Geosynthetic reinforcement for reflective cracking reduction in asphalt pavements

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ABSTRACT: A survey by the National Confederation of Transportation of Brazil (CNT, 2011) shows that 47.9% of the country's roads need urgent interventions to recover satisfactory traffic conditions. This paper presents results of an investigation on the use of geosynthetic reinforcement in asphalt pavements with reference to capping of old courses. The use of geosynthetic reinforcement was intended to reduce crack reflection between an old surface course and the new hot mix asphalt (HMA) layer. In order to investigate crack reflection, two prismatic beams of dense HMA were prepared and geogrids or a geocomposite (geogrid with a geotextile coated with bitumen) reinforcement was placed in between them. An initial crack was induced by cutting the lower HMA specimen and a vertical cyclic loading was applied with a steel plate at the center of top layer. The test was interrupted when the vertical displacement at the surface reached 25 mm. The results show that geogrid reinforcement may increase by up to 15 times the number of loading cycles required to reach the pre-established value of vertical displacement (25 mm). In addition, it was noticed that the severity of the cracking mechanism was reduced and that crack reflection to the upper layer was reduced by the reinforcement inclusion.

Keywords: reflective cracking, asphalt overlay, paving fabric, reinforcement, asphalt pavement, geosynthetics.

1 INTRODUCTION

The investments on the highway infrastructure in Brazil are of the order of billions of dollars annually. Despite such increasing investments the need for maintenance of old highways and construction of new ones is urgent. The lack of good quality of roads and highways in some parts of the country has a direct impact on the final cost on the transportation of products and competitiveness of the country's exports.

According to IPEA (2010), 60% of the good produced in Brazil are transported through paved roads. In other counties this percentage is smaller, like in the USA (26%), Australia (24%) and China (8%). At the present time the Brazilian road network is 1,581,104 km long, with approximately 213,909 km (13.5%) consisting of paved roads. With such dependence on the roads for transportation of goods, proper maintenance of existing roads, particularly with the use of new techniques, becomes very important.

The presence of geosynthetic reinforcement in asphalt caps can increase its lifetime and reduce the number of pavement maintenances. Several researchers (Komatsu *et al*. 1998, Montestruque 2002, Fritzen 2005, Ferrotti *et al.* 2011, for instance) investigated the use of geosynthetics to avoid or minimize the reflection of cracks from old asphalt caps to new ones. These studies have shown that the contributions of the reinforcement are: change in the direction of crack propagation or reduction of their dimensions and to delay their propagation in comparison with the cap without geosynthetic.

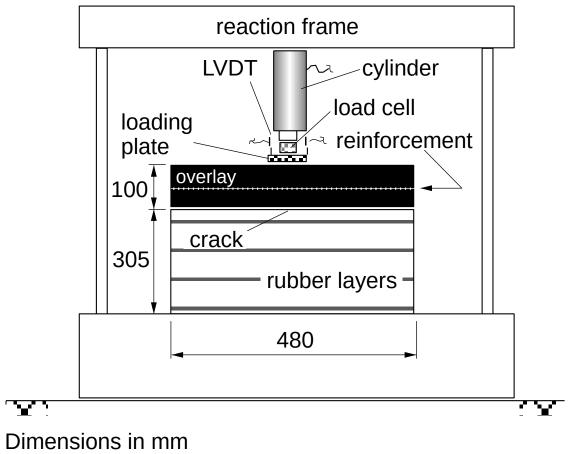
The use of a geocomposite to minimise crack reflection in real scale experiments was examined by Austin and Gilchrist (1996). One of the reinforced sections had the geocomposite placed at the middle of the asphalt layer and the other at the base of the layer. The tire pressure in the experiments was equal to 300 kPa. The results obtained showed that the reinforced layers resisted three times more load repetitions than the control unreinforced section. Similar researches and findings were reported by Fritzen (2005) and Zou *et al.* (2007).

This paper presents and discusses the use of geosynthetics as reinforcement in asphalt overlays. The test programme and results obtained are presented and discussed in the following sections.

