

Extended summary

Study and optimization of geosynthetics for flexible reinforced pavements

Curriculum: Structures and Infrastructures Engineering

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Abstract. In road construction, pavement rehabilitation reinforcement systems can be employed to improve pavement service life. In particular, many studies focused on geosynthetics, materials widely used as reinforcement systems.

The main objectives of this experimental research was to study the effects produced by geosynthetic and to implement their properties for asphalt pavement. The work program was divided in two different parts.

The first step describes the construction of two trial sections. A glass fiber grid and a carbon fiber grid were installed at the interface between two asphalt layers of pavement.

Moreover, one of the two abovementioned sections was instrumented in order to measure the stress-strain. The reinforced pavements are part of the international project RILEM "Advanced Interface Testing of Geogrids in Asphalt Pavements" developed by laboratory tests and in situ observations.

The second part of the research intended to improve geocomposites with tests carried out in laboratory. In order to evaluate the effects of various variables on bituminous systems, different types of geocomposites were studied. The laboratory study developed has allowed the selection of an optimun geocomposite for road applications.



ASTRA shear tests, three point-bending tests (3PB) and fuor point-bending tests (4PB) were carried in the experimental program.

The experimental findings systems showed a reduction of interface shear resistance and an enhanced flexural resistance in reinforced geosynthetics.

Keywords. asphalt concrete, geosynthetics, geogrid, geocomposite, interface, reinforcement.

1 Problem statement and objectives

The continuous increase of traffic loading is the main responsible of premature failures in the in-service road pavement network. This is one of the reasons for the worldwide growing interest on pavement reinforcement with geosynthetics. In fact, the performance of asphalt pavement can be considerably improved by the use of geosynthetics both in the initial construction phase and in the rehabilitation of existing pavements.

Different categories of geosynthetics like geogrids, geomembranes and geocomposites, have been used as reinforcement at the interface of asphalt pavement layers.

Geosynthetic reinforcements, under or inside asphalt concrete layers, can lead to many positive effects including: limitation of reflective cracking enhancement of fatigue resistance and reduction of rutting and permanent deformation [1, 2, 3, 4, 5].

In order to improve reinforcement systems must be appropriately chosen and correctly installed in asphalt layers when correctly installed, the mechanical properties of pavements against cracking due to repeated loading [6, 7].

An important aspect to be considered is the geogrid influence on interface properties. In fact, the reinforcement benefits could be canceled if the geogrid causes a significant shear strength reduction at the interface between asphalt layers [8, 9].

The main objectives of this experimental research was to study the effects induced by geosynthetics and to implement their properties for asphalt pavements. The work program was divided in two different parts: the first step describes the construction of two trial sections reinforced with geogrids; the second part of the research aims to improve geocomposites through tests carried out in laboratory.

2 Research planning and activites

2.1 First part: construction and study trial section

The study described in this step is part of a research project named "Advanced Interface Testing of Geogrids in Asphalt Pavements" promoted by Task Group 4 "Pavement Performance Prediction and Evaluation" of RILEM Technical Committee 237-SIB "Sustainable and Innovative Bituminous Materials".

The main project goal is the comparison of experimental procedures and devices for the mechanical characterization of geogrid reinforced interfaces in asphalt concrete pavements. This approach requires the preparation of representative samples, focusing the attention on interface preparation, reinforcement installation and mixture compaction.

Since both real-scale dimensions and loading conditions are difficult to reproduce in the laboratory, test results must be compared to actual field performance of reinforced pavements. In order to meet these challenges, the RILEM research project is based on the construction of two full-scale pavement test sections. The first (Section A) is devoted to an interlaboratory test involving several research laboratories and is realized using real scale paving equipment and geogrid installation techniques. From this section, double-layered asphalt pavement samples were cut and shipped to the participating laboratories in order to be tested using different devices. The second section (Section B), constructed with same materials, paving equipments and interface configurations, is used to compare field performance of reinforced asphalt pavements to laboratory test results in order to estimate



the potential of each test method to predict in situ performance. For this purpose, Section B was instrumented with pressure cells, asphalt strain gauges and temperature sensors to measure the main components of the stress and strain fields inside the pavement.

In each experimental section, geogrid reinforcements were placed at the interface of two asphalt layers, creating reinforced double-layered systems. In particular, two geogrid types were installed in each test section: a Glass Fiber Reinforced Polymer geogrid (FP) and a Carbon Fiber/Glass pre-bituminised geogrid (CF).

