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# Evaluation of anti-reflective cracking systems using geosynthetics in the interlayer zone

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The purpose of this study is to evaluate the durability of anti-reflective cracking systems that have a geosynthetic, geotextile or SAMI layer in the interlayer zone. For this purpose, a dynamic test has been designed that simulates the passing of traffic loads on the road surface. Stresses are applied to a two-layer test piece, which represents the pavement structure, with an anti-crack reflection system between the lower part, which is to be reinforced, and the upper part, which is the new pavement. In the lower layer, a longitudinal groove has been made that simulates an initial crack. All interlayer systems delay crack reflection. The test procedure is sensitive to the kind of interlayer system and helps to determine the optimal dosage of tack coat. Moreover, it has been verified that geogrids show higher resistance to repeated loading cycles, and geogrids with a higher stiffness modulus show better behaviour.



## 1. Introduction

One of the main problems that administrations in charge of road maintenance and rehabilitation face is overlaying cracked asphalt pavements.

Cracks appearing on the new asphalt surface placed over a cracked pavement correspond to an upward extension of the cracks in the lower layer. The main causes of cracking are: fatigue, shrinkage, consolidation processes, construction joints and age.

Nunn (1989) pointed out the three mechanisms that start this reflection: fatigue due to thermal action (which produces expansion and contraction movements in the old layer), fatigue due to thermal shrinkage (because of the thermal gradient variations throughout the pavement) and fatigue caused by the action of traffic. However, De Bondt (1999) states that there are other reflective cracking catalysts due to differential consolidation and/or ground contraction.

Kim and Buttlar (2002) stated that in the reflective cracking process, traffic loads help to spread cracks. Loads produce high tension and deformation levels in the new layer, just above the existing crack in the pavement below. This discontinuity reduces the bending strength of the rehabilitated section and creates an area of stress concentration. When these stresses exceed the new pavement's fracture resistance, the crack appears and spreads.

As the loads increase, the magnitude of movement also becomes greater, increasing crack growth, which is reflected quickly in the pavement surface (Cleveland et al., 2002).

Three cracking mechanisms can contribute to the fracture: mechanism I or tensile mechanism, in which the stress is perpendicular to the plane of the crack; mechanism II or shear mechanism, in which the stress is parallel to the crack plane and perpendicular to its front; and mechanism III or torsion mechanism, in which the stress is parallel to the crack plane and to the front plane, applied to longitudinal cracks. Traffic loads produce a combined effect between the displacement mechanisms, I and II (Lytton, 1989). This is because when a vehicle wheel comes close to the surface, a vertical pavement displacement is started before reaching the crack (mechanism II). Later, there is a horizontal displacement at the moment the wheel is on the crack borders (mechanism I), and a new vertical displacement when the load passes the crack (mechanism II). Mechanism III appears, as Colombier (1997) states, when a vehicle passes just beside an existing longitudinal crack.

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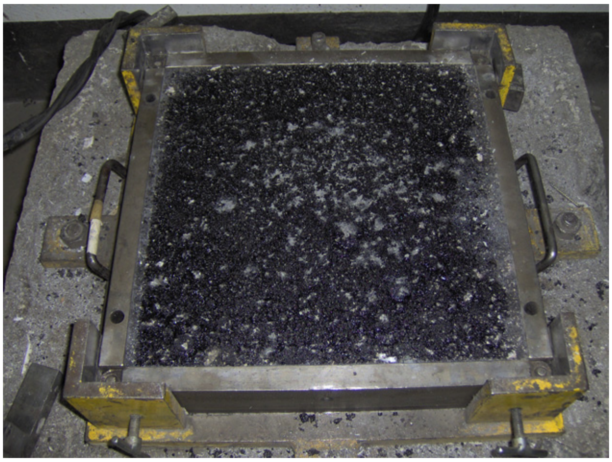