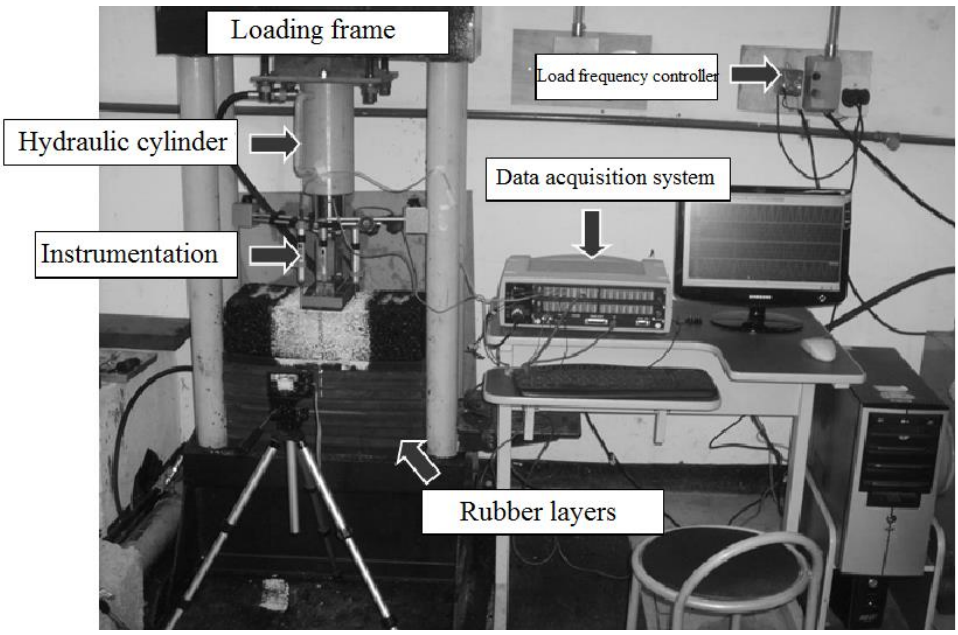
2 EQUIPMENT, MATERIALS AND TESTING METHODOLOGY

2.1 *Equipment*

The apparatus used in the tests was a loading frame aimed at applying cyclic loads on concrete asphalt beams, as shown in Figures 1(a) and (b).The load was applied on the beam by a rigid steel plate (100 mm wide, 25.4 mm thick and 200 mm long) connected to a hydraulic cylinder. The loading plate covered the entire width of the asphalt layers. A load cell was used to measure the load transferred to the beam and displacement transducers measured the loading plate vertical displacements during the tests. A data acquisition system connected to a microcomputer acquired and processed the instrumentation signals. The loading frequency was equal to 1 Hz and the vertical pressures applied at the top of the beam by the loading plate were equal to 350 kPa, 450 kPa and 560 kPa, which are values consistent with those expected in real highways. A camera was used to film the behaviour of the loaded beams and crack development during each test (Fig. 1b).



(a) Schematic view of the apparatus and test conditions.



(b) View of the apparatus during one of the experiments.

Figure 1. Equipment used in the tests.

The entire concrete asphalt beam specimen consisted of two individual beams. Each beam was 480 mm long, 200 mm wide and 100 mm high. The lower beam simulated a damaged asphalt cap, whereas the upper one a new overlay. An initial crack (16 mm high and 4 mm wide) was produced in the lower beam (Fig. 1a) in other to favour the development of crack reflection in the overlay. Tests with and without geosynthetic reinforcement in between the asphalt layers were carried out as part of the research programme.

Twelve layers of rubber were used underneath the asphalt layers to simulate a rather compressible pavement base (Fig. 1b). Each rubber layer was 480 mm long, 25.4 mm thick and 200 mm wide, with a Young's modulus equal to 21 MPa. The total thickness of the compressive layer underneath the asphalt layers was then equal to 305 mm.

The tests were interrupted when the vertical displacement of the loading plate reached 25 mm.

2.2 *Materials*

Aggregate material commonly used in the construction of pavement caps in the Federal District, Brazil, was used in the preparation of the asphalt beams as well as CAP 50-70 (penetration grade) asphalt binder. Tack-coat (cationic with viscosity degree equal to 1, RR-1C) was employed to favour a proper adherence between the geosynthetic reinforcement and the concrete asphalt beams. The main properties of the aggregate used to manufacture the concrete asphalt beams are presented in Tables 1 and 2. The main properties of the asphalt binder used are listed in Table 3.

Table 1: Grain size characteristics of the aggregate.

Sieve No.	1"	3/4"	1/2"	3/8"	Nº4	Nº10	Nº40	Nº80	Nº200
% Finer	100	99	93	88	59	33	14	11	9

Table 2: Physical characteristics of the aggregate.

