes it possible to insert optical fibers in the final product, allowing manufacturing intelligent geosynthetics that can be used to monitor pavement deformation, temperature and/or traffic speed [16].

2.2. Main properties

As briefly explained in the introduction, and although other variations still exist, the geosynthetics currently used for asphalt reinforcement mainly combine a light geotextile to a fiber-glass geogrid. Their properties are evaluated based on EN 15381 [17], from which CE marking of the products is made. This standard is further described in the next section, and the main properties of the geosynthetics described in this paper are given in Table 1:

2.3. 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 [7;13;14], 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 [18]. 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 coated geosynthetics or 800 g/m^2 for (uncoated) GG/veil geosynthetics. 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 [7].
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 is provided later on in the case study on Paris Charles de Gaulle (CDG) Airport (Figure 8). Validating that the product is well bound can be done in the lab using the procedure detailed in section 4. The same procedure can be applied to cores extracted from real jobsites.
In addition to following the above instructions, 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. STANDARDIZATION

3.1. European standard

The use of geosynthetics in asphalt pavements is described in EN 15381 [17]. 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 [8]. It is believed to be the main reason why non-woven geotextiles can reduce reflective cracking as described earlier.
Reinforcement relates to the ability of geogrids and corresponding geosynthetics, to delay reflective cracking thanks to their high strength.
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 [17].
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). Even if this goal remains distant at the present time, the rest of the paper gathers some information that might allow in the long run achieving this objective.

3.2. Caltrans guidelines

The Californian specifications [14], based on years of practical experience with most of the available products, give a better idea on what a good product should look like. To the best of our knowledge, they are the most complete specifications in the World for geosynthetics in asphalt overlays. They define the following classes (Table 2), where it is clear that the most restrictive specification is the one on elongation at break, < 5% as soon as the strength is higher than 50 kN/m. This limits the choice of fiber types, excluding polymeric ones like polypropylene (> 15%) and polyester (> 10%), and accepting mostly glass (~3%), or the more expensive carbon (~2%) or aramid (~3%) fibers [19].

Table 2. Paving grid specifications in the Caltrans guidelines [14]. Note that the thresholds were converted to SI units.

Property	Method	Units	P1	P2	P3
Mesh size	-	mm	> 12	> 12	> 12
Elongation at Break	ASTM D6637	%	< 5	< 5	< 10
Mass per unit area	-	g/m^2	> 543	> 340	> 186
Tensile Strength (MD x TD)	ASTM D6637	kN/m	100 x 200	100 x 100	50 x 50

Even if they don't describe the way the classes have to be chosen as a function of context, the Caltrans guidelines clarify that **paving grids combined with geotextiles are the only solution ranked as "excellent"** for the following distresses [14]:

- Alligator cracking, for both low-medium and medium-high age oxidation ranges,
- Block and longitudinal cracking, for both low-medium (crack width < 1.2 mm) and high (2.5 mm > crack width > 1.2 mm) ranges,
- Thermal cracking, for low (crack width < 0.6 mm), medium (1.2 mm > crack width > 0.6 mm) and high (crack width > 1.2 mm) ranges,
- Moisture intrusion (provided sufficient binder is used).

Their use must be combined with a preliminary crack filling in the case of high extents of block/longitudinal or thermal cracking. A levelling course (~2 cm asphalt layer) is recommended for pavements experiencing medium-high age-oxidation alligator cracking. The conditions for preventing moisture intrusion are reminiscent of the ones for interlayer barrier in the European standard, i.e. at least 0.9 l/m^2 of binder demand [17].
Note that non-woven geotextiles (called "paving fabrics" in the document) are only ranked as excellent for low-medium age oxidation alligator cracking and moisture intrusion. They are considered to be only fair/good for the other distresses and are not recommended for large thermal cracks.

4. LABORATORY EVALUATION

4.1. Adhesion between layers

Given that it is so critical to properly place the geosynthetics, their correct installation was validated using the so-called "Leutner test", corresponding to the shear bond test in prEN 12697-48 [20]. The test was performed at CIESM-Intevia (Madrid, Spain) by first preparing a 21 mm x 46 mm^2 slab of asphalt mixture (AC 10 surf according to EN 13108-1 [21] or BBSG 0/10 class 3 in the French context), place the geosynthetic in the fresh emulsion with a given tack coat rate (600 or 800 g/m^2 of residual binder) and then lay a second layer of 2.5 mm of BBSG 0/10 on top of it. 6 cores (100 mm diameter) were then extracted from each slab in order to break the interface in a "guillotine"-type set-up at 50 mm/min and 20°C. The bond strength is the average of 6 measurements, giving a standard deviation close to, but below 10%.
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 [22].