**Fig. 1.** The lower test piece.

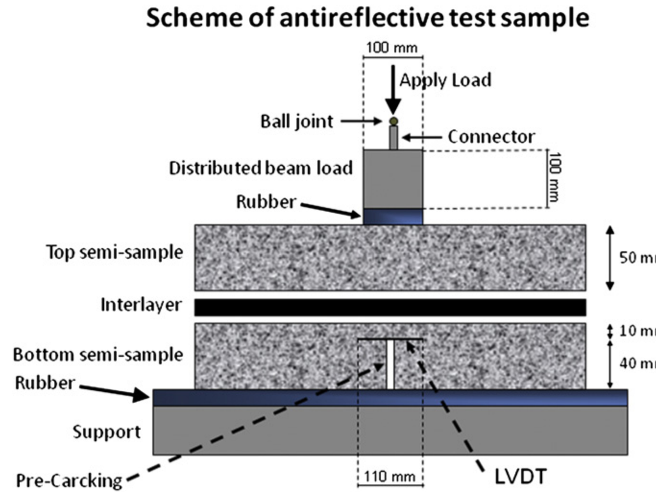


**Fig. 3.** Anti-reflective cracking test piece schematic.

Some authors consider that the most important effect is achieved by the opening of the cracks, type I, while other consider that in type II, shear stresses due to load transfer between edges are more damaging. Nevertheless, these are not the only effects to be considered, there are also micro-fissures caused by poor compaction, a roller checking cracks during construction, ground humidity variation, and lack of homogeneity in the subgrade.

To analyse crack propagation, a large number of lab tests have been designed in order to reproduce some of the stresses or displacements caused by the above mentioned mechanisms, studying the influence of the materials making up the pavement and the anti-reflective cracking systems, e.g. Prieto et al. (2007); Virgili et al. (2009); Khoddaii et al. (2009).

Although there are many proposals, the solutions have various shortcomings for several reasons:

- It is difficult to include in a single test, at a reasonable cost, all the mechanisms participating in the reflective cracking processes.
- The large number of anti-reflective cracking systems on the market, with different types and different installation procedures, is not conducive to a unique test piece size.
- Pavement testing labs do not have the required facilities to perform this kind of tests.

Francken and Vanelstraete (1993) presented a test whose objective was to observe and study crack reflection in a semi-stiff pavement structure, containing an induced discontinuity in the base layer, simulating the influence of thermal contractions and traffic loads. The procedure enables the causes of the beginning and propagation of cracking to be observed. There is a similar test in the "Ponts et Chaussées" Central Laboratory, which measures the propagation time of fissures through a layer, determining an efficiency coefficient that helps classify the different anti-reflective cracking techniques (Vecoven, 1990; Cancela Rey and Bardesi Otue-Echevarrí, 1995). Elsing and Sobolewski (1998) tried a similar experiment. They studied the effectiveness of two geosynthetic materials (geotextile and geogrid), in preventing crack propagation due to thermal action, comparing them to a sample without geosynthetic materials, using concrete specimens. The tests are performed at −10 °C for 100 h with a crack velocity of 1 mm/h. In each cycle, the fissure between the two concrete blocks is displaced 1 mm and returns to the original position. The effect of concrete shrinkage and expansion was simulated, achieving a better result with the geogrid.

The Texas Transport Institute (TTI) developed a hydraulically controlled device to simulate the tensile and compression stress induced by the displacements originated in a pavement as a result of temperature variation. Zhou et al. (2004) pointed out that many studies have been done with this kind of test to evaluate geosynthetic materials' effectiveness. However, they state that building test pieces is very difficult because of their sizes (375 mm length, 75 mm width, and a variable height from 25 to 75 mm), so that later size has been modified to build smaller test pieces.