Property		Value
Shape index		0.6
Percent of fractured particles	(%)	96
Sand angularity	(%)	42.5
Sand equivalent	(%)	64.0
Los Angeles Abrasion	(%)	15.6
Uniformity coefficient	(C_u)	41.9
Curvature coefficient	(C_c)	4.3

Table 3: Asphalt binder properties (CAP 50 – 70)

Property		Value
Penetration (0.1 mm) (100g,5s,25°C)		56
Softening point	(ºC)	49.2
(RTFOT) @ 163°C, 85 min. Inc. penetration	(%)	57
(RTFOT) @ 163°C, 85 min. Inc. softening point	(ºC)	4.1
Ductility at 25ºC	(cm)	> 150
Penetration index		-1.1
Specific gravity at 15.6ºC		1.003

The tests performed showed that the asphalt cement used has low susceptibility to aging. This was corroborated by the value of the penetration index obtained (Table 3), which for conventional asphalts should vary between – 1.5 and 0.7.

The Marshall method of asphalt concrete mix design was employed for the determination of the optimum content of asphalt binder in the mixture used to produce the beams. The tests were carried out following the recommendation of the Brazilian National Department of Transportation Infrastructure (DNIT). The results obtained are summarized in Table 4.

Table 4: Results for the asphalt concrete.

Property	Value
Percentage of aggregate %	95.0
Total binder content % (P_b)	5.0
Bulk specific gravity (G_{mb})	2.404
Maximum theoretical specific gravity (G_{mm})	2.529
Air voids % (V_A)	4.93
Voids in the mineral aggregate % (VMA)	14.59
Dust/Asphalt ratio	2.23
Marshall stability (N)	9751
Marshall flow (mm)	4.5
Stability Marshall/flow ratio (N/mm)	2166

From the results obtained and reported above, the mixture used fulfils the requirements of the Brazilian highway specifications regarding concrete asphalt mixtures.

The beam specimens were prepared using static compaction in a rigid mould. The aggregate was heated to a temperature of 160^{o}C and mixed with the asphalt cement, previously heated to a temperature of 150^{o}C. The mixture was then submitted to static compaction under a pressure of 312.5 kPa. This procedure led to the concrete properties presented in Table 4. When the reinforcement was present, after cooling of the bottom asphalt concrete beam under ambient temperature, the reinforcement layer was installed using the appropriate content of asphalt emulsion. Then the upper asphalt concrete beam was prepared under the same static compaction pressure of 312.5 kPa. Figure 2 shows the stages of beam preparation in one of the reinforced tests. Montestruque (2002) and Bulher (2007) employed similar procedures to manufacture asphalt concrete beams.

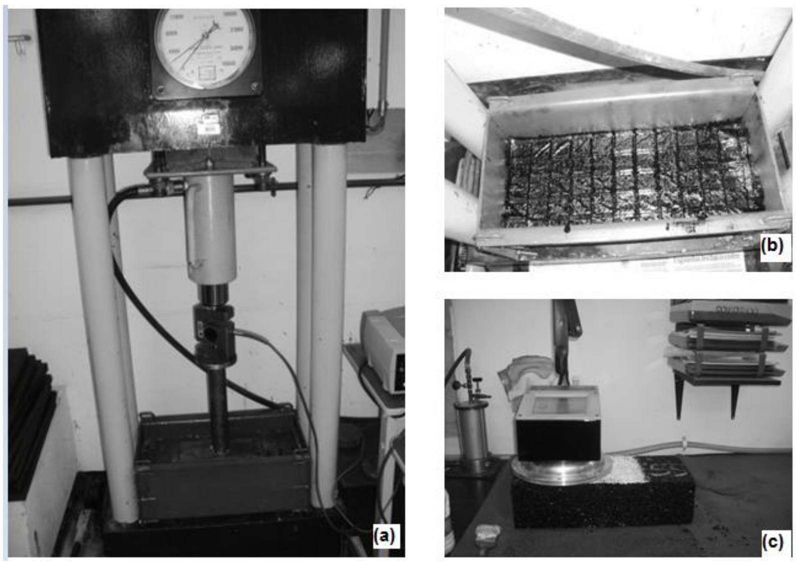


Figure 2. Preparation of an asphalt concrete beam in one of the reinforced tests. (a) compression under static load; (b) reinforcement installation; (c) beam density check.

Four types of reinforcements were used in the tests. Table 5 presents the main properties of these materials. Reinforcement G1 consists of a geocomposite made of a woven material reinforced by a grid and coated with asphalt on both sides. Reinforcement G2 is a steel wire mesh and was used for comparison purposes, as it has the greatest tensile stiffness. However, under unconfined conditions G2 can be quite extensible because of the type of manufacturing process and the way the wires are connected to each other. Reinforcements G3 and G4 are geogrids made of polyester fibres protected by a PVC cover. Reinforcement G3 is a uniaxial geogrid. The tensile stiffness ($J_{5\%}$) of the reinforcement layers varied between 557 kN/m and 2320 kN/m and the aperture dimensions of the geogrids between 20 mm and 40 mm. The reinforcements were oriented in the asphalt concrete beams with their strongest direction aligned with the direction of maximum tension. Asphalt concrete beams without reinforcement were also tested as a reference condition.