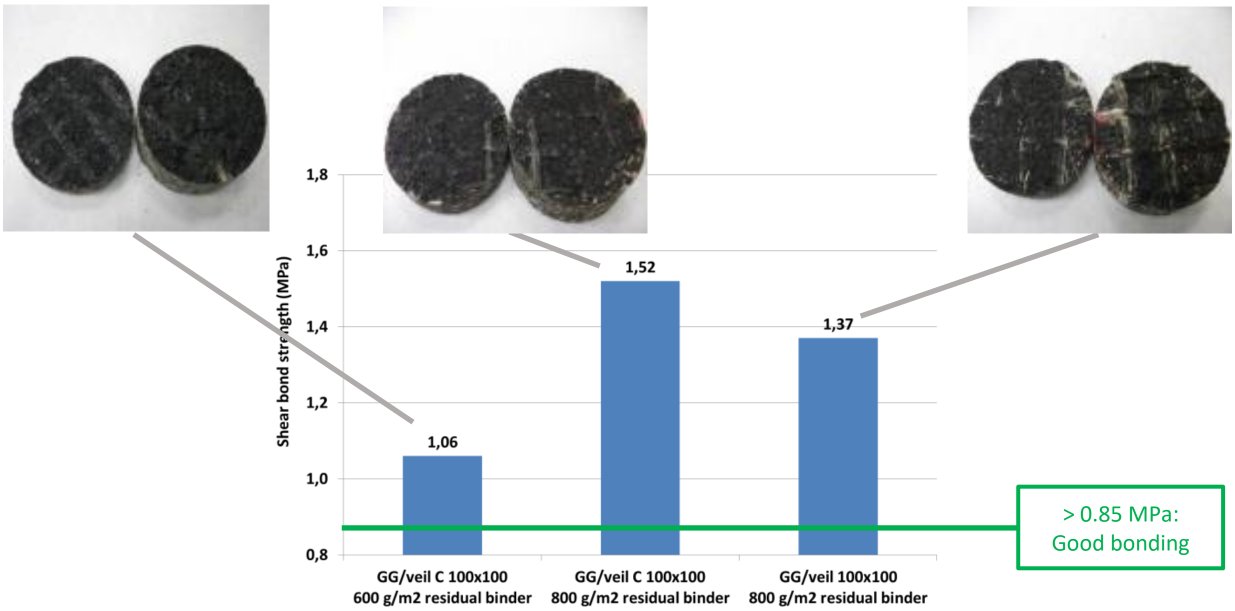

Figure 2: Shear bond strengths (prEN 12697-48) of various combinations of products (see Table 1) and tack coat rates between two layers of AC 10. The picture illustrates the broken interface. The threshold corresponds to the minimal value specified for surface/binder courses in Swiss or German jobsites [22].

The combined effect of product design on one side and tack coat rate on the other side is illustrated in Figure 2. 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 2). 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 2). 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 2). 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.

4.2. Reflective cracking

Unfortunately, no widely accepted method currently exists in order to estimate the resistance of any solution, whether geosynthetic or not, to reflective cracking. As a consequence, only a few labs in the World developed testing protocols generally based on the use of large pre-cracked slabs where crack propagation can be forced and monitored thru the tested solution. In France, the reference method is the tensile-bending test available at Cerema in Autun [23]. It consists in preparing a 110 x 80 mm^2 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 3). The test results are generally summarized by giving only the mean time at which complete failure occurred, corresponding to a mean value for 6 beams.