From 2004 to 2006, the Transport and Road Research Laboratory of the Polytechnic University of Madrid developed a new equipment to study reflective cracks, called WRC (Wheel Reflective Cracking), based on the Wheel Tracking Test. According to Prieto et al. (2007), this equipment applied a flexion bending effect due to the wheel passage on a material that is undergoing traction stresses induced by complementary equipment. The test is original and it is

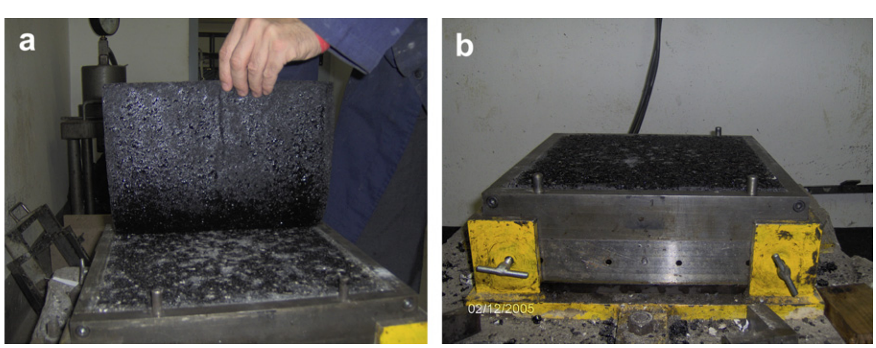


**Fig. 2.** Geotextile material placement and 2nd test piece view.

**Table 1**
Test characteristics.

| | Sine wave | |
|---|---|---|
| | Load (kN) | Pressure (MPa) |
| Maximal | 19.0 | 0.65 |
| Minimal | 3.0 | 0.10 |
| Frequency | 10 Hz | |
| Temperature | 20 °C | |

performed on specimens with sizes 305 mm × 305 mm × 60 mm, with a tack coat dosage of 1.2 kg/m$^2$. The wheel that conveys a vertical pressure of 0.65 MPa is passed 43 times/min on a hydraulic system that introduces horizontal displacements that simulate the crack opening. The fracture criterion was the emergence of a vertical step between the crack faces of 0.2 mm (relative vertical movement between edges) at a crack opening velocity of 0.6 mm/h, at 5 °C.

## 2. Experimental programme

In this paper, after the corresponding study of the influence of the different types of geotextiles and geogrids on the adherence between bituminous layers (Zamora-Barraza et al., 2010), we have attempted to develop a straightforward procedure enabling the evaluation of the durability of anti-reflective cracking systems using a geogrid, geotextile or a Stress Absorbing Membrane Interlayer (SAMI), and the comparison of these with a reference system that does not include an interlayer. Moreover, the procedure enables the determination of how the bitumen content influences the capacity to delay crack reflection. The experimental programme is:

- Dynamic tests to determine the influence of tack coat on the anti-reflective system durability.
- Studies of different anti-reflective crack systems using dynamic tests to compare the durability of geotextiles, geogrids and SAMIs.

## 3. Materials

The test specimens were manufactured with a dense D-12 mix (equivalent, nowadays, to an AC 16 surf mix, according to the UNE-EN 13108-1). To make the mix, ophitic aggregate and a B 60/70 asphalt concrete were used. The emulsion used in the tack coat was ECR-3 (equivalent to a C69B3 emulsion of the UNE-EN 13808); that is to say, a rapid break cationic emulsion with a minimal binder content of 69%. In some case, an antistick-m emulsion has also been used. It is a thermo-adherent emulsion manufactured with a B13/22 asphalt concrete. These emulsions are typified by achieving good adherence to the support with the minimal tackiness to the wheels of the work vehicles.