Moreover, in order to obtain control data, an unreinforced interface (UN) was realized in both sections spreading a polymer modified tack coat emulsion, which was also applied in the reinforced sub-sections.

Before the construction of Section A, a regulating course of asphalt concrete was laid down on the existing pavement. In order to facilitate the removal of pavement samples after saw cutting, dry sand was then spread to create a separation between the regulating course and the asphalt double-layered system.

Slab samples of different sizes (52×52 cm and 65×65 cm) were cut in order to satisfy the needs of the laboratories participating to the interlaboratory test. Each slab was coded to identify both the interface type and the position, and marked with a line parallel to the compaction direction.

Section B is located along an existing local road, inside an industrial area, and is subjected to heavy-truck loads. Pavement construction phases and installation of sensors are described in detail in the following chapters, whereas the performed measurements and the result elaboration are currently in progress. In this paper, the periodic visual distress inspection of the instrumented pavement section was performed considering areas with "simulated" cracks and critical bonding conditions, prepared in the lower asphalt layer before the geogrid installation. The objective was the simulation of challenging situations frequently encountered for road pavements in rehabilitation and overlaying field activities. The simulated cracks were obtained by full-depth saw cuts in the lower asphalt layer, whereas a thin layer of fine sand was used to create de-bonding at the interface between the asphalt layers.

The Asphalt Concrete (AC) used for the lower and the upper asphalt layer was a typical dense graded mix formulation, with 12 mm maximum aggregate dimension (AC 12) and bitumen dosed at 5.4 % by aggregate weight.

Two different geogrids were installed. The Carbon Fiber/Glass geogrid (CF) is precoated with bitumen and characterized by carbon fibers in the transversal direction and glass fibers in the longitudinal direction, with a square 20 mm mesh. The Glass Fiber Reinforced Polymer geogrid (FP) is obtained by weaving continuous alkaline-resistant pretensioned glass fibers, covered with a thermosetting epoxy resin (vinylester). The grid has flat transversal strands woven into longitudinal twisted strands, with a square 33 mm mesh.

2.2 Second part: optimization of geocomposites

The second part of the research aimed at evaluating the effectiveness of asphalt pavement rehabilitation with reinforced geomembranes. In particular, the experimental study aimed to implement new products for asphalt interfaces by selecting the optimum combination among different geomembrane compounds, reinforcement types, reinforcement positions and interface conditions.



For this purpose, shear and flexural tests were carried out on samples prepared in laboratory combining two geomembrane compounds, different reinforcement types, two reinforcement positions and different interface conditions.

As far as the bituminous compound is studied, two polymer modifiers were selected to manufacture the geomembranes: atactic polypropylene plastomeric polymers, hereafter named APP, and styrene-butadiene-styrene synthetic elastomeric copolymers, hereafter named SBS.

These polymer modified bituminous membranes were reinforced with two similar fibreglass geogrids characterized by different mesh sizes. In particular, a geogrid having a mesh dimension of $12.5 \times 12.5 \text{ mm}^2$, and a geogrid characterized by a mesh dimension of $5.0 \times 5.0 \text{ mm}^2$.

Finally, the reinforcement position within the geomembrane was selected as further variable for the optimization of the studied materials. In fact, the reinforcing geogrids were placed either near the upper side or near the lower side of the geomembrane.

It is worth mentioning that the upper side of all materials was coated with a fine sand whereas the lower side was characterized by an auto-thermoadhesive SBS-modified bituminous film.

Double-layer slabs were prepared in the laboratory using the same type of asphalt concrete for both layers. This material, prepared with limestone aggregates and plain bitumen, is characterized by a maximum aggregate size of 8 mm and a bitumen content of 5.6% by the weight of the mix.

During the experimental investigation, two types of bituminous materials were applied as bonding agent at the interface of the double-layered slabs: an SBS polymer modified emulsion and a water-based elastomeric bituminous primer, specifically formulated for the application of the studied geocomposites and characterized by a binder content of 40% by weight of the material. The curing time of the water-based primer was selected as test variable (1 hour or 3 hours).