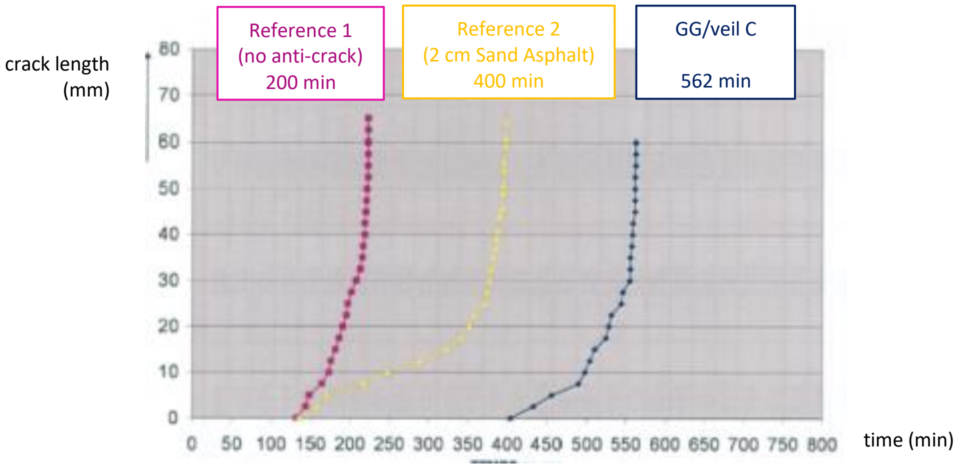

Figure 3: Tensile-bending test results comparing crack propagation in two reference systems and in the presence of a coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100).

As references, two solutions are generally compared in the French context (Figure 3):

- Propagation only thru the AC (ref. 1 - Figure 3),
- Propagation thru 2 cm sand-bitumen mixture, a common solution [9] to retard crack propagation (ref. 2 - Figure 3).

When performing the test with a GG/veil C 100x100 geosynthetic (Figure 3), 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 3 gives an idea on the mechanisms at stakes:

- 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 [24].
- 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.
- 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 that there are at least two mechanisms behind the performance: stress-relief and crack-bridging.

4.3. Fatigue

From the beginning of their use in asphalt mixtures, glass-fiber geogrids where shown to increase fatigue life [12]. It was further successfully demonstrated in the field that the presence of a glass-fiber geosynthetic allowed removing ~8 cm of asphalt layers in a structure submitted to 400 heavy vehicles/day, generating significant cost savings and reducing the environmental footprint by ~45-50% in terms of energetic consumption and carbon footprint [25].
As a consequence, the impact of geosynthetics on the fatigue of bituminous structures has gained increasing interest in the recent years. It remains a vivid research field and some authors proposed for example to test asphalt beams reinforced by geosynthetics in 4-points bending (4PB) under constant load [25;26], others in 4PB but under constant deformation [26] and yet others proposed in 3-points bending (3PB) under constant stress [27]. Similarly, the position of the geosynthetic in the beam could be at the lower third [12;25;27] or with two symmetrical layers at each quarter of the beam [26].
Given the above diversity of testing protocols, with several more reviewed by Islam et al. [28], we chose to use a 3PB device according to EN 12697-24 method C [29] at 10°C and 10 Hz.
100 x 75 x 300 mm^3 beams (Figure 4) were prepared at CIESM-Intevia (Madrid, Spain) in a slab compactor by:

- laying 2.5 cm of AC 10,
- placing a first geosynthetic in a tack coat following the same procedure as before (see section 4.1),

- laying 5 cm of AC 10,
- placing a second geosynthetic as before,
- laying a final 2.5 cm of AC 10.

Two layers of geosynthetic were used so that one will always be strained in tension and the other in compression at each loading cycle, making it mechanically symmetrical at all stages.

Figure 4: 100 x 75 x 300 mm^3 beams for the fatigue test of the AC reinforced with two layers of the coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100).

The fatigue test was performed with a the coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100), as compared to a neat 10 cm thick AC beam prepared in one step, with no interface (Figure 5). For each specimen, at least 10 beams were tested at various constant-strain levels in order to plot the full fatigue law (Figure 5). Failure criterion was the usual stress reduction by 50% as specified in the standard [29]. Special care was taken to have a significant amount of points with failure above 1 million cycles, in order to properly calculate ε_6, the strain for which the fatigue life would be exactly 1 million cycle.