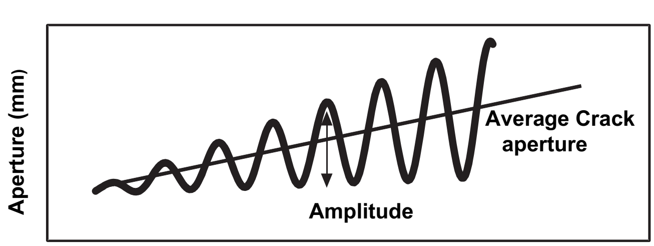


**Fig. 4.** Scheme of a sine wave curve of the crack development.

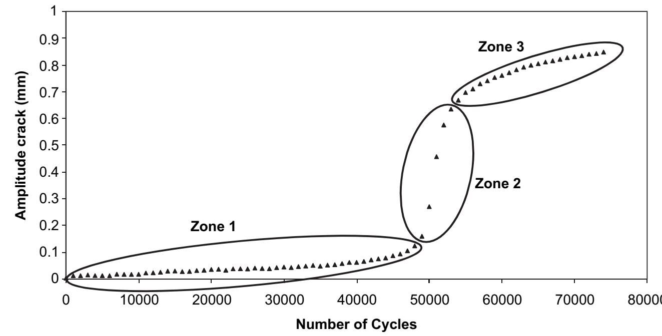


**Fig. 5.** Amplitude crack curve (interlayer P-5).

The following anti-reflective cracking systems were analyzed:

- P-1: Polyester geogrid with a light unwoven fabric on one side, all covered by a binder.
- P-2: Polyester geogrid, whose fibres are covered with Polyvinyl chloride (PVC).
- P-3: Geogrid with reticulate structure of glass fibre threads, overlaid with polymers and with a layer of pressure-sensitive glue.
- P-4: Geotextile with non-woven polypropylene needle fibres, with continuous filaments stabilised against UV rays.
- P-5: Geotextile with unwoven polypropylene fibres.
- P-6: SAMI.

## 4. Dynamic test equipment and methods

For the study, dynamic tests were performed that simulate the fissure movements due to traffic loads of wheels, specifically those of mechanism I.

### 4.1. Test specimen

The specimens used in the test aim to simulate the behaviour of an interlayer from the point of view of crack propagation. For this reason, a kind of specimen was designed that will not receive exactly the same loads as in situ. However, the objective is to perform a comparative study of the different kinds of materials.

The anti-reflective cracking system is interlaid between two prismatic test specimens with 305 mm side and 50 mm height. The 305 mm sides are established by the moulds of the Wheel Tracking Test (Transport and Road Research Laboratory). The 50 mm thickness is chosen in an attempt to reproduce the common thickness generally used in pavement rehabilitation. For the lower layer, although its influence is smaller, the thickness was also 50 mm. A cut was made in the lower specimen of 40 mm to simulate the effect of a crack in the old pavement, at a distance of 10 mm from the interlayer. A cut of 50 mm could have been made in the lower layer, but this might have damaged the geosynthetic. Besides, the

**Table 2**
Bitumen content used in the study.

| Kind | Sample | Bitumen content (kg/m$^2$) |
|---|---|---|
| Reference | S–G | 0.1–0.3–0.4–0.5 |
| Geogrid | P-1 | 0.1–0.3–0.5–0.7 |
| Geotextile | P-4 | 0.5–0.7–0.9–1.3 |