2.3 Testing equipement

2.3.1 ASTRA Test

The ASTRA device, in accordance to the Italian Standard UNI/TS 11214, is a direct shear box, similar to the device usually used in soil mechanics. The specimen is installed in two half-boxes separated by an unconfined interlayer shear zone. During the test, a constant displacement rate of 2.5 mm/min and a constant vertical load, perpendicular to the interface plane, to create a given normal stress are applied. Interlayer shear stress, horizontal and vertical displacement are recorded, allowing the calculation of the maximum interlayer shear stress.

2.3.2 Three-Point Bending Test (3PB)

The prismatic specimens selected for 3PB tests are placed on supports with a span of 240 mm and subjected to flexural loading at displacement control. Both load and beam deflection in the middle span are measured until failure by means of a load cell and an LVDT, respectively. During the test, the prismatic beam samples are subjected to a bending load under displacement control, at a constant rate of 50.8 mm/min.

Performance evaluation of double-layered reinforced systems is related to the following parameters: maximum pre-cracking flexural load, dissipated energy to failure D, the area under the load-vertical deformation curve until the maximum pre-cracking load of the sys-



tem is reached, total fracture energy or toughness T, area under the whole load-vertical deformation curve. In particular, the dissipated energy to failure D may account for crack initiation, whereas toughness could provide an indication of the performance of the reinforcement direction crack propagation.

2.3.3 Four-Point Bending Test (4PB)

The 4PB device is basically composed by a temperature controlled chamber, a loading frame and a hydraulic actuator able to apply haversine loading waves up to a peak load value of 4.0 kN, with a maximum frequency of 5 Hz. The vertical displacement at the midspan of the beam is measured during the test through a strain gauge based extensometer.

The performance of double-layered systems in the cyclic 4PB test is analyzed in terms of permanent deformation and damage associated to crack propagation.

Permanent deformation is measured by means of the accumulated mid-span deflection at each load cycle. Since reinforced beams often do not reach a complete collapse during the test time, a failure criterion to compare different interface configurations was defined by the number of load cycles (or time) required to reach the flex point in the permanent deformation curve.

3 Analysis main results

3.1 First part: construction and study trial section

The peak and friction envelopes of the interlayer shear resistance obtained for the studied interface configurations at T = 20 °C are presented in Figure 1.

In terms of peak values (τ_{peak}), the comparison of the three systems shows that geogridreinforced samples (CF and FP) provide lower interlayer resistance compared to unreinforced systems (UN), particularly in terms of pure shear component (c_0). This is due to the higher thickness and stiffness of the FP geogrid, which probably inhibits the achievement of an optimal compaction of the upper layer in the interface proximity, and reduces the interlocking between the two bituminous layers that are in contact.

As far as the influence of test temperature on τ_{peak} is analyzed, results show a decrease of interlayer shear resistance with increasing temperature, for all the interface configurations. This indicates that the geogrid influence tends to disappear and τ_{peak} is controlled mainly by the characteristics of the two AC layers in contact, particularly at higher temperatures.

Comparing results of ASTRA tests performed at 20 °C on samples of different ages, for all test configurations the same increase of peak shear resistance is observed for the two years aged samples compared to the one year aged.



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Figure 1. ASTRA Shear Results - Peak and friction envelopes

The average values of 3PB static test are summarized in Table 1.Up to the flexural strength point the shape of curves is very similar for the studied double-layered systems, resulting in similar magnitude of the pre-cracking energy D values (Table 1). Although the geogrids lead to higher values, results confirm that these parameters largely depend on the characteristics of the un-damaged AC mixture. Beyond the flexural strength point (crack initiation), both reinforced and unreinforced systems show an initial rapid decrease of load carrying capacity due to the crack propagation towards the interface. Afterwards, UN systems rapidly and steadily lose their resistance until complete failure, whereas CF and particularly FP systems show a post-peak deformation phase, leading to higher toughness values (T average values for CF and FP configurations are about 2 times and 6 times higher than the UN configuration, respectively).

Section	Energy [N m]			
	Energy to failure D	Total fracture energy T		
UN	4.19	7.88		
FP	5.61	44.66		
CF	5.01	16.00		

Table 1. Summary of 3PB test results.



Results of 4PB Tests at F=1, 1.5, 2 kN and f=1 hz (T=20 °C) showed the number of cycles necessary to determine the failure of the tested specimen is variable as a function of applied load and configuration at the interface. Reinforced specimens required, for a given load, an higher number of cycles to failure compared to unreinforced specimens.