Table 5: Reinforcements used.

		G1	G2	G3	G4
MD	$J_{sec\ 5\%}$ (kN/m)	585	2320	1390	875
	(T_{max}) (kN/m)	38	49	128	55
	(ε_{max}) (%)	9.1%	4.5%	14.2%	7.6%
CMD	$J_{sec\ 5\%}$ (kN/m)	657	2055	557	585
	(T_{max}) (kN/m)	34	49	48	43
	(ε_{max}) (%)	12.1%	4.7%	11.1%	9.3%
Aperture dimensions (mm)		40 x 40	20 x 20	20 x 20	20 x 20
Mass per unit area (g/m^2)		270	1850	440	280
Type		Geocomposite	Wire mesh	Geogrid	Geogrid
Material		PET	Steel	PET	PET

Notes: MD = machine direction; CMD = cross-machine direction.

3. RESULTS

Figure 3 shows the results obtained in the tests in terms of load repetitions versus vertical displacements of the loading plate for a vertical stress on the plate equal to 560 kPa. As mentioned earlier, the tests were interrupted when the loading plate reached a vertical displacement of 25 mm. It can be noted that the number of load repetitions (*N*) in reinforced tests was considerably larger than that obtained in the unreinforced (reference) situation. Regarding the reinforced beams, the best performance was achieved with the use of reinforcement G4, whereas the poorest was noted with the use of reinforcement G1 (geocomposite). Despite the poorest performance of the latter, it still increased the number of load repetitions by a factor of 5. In addition, in a real pavement reinforcement G1 would also act as a barrier, avoiding the passage of fines from the pavement base through the cracks in the asphalt caps, a capability not provided by the other reinforcements tested.

Figure 4 shows images at the end of the test without reinforcement and of the test reinforced with reinforcement G1. It can be noted that after the fatigue of the lower layer the vertical displacements of the loading plate were predominantly a consequence of punching failure of the overlay. Exhumation of the reinforcement was tried after the end of the test with G1, but that was not possible because of the great adherence between the reinforcement and the asphalt concrete layers. Low adherence with the asphalt layers was noted for reinforcement G2. This was a consequence of the smooth nature of the surface of the steel wires of the mesh. Reinforcements G3 and G4 showed the best performance. From images taken during these tests it was noticed that the initial crack in the lower beam had its length increased upwards until reaching the reinforcement layer. Further loading plate vertical displacements were mainly a consequence of the punching failure of the upper beam (Fig. 4) with some crack reflection in this layer. However, the presence of reinforcements G3 and G4 delayed quite considerably the failure mechanisms and crack reflection developed in the beams.

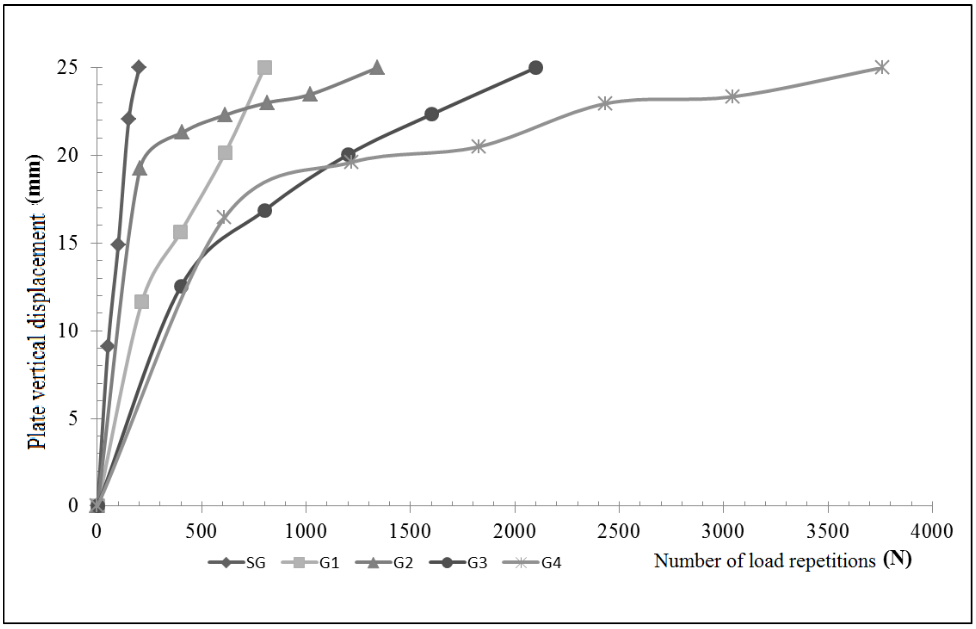


Figure 3: Results of plate vertical displacement versus number of load repetitions (vertical stress of 560 kPa).