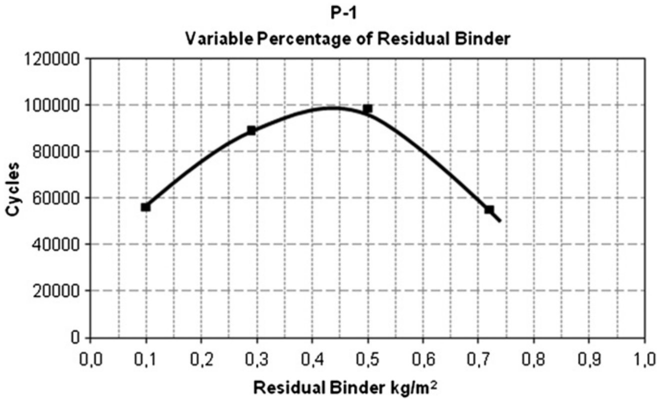


**Fig. 6.** Variable percentage of residual binder without geosynthetic materials.

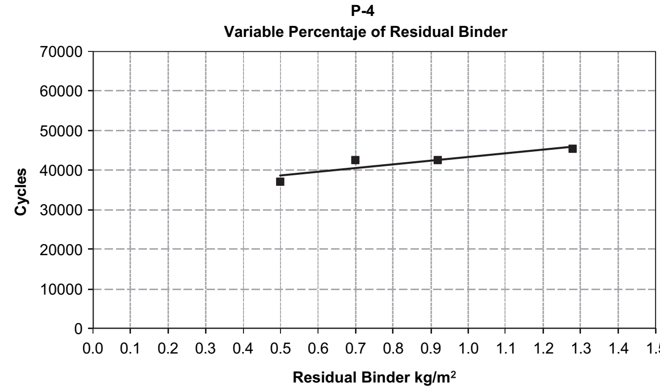


**Fig. 8.** Variable Percentage of Residual binder. Polypropylene geotextile P-4.

crack up to 10 mm below the interlayer extended completely in the first cycles of the test. In this way, all the tests were performed with the lower layer totally cracked. The purpose of the cut was to control the area where the crack spread was desired.

Test specimens were built with a D-12 bituminous mix (equivalent to European AC16 surf, according to UNE-EN 13108-1), with 5% of bitumen by aggregate weight. As tack coat, a quick break emulsion has been used in all cases.

### *4.2. Test specimen fabrication procedure*

To manufacture the lower test specimen, the hot bituminous mix is poured into the mould (Fig. 1). It is compacted following the Wheel Tracking Test procedure.

Later, it is left to cool to ambient temperature, and a geotextile material impregnated with bitumen (Fig. 2a) is placed in the interface area.

Afterwards, a second metallic mould is placed on the first, and again the hot bituminous mixture is poured onto the geosynthetic material. It is compacted as before and everything is left to cool to ambient temperature before taking it out of the mould (Fig. 2b).

### *4.3. Test device*

To apply loads, a stiff steel support base was designed to ensure a rigid support system (Fig. 3).

The load is transmitted to the test specimen through a prismatic steel element, with a 100 × 100 mm square cross-section and 330 mm long (Fig. 3)

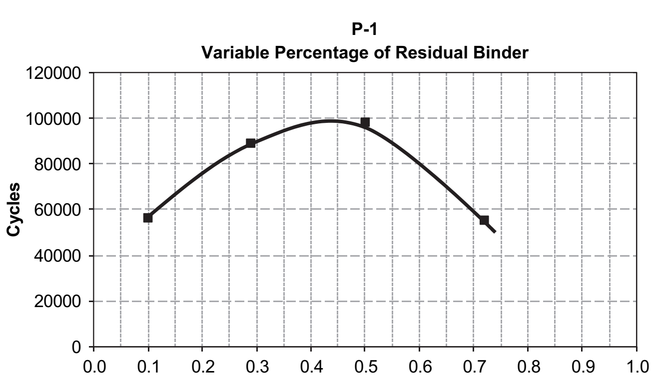


**Fig. 7.** Variable percentage of residual binder. Polyester geogrid P-1.

The load transmission system is composed of a flexible joint that enables the load to be vertically applied, reducing any movement in other directions during the test.

A 18 mm thick rubber layer, with a modulus of elasticity of 70 MPa, is placed between the lower part of the test specimen and the support base that enables deformations to appear in the lower base and cracks to extend. Moreover, a 6 mm thick rubber layer, with the same characteristics cited above, is inserted in the lower part of the element transmitting loads, to obtain good support and to avoid side displacements during the test phase.

### *4.4. Test conditions*

The dynamic test is done through a load control system and test pieces are conditioned to a temperature of 20 °C for a period of at least 24 h.

During the test, three variables are simultaneously monitored: applied load, vertical displacement (used to control the dynamic equipment although it is irrelevant in the test results as it includes the vertical displacements in the rubber), and crack opening in two opposing sides (through LVDT displacement sensors), in accordance with Fig. 3.