The geogrid application improves the permanent deformation resistance of the doublelayered systems respect to the unreinforced specimens which always reach collapse before the planned test conclusion. In particular, CF and FP reinforced systems did not always reach complete collapse before test conclusion and produce a remarkable increase of permanent deformation resistance.

This derives from the fact that, at each load cycle, part of the deformation energy provided by the external load is carried by the geogrid reinforcement itself as reversible deformation. Consequently, the presence of the reinforcement reduces the load fraction carried by the AC double-layer and therefore reduces damage accumulation of the AC mixture.

However, considering the different stress level applied in the tests, this may actually indicate that the geogrid de-bonding effect, particularly evident for the FP grid, is attained only when interface shear stress reaches failure conditions.

In CF systems the crack moves vertically and propagates across the interface and the geogrid, whereas in FP systems as soon as the crack reaches the interface it starts to propagate horizontally. This change of crack propagation mode, can be related to the marked reduction of peak interlayer shear strength measured by ASTRA tests for FP specimens.

3.2 Second part: optimization of geocomposites

ASTRA shear Test results indicate an higher decrease of shear strength in reinforced systems with geocomposite than unreinforced systems with emulsion modified interface.

The experimental results showed that the presence of a tack coat, modified emulsion or bituminous primer to the interface, does not provide appreciable contributions to the shear performance in the bituminous system. In fact, the presence of tack coat inhibits the auto-thermoadhesive SBS-modified bituminous film at the bottom of the geocomposite.

As far as the bituminous compound of geomembranes is considered, the geocomposites in styrene-butadiene-styrene synthetic elastomeric copolymers, demonstrated a higher shear resistance in double-layered specimens than APP compound, polypropylene plastomeric polymers.

Overall 3PB test results are presented in Table 2 in terms of maximum precracking flexural load Pmax and corresponding deflection δ , dissipated energy to failure D and total fracture energy T.

Configuration	P _{max}	δ	D	Т
Configuration	kN	mm	Nm	Nm
EM.00	5.40	1.99	6.15	13.40
PR.R5	5.33	1.90	6.49	20.27
00. R 7	5.13	2.39	8.97	26.76
PR.R7	4.74	2.52	8.02	28.19
00.R8	5.17	2.64	9.10	29.36
PR.R8	4.91	2.65	8.53	28.11

Table 2. Summary of 3PB test results.



Higher values of dissipated energy D related to crack initiation and higher total energy T related to fracture are recorded in reinforcement systems compared to the reference system EM.00.

On the contrary, in terms of maximum load the configuration without reinforcement requires a higher load for crack initiation. In samples with geocomposite, as soon as the section is cracked, the action of reinforcement starts to provide its contribution of resistance, giving to the system a ductile behavior. Such ductility delays the propagation of cracks within the double-layered systems.

In case of application of primer at the interface, the reinforced specimens with grid size 12.5x12.5 mm² (PR.7) showed total fracture energy T higher than geogrid 5x5 mm² (PR.5).

Regarding the results of the 4PB tests conducted at a load level of 1.6kN (f = 1 Hz), it is possible to state that the geocomposites used are able to provide to the system with reinforce a significant contribution in terms of fatigue resistance, equal about 5 times as much as exhibited by the reference specimens, both with and without primer.

Moreover, the reinforced specimens showed a value of displacement to the higher inflection accompanied by a marked increase in the number of cycles. The increase of the average values of the arrow to the reinforced specimens is to be considered due to the lower shear strength at the interface compared to the control configuration without reinforcement, resulting from the application of geosynthetic.

Analyzing systems having the same type of reinforcement, geogrid fiberglass, but different openings of the mesh (geocomposites R5 and R7), in Figure 2 it is possible to evaluate the influence of the mesh size on the flexural dynamic performance. The experimental results demonstrate a better response of the bituminous systems reinforced with geocomposite R7, equipped with geogrid fiberglass mesh from 12.5×12.5 mm² compared to geocomposites R5 (mesh 5×5 mm²). This finding confirms what has already been reported for static 3PB tests, carried out both on geosynthetic-compound APP plastomeric of those elastomeric SBS.