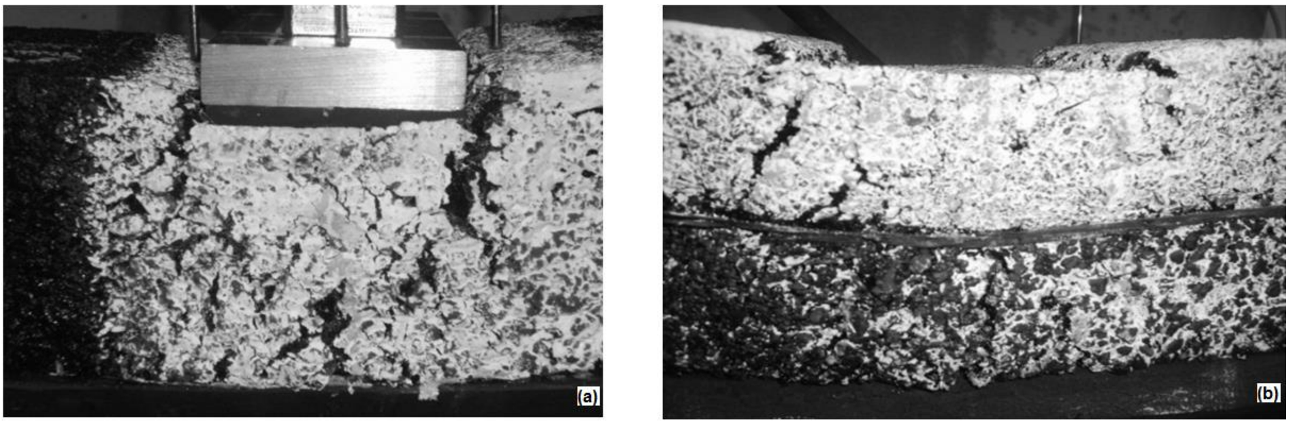
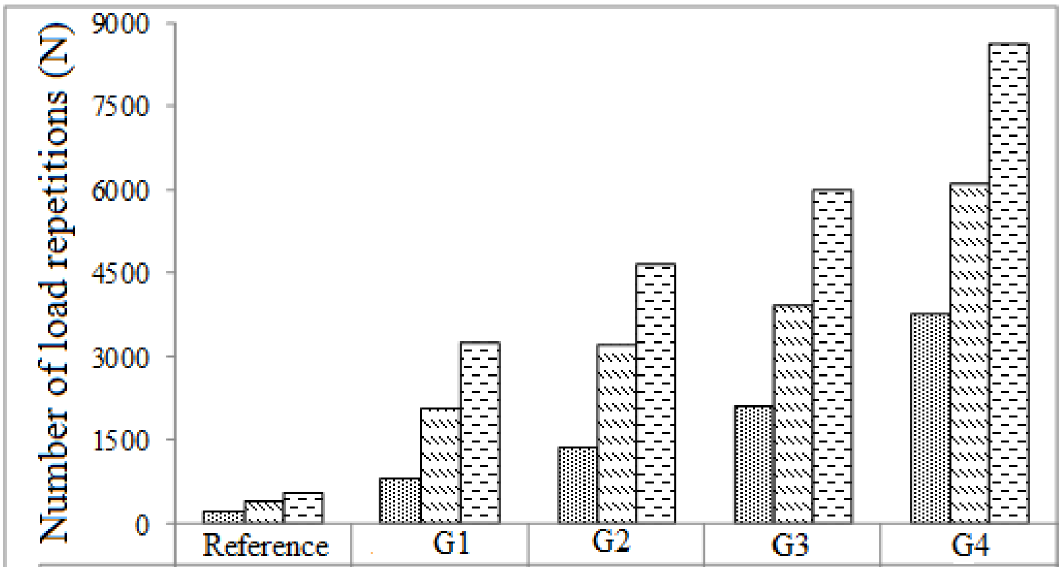


Figure 4. Images of tests without and with reinforcement: (a) unreinforced test; (b) reinforced with G1.

It is interesting to note in Figure 3 a change of pattern of the curves relating plate vertical displacements against number of load repetitions for values of *N* between 200 and 600, depending on the reinforcement considered. The