The characteristics of the test are presented in Table 1. The choice of 10 Hz as the frequency was related to the characteristics of the available dynamic machine and corresponds to a quite usual value in fatigue studies of bituminous mixtures. As the study is a comparison of the performance of different anti-reflective cracking systems, the maximum load value (19 kN) was established so that the test duration would not be excessive, producing a maximum of 250,000 resisted cycles, equivalent to 7 continuous working hours of the machine. The minimal load value (3 kN) was fixed to guarantee permanent contact between the load applicator and the specimen, given that guaranteeing load values exactly equal to zero is complex using these machines and in this way, the loss of contact between the different elements is avoided.

**Table 3**
Studied products.

| Kind | Sample | Residual bitumen (kg/m$^2$) |
|---|---|---|
| Reference | Without geosynthetic (S-G) | 0.40 |
| Geogrid | P-1 | 0.35 |
| | P-2 | 1.10 |
| | P-3 | 0.00 |
| Geotextile | P-4 | 1.10 |
| | P-5 | 1.10 |
| SAMI | P-6 | 2.80 |

**Table 4**
Properties of different geosynthetic materials.

| Properties | Test standard | Units | P-1 | P-2 | P-3 | P-4 | P-5 |
|---|---|---|---|---|---|---|---|
| Mass per unit area | ISO 9861 | g/m$^2$ | 250 | 360 | 370 | 140 | 120 |
| Tensile strength | ISO 10319 | kN/m | 50 | 50 | 100 | 9 | 8 |
| Elongation at break | ISO 3341 | % | 12 | | 3 | 55 | 50 |
| Asphalt retention | ASTM D 6140 | kg/m$^2$ | – | | | 1.1 | 0.90 |
| Grid size | | mm | 40 × 40 | 35 × 35 | 12.5 × 12.5 | | |

In Fig. 4, a scheme of the crack development in relation to the number of cycles is presented. Here it is possible to observe the two main parameters in this kind of test, namely, the crack amplitude, defined as the difference between the minimal and maximal deformation in a cycle, and the crack opening, the average crack size during a cycle.

### 4.5. Failure criteria and results

All tests were continued until the crack, which is enlarging during the test, is reflected on the surface.

The damage is induced when the crack spreads through the lower test specimen quickly reaching the interface area. From this moment, the evolution is slower and depends on the kind of interface used. The crack spreads from the interlayer through the upper test specimen until reaching its surface.

The crack amplitude increases throughout the test, tending to stabilize when the crack reaches the surface, because the only element that does work to keep the two separate parts together is the interface, which did not break in any test.

The graph shown in Fig. 5, which corresponds to the amplitude in relation to the number of cycles, shows a similar type of curve for all the geosynthetics, but logically, the cycle where each zone starts depends on the material tested. In the graph, it is possible to appreciate three clearly differentiated zones, which show the stages in the breakage process:

- Zone No. 1 represents the reflection of the cracks from the lower part until they have almost reached the test piece surface. In this zone, the amplitude increase varies in an almost linear way with the number of cycles.
- Zone No. 2 starts when there is a sudden rise in the slope, which happens in all cases, until the crack amplitude reaches 0.1 mm. This coincides with the beginning of this zone. For this reason the aforementioned amplitude was used as failure criterion, because in all the products used, this value was found at the first bend of the curve. The system's higher or lower efficiency is related to the number of cycles until it reaches 0.1 mm amplitude. At the end of this zone, the crack reaches the surface.
- Zone No. 3 corresponds to a new slope change, passing to a less steep slope than before, and where the test piece is absolutely broken. From this moment, the amplitude increase augments, but with a small slope.

**Table 5**
Characteristics of SAMI products.

| Description | Amount | |
|---|---|---|
| Stony aggregate | Max. size 10 mm<br>Min. size 8 mm | 7 kg/m$^2$ |
| Modified bitumen | BM-4 | 2.8 kg/m$^2$ |

Transverse band.