Figure 2. 4 PB results -



influence of reinforcement mesh

4 Conclusions

The first part of this research is focused on the effects of interlayer geogrid reinforcement on the behavior of asphalt pavement: interlayer shear resistance and bending resistance. Three interface configurations were considered: unreinforced (UN), Carbon Fiber/Glass pre-bituminised (CF) geogrid and Fiber Reinforced Polymer (FP) geogrid. Double-layered AC samples were obtained from an experimental test section allowing the evaluation of for real scale reinforcement installation and mixture compaction techniques.

ASTRA tests, carried out to investigate interlayer shear resistance, showed that geogrid installation leads to a peak strength reduction. The peak de-bonding effect is particularly evident with the FP geogrid which is characterized by higher thickness and torsional stiffness compared to CF geogrid. Binder aging leads to an increase of the peak strength, especially the pure shear component, for both reinforced and unreinforced interfaces.

Repeated loading 4PB tests, carried out on double-layered systems, showed that geogrid reinforcement leads to a remarkable increase of permanent deformation resistance, especially at higher load levels. In particular, although vertical cracks movement is delayed by the CF geogrid, it can lead to failure, whereas the FP geogrid induces an horizontal propagation along the interface allowing longer specimen life.

3PB tests confirmed that geogrid installation has a minor impact on the crack initiation resistance, whereas CF and particularly FP systems show a post-peak deformation phase, with higher toughness values. The CF geogrid delays crack propagation in the vertical direction but the failure mechanism and the fracture process area remains analogous to unreinforced systems. On the other side, due to the reduced interlayer shear strength, the FP geogrid leads to a significant horizontal crack propagation phase and consequently the failure mechanism becomes more ductile.

Observation of the in-situ performance of the two geogrids revealed a post-cracking behavior consistent with laboratory test results. In particular, there is a similar reflective cracking pattern developed in the field in UN and CF reinforced pavements, whereas the FP geogrid provided an improved reflective cracking resistance. In addition, the debonding effect highlighted by ASTRA test did not reduce the overall pavement performance, in case of reinforcements installed as anti-reflective cracking systems.

The second part of research aimed at implementing new geocomposites for pavement rehabilitation by selecting the optimum combination among different geomembrane compounds, reinforcement types, reinforcement positions and interface conditions. For this purpose, ten configurations were analyzed in laboratory through interface shear tests, performed using the ASTRA apparatus, and three-point and four-point bending tests. Based on experimental results obtained during the present research study, the following general observation can be drawn.

Regarding the shear behavior of double-layered bituminous systems analyzed, the presence of geocomposite at the interface induces a reduction of the shear strength compared to unreinforced reference samples.

However, although there was a decrease in the shear strength due to the interposition of a geocomposite, this phenomenon has not prevented from producing systems with an



appreciable improvement in performance in terms of resistance to bending loads, both static and dynamic.

The geocomposites analyzed do not require the application of a bituminous tack coat. In fact, in cases where such treatment is found to be present at the interface (bitumen emulsion or bituminous primer), there has been no appreciable improvement in performance compared the case with only geocomposite at the interface. In the case of application of bituminous primer, the aging time has proved to be crucial on performance that increased for a curing time of 3 hours.

The optimization process has enabled us to evaluate the influences of some variables of the geocomposite inside of the reinforced systems studied.

The surface treatment of the upper side of the geocomposite (sand or PE) does not appear to significantly influence the performance compared to the stresses studied.

The research has unequivocally demonstrated that bituminous geomembranes whose modification polymer is carried out with elastomers SBS, ensure superior performance, both in terms of shear strength and resistance to bending loads, both on samples made in the laboratory and samples taken in situ, compared to similar products modified with APP plastomers.

Furthermore, the behavior of the geogrid fiberglass embedded within the geocomposite, it seems that that does not substantially affect the performance in cutting of the interfaces of reinforced systems, while significantly improves the mechanical flexural performance. In particular, between the reinforcements studied, it can be concluded that the glass fiber grid characterized by a mesh size equal to 12.5x12.5 mm² ensure the best performance.

The position of the reinforcement does not seem to have a significant impact on the performance analyzed with respect to which, moreover, were obtained of non-unique directions about the hierarchy of performance to vary the position of the reinforcement.

In conclusion, based on the results and interpretations carried out it can be stated that, limited to the variables analyzed, the geocomposite made by coupling a geomembrane modified bituminous-based elastomers SBS and a geogrid reinforcement fiberglass mesh opening with equal to $12.5 \times 12.5 \text{ mm}^2$, is suitable for the reinforcement of road flexible pavement.



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