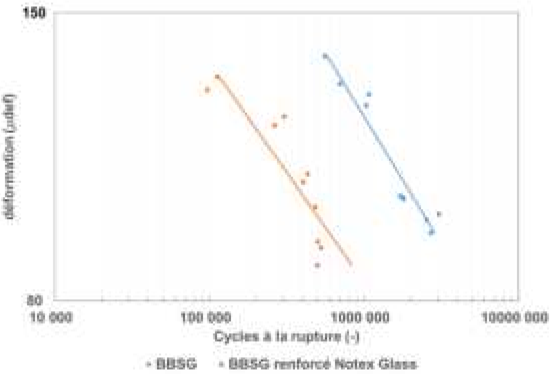

Figure 5: Fatigue law at 10°C and 10 Hz in 3PB for the reference AC 10 (BBSG 0/10 classe 3 - ε_6 = 83 µdef) and the same AC reinforced with two layers of of the coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100 - ε_6 = 120 µdef - see Figure 4 and text for details on sample geometry).

The results in Figure 5 illustrate that the fatigue life of the AC is strongly improved thanks to the presence of the geosynthetics. A ~45% increase in ε_6 was found after reinforcement, with a value of 120 µdef as compared to 83 µdef for the reference. Interestingly, the slope of the fatigue line remained essentially unchanged (Figure 5), meaning that the reinforcement is proportionally equivalent at all loadings, whether high or low.

4.4. Recycling

Finally, the possibility to recycle the presented geosynthetics was evaluated in a full scale experiment using the test section already described elsewhere [16]. The experimental pavement consisted of 9 cm of AC 14 base (GB 0/14 in the French context) covered by 5 cm of AC 10 surf (BBSG 0/10). A geosynthetic combining fiberglass geogrid and light veil (GG/veil 100x100) was placed between the GB and the BBSG [16].
The pavement was milled at a depth of 6 cm in order to maximize the relative quantity of recovered geosynthetic in the Reclaimed Asphalt Pavement (RAP), still making sure the interface will be completely removed by adding 1

cm below the reinforcement. As a reference, a section built with the same asphalt materials at the same time, but without the geosynthetic, was also milled in order to obtain a reference RAP.
The milling was performed with a Wirtgen W 100 CF compact cold milling machine. As a first observation, no specific difficulty was recorded when milling the section containing the geosynthetic. This was somewhat expected given that glass-fibers have a limited strain at failure (~3%) and therefore should be easily broken by the machine drum, especially given the fact that the mesh size of the product (Table 1- Figure 1) makes it easy for the teeth of the milling drum to really enter the product hence favoring its elongation and break.
The RAP was further tested at Cerema Clermont-Ferrand (France). It was observed that the RAP with geosynthetic had 12 % passing the 14 mm sieve and that fibers/filaments up to 20-30 cm long, could be found in this fraction (Figure 6). These fibers represented however less than 1% of the total mass of RAP, as expected given the mass per unit area of the product (420 g/m^2) as compared to the mass per unit area of 6 cm of the asphalt mixture (~13 kg/m^2).

Figure 6: Picture of the coarser fraction (> 14 mm) of the RAP obtained when milling the section containing the geosynthetic. Some fibers/filaments are visible but represent less than 1% of the total weight of the RAP.

Both RAP were then added at 20 wt.% in the formulation of a new AC 10 (BBSG 0/10 class 3 in the French context). The two formulas were evaluated by measuring their air voids in the Giratory Shear Compactor (GSC - EN 12697-31 [30]), their resistance to moisture damage (EN 12697-12 method B [31]) and their rutting resistance in the French rut tester (EN 12697-22 [32]).

Table 3. Properties obtained for the AC 10 (BBSG 0/10 class 3) containing 20% of the RAP milled with or without the geosynthetic combining fiberglass geogrid and light veil (GG/veil 100x100).

Material	**Air voids (GSC 60 cycles)**	**Dry compressive strength (C)**	**Wet compressive strength (i)**	**Retained strength (i/C)**	**Rut depth (30,000 cycles)**
Method	**EN 12697-31**	**EN 12697-12**	**EN 12697-12**	**EN 12697-12**	**EN 12697-22**
Unit	%	MPa	MPa	%	%
RAP from geosynthetic	8.6	12.4	10.7	85.8	4.4
Reference RAP	8.3	13.3	11.3	85.2	4.3
Specifications for BBSG cl. 3	5-10	-	-	> 75	< 5

As can be seen in Table 3, there was no significative difference between the asphalt mixtures, that both complied with the current specifications. Clearly, the presence of a small quantity of fibers in the RAP from the section with the geosynthetic, didn't affect its potential to be recycled.