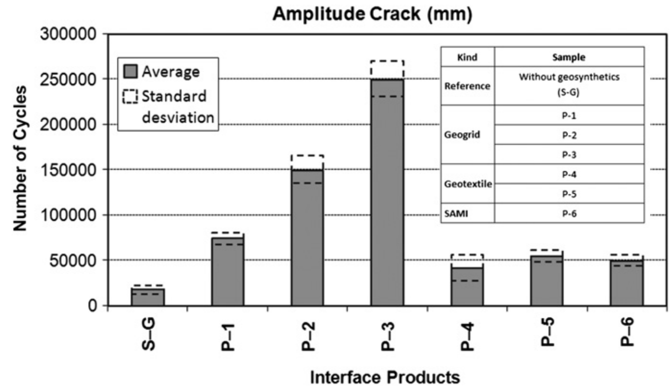


**Fig. 9.** Number of life cycles of different products.

## 5. Influence of the tack coat content on durabililtys

With this test, the influence of the bitumen content on the anti-reflective cracking system is analyzed. The study was carried out in three of the systems:

- Reference test piece (S-G) without geosynthetic materials in the interface area.
- A polyester geogrid (P-1).
- A polypropylene geotextile (P-4).

The applied bitumen content is shown in Table 2. A range of bitumen contents has been chosen according to previous research by Zamora-Barraza et al. (2010), in which the optimum bitumen dosage was determined to achieve the maximum adherence between layers, for each of the interlayer systems.

### 5.1. Results of the reference system, without geosynthetic materials

Fig. 6 shows the influence of the percentage of residual binder on the durability of the pavement without anti-reflective cracking system. It can be seen that the test is sensitive to the bitumen content variation. The optimum content is found around of 0.3 kg/m$^2$ bitumen, a value close to the one generally used in tack coats.

### 5.2. Results for the polyester geogrid system

Fig. 7 shows the influence of the percentage of residual binder on the durability of the pavement with an anti-reflective cracking system in which a geogrid is employed. In this case, the test is also sensitive to the bitumen content used to fix the geogrid. The

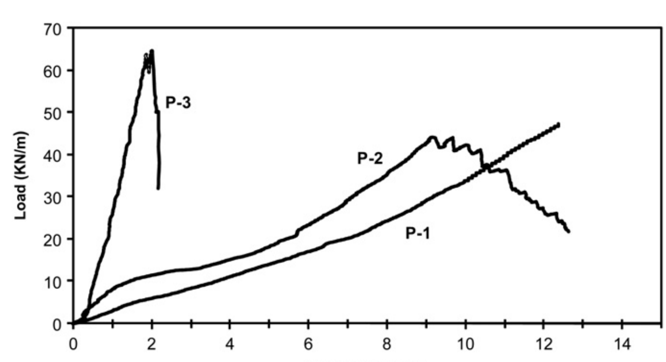


**Fig. 10.** Load deformation of the different geogrids.

optimum value is found around a content of 0.4 kg/m$^2$ and it corresponds to higher contents than the ones generally used in real set-ups.

### 5.3. Results of the polypropylene geotextile system

Finally, Fig. 8 shows the influence of a geotextile. In this case, the bitumen content influence is very low, at least within the range of study, so that it is difficult to establish an optimal content.

## 6. Anti-reflective system influence on durability

At this stage, the efficacy of the different solutions is compared. In order not to introduce extra test variables, the bitumen contents have been selected in three cases, taking into account the results of the tack coat influence, and in three other cases, using the content recommended by manufacturers. The solutions studied and amounts in each of them are shown in Table 3.

In the reference test piece (without geosynthetic materials), a content of 0.40 kg/m$^2$ (emulsion ECR-3) is used.

The geosynthetic material's mechanical characteristics are shown in Table 4.

Sample P-1: Polyester geogrid, overlaid with bituminous mixture, which has a non-woven ultralight fabric, fixed on one side, also overlaid with a bituminous product. In the load-deformation test, to achieve deformation of 1.2%, a load of 6.4 kN/m is required.

Sample P-2: Polyester geogrid, with Polyvinyl chloride PVC overlay and conventional modulus (to achieve deformation of 1.2%, a load of 11.8 kN/m is required).

Sample P-3: Geogrid with reticulate structure of glass fibre threads, overlaid with polymers and a layer of pressure-sensitive glue. In the load-deformation test, to achieve deformation of 1.2%, a load 64 kN/m is necessary.

Sample P-4: Geotextile with non-woven polypropylene needle fibres, with continuous filaments stabilised against UV rays.

Sample P-5: Geotextile with polypropylene fibres compacted by punching and with thermal finishing.

Sample P-6: SAMI. Fabricated with lime aggregate with homogenous size between 8 and 10 mm, and modified bitumen (Table 5).

In total, three test specimens were fabricated for each one of the seven types mentioned in Table 2. This is a minimal number that enables deviations to be observed so any specimen showing defects can be rejected.

### 6.1. Test results

Fig. 9 shows the average number of cycles tolerated up to breakage, using a 0.1-mm crack amplitude as breakage criterion.

In most cases, the result shown is the average of three tests, although in one case it corresponds to two, due to a problem during a test. The variances were between 23,750 cycles for an average value of 250,000 cycles and 4160 cycles for an average value of 16,000 cycles.

Based on the results presented in Fig. 9, it is possible to make the following comments:

- It is observed that the test is sensitive to the anti-reflective cracking systems used in the interlayer, the specimen resisted loading cycles varying from 16,000 to 250,000.
- All anti-reflective cracking systems perform better than the reference one (S-G).
- The SAMI system used and the two polypropylene geotextile materials perform similarly. The durability before reflective crack spread is from two to three times higher than the reference test piece durability.
- In geogrid systems, performance is uneven. The durability of all these systems is greater than the previously commented ones. In relation to the materials, all geogrids withstand at least four times more loading cycles. Geogrid P-3, which has the best results, bears at least 50% more than P-2 and three times more than P-1.

These results can be explained in relation to the deformation modulus of the geogrid used, see Fig. 10. For this reason it is important to remember that crack propagation is more closely related to deformations in the lower fibre than to the final resistance that a geosynthetic material may achieve. In fact, during the anti-reflective crack test no geosynthetic material was broken, but in all cases the crack has gone up to the surface.

The crack reflection onto the surface, at least for the 50 mm mixture thickness used, is produced when the unitary deformation is around 1.2%. This level of deformation is very far from the geosynthetic material's breakage deformation, and also from the geogrid's.

As a result, the initial slopes of the geosynthetics' tensile curves are more interesting than the maximal breakage values that can be reached. The relevant finding is the value of the load supported by the geosynthetic for deformations below 1.2%, which is directly related to the initial modulus of the geosynthetic.

## 7. Conclusions

The durability of anti-reflective cracking systems using a geogrid, geotextile or a Stress Absorbing Membrane Interlayer (SAMI) has been evaluated through a straightforward procedure which helps determine how the bitumen content influences the capacity to delay crack reflection.

The use of geosynthetics in the pavement structure is advantageous as an anti-reflective cracking system and the test is sensitive to the interlayer type.

The test set-up used was very simple and easily implemented, given that the machinery necessary for manufacture and test of the test pieces is available in any highway research laboratory. The only requirement is an easily developed support and a press.

All systems analyzed delay the reflective crack spread. The most durable are the geogrid systems that withstand between three and six times more cycles than the reference sample.

Geogrids with higher modulus give better performance.

Increasing the geogrid stiffness is important for the geogrid to provide higher resistance to deformation. Moreover, the geogrid cross-section is also important, because both stiffness and cross-section will determine the stress per longitudinal unit that the anti-reflective system may resist.

Geogrid systems are sensitive to the bitumen content and help determine the optimal coating content, achieving better durability.

The results of this comparative study were obtained under ideal laboratory conditions, and may contradict some field evidence. In order to obtain a good result using these products in roads, it is essential to take care in the placement process because the product itself does not guarantee a good performance unless it is appropriately installed.

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