5. SELECTED CASE STUDIES

The following examples show how the performance testing presented above, relates to current jobsites.

5.1. RN1 - Burkina Faso - 2015

A first interesting example is the refurbishment of National Road 1 (RN1) of Burkina Faso in the Sakoinsé-Boromo section (PK 65 to 110), performed by French contractors Sogea-Satom and DTP Terrassement in 2015 (Figure 7).

The old pavement was recycled in place with cement over 20 cm. A coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100) was then laid with a subsequent single layer chip seal. The asphalt structure consisted in a 14 cm AC 14 base course covered by a 5 cm AC 10 wearing course.
The design was chosen by experience, based on earlier road works that used the same structure and worked perfectly. In this case, only the failure strength of the geosynthetic was tested.

Figure 7: Laying of a coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100) on RN1 in Burkina Faso in 2015.

5.2. Runway 2 - Paris CDG airport - 2016

A second example is the renovation of runway 2 of Paris CDG airport (owner: ADP), performed by French contractor Colas in 2016 (Figure 8). The runway is 4.2 km long and 60 m wide, and handles 120 000 airplanes per year, including the very large Airbus A380.
20 cm of the old pavement were removed down to the concrete base. A 2 cm sand-bitumen mixture was then laid, and a coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100) was placed. The remaining asphalt structure consisted in 14 cm of AC 14 base course covered by an AC 10 for airports (French BBA).
The design was also chosen by experience, but the owner also wanted some proof of performance and therefore asked for results in terms of resistance to fatigue of modified mixtures, in a protocol very similar to the one described above. A minimum 10% improvement in ε_6 was specified, a level clearly obtained with our product (Figure 5).
In addition, the product was perfectly applied thanks to the association of an unrolling device directly hooked to the tack coat emulsion spreader (Figure 8). This way, the recommendation to install the product in fresh emulsion was always fulfilled insuring excellent adhesion of the product to the structure.

Figure 8: Laying of the coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100) on runway 2 of Paris CDG airport in 2016. Picture courtesy of Colas.

5.3. A7 - France - 2017

A last example is the renovation of French conceded highway A7 on 24 km near the city of Montélimar (owner: ASF) performed by French contractors Eiffage and Malet in 2017 (Figure 9). This is one of the busiest highways in France, with average yearly traffic of order of 80,000 vehicles/day.

The old pavement was milled down 13 or 16 cm depending on the exact location, leaving a milled asphalt surface. A coated geosynthetic combining fiberglass geogrid and light veil (GG/veil C 100x100) was then placed and a total of 13 or 16 cm of new asphalt layers were added.
The design was again chosen by experience, but the owner also wanted several proofs of performance. He therefore not only asked for results in terms of resistance to fatigue of modified mixtures as described above (with this time > 15% improvement), but also for at least 460 min of cracking time in the tensile-bending device of Cerema Autun (Figure 3).

Figure 9: Laying of the coated geosynthetic combining fiberGlass geoGrid and light veil (GG/veil C 100x100) on French highway A7 in 2017.

6. CONCLUSIONS

In this paper, the design of the geosynthetics combining a glass-fiber geogrid and a geotextile was presented. These products were shown to be well suited for their use in asphalt pavement reinforcement given that their installation is optimized by design.
The way their performance can be assessed was illustrated, showing that the correct bonding can be assessed using the so-called Leutner test. The right tack coat dosage for each product must be carefully applied in order to insure proper bonding. If the correct tack coat rate must be used, it is better to have a slight excess rather than a lack of it.
The ability of the products to retard reflective-cracking can be demonstrated in the tensile-bending test of Cerema Autun, illustrating the two mechanisms at stakes: stress-relief and crack bridging. Their potential to reduce fatigue damage was also illustrated, even if this remains a research field. It opens the possibility to optimize pavement thicknesses as already validated elsewhere [25].
The recyclability of the layers containing this type of geosynthetic was also documented, showing that current means (milling, formulation) can be maintained in the presence of such materials.
In the current absence of accepted design guidelines, allowing rationally selecting for example product strength, we sure hope that this work will help project designer better select the needed product for each project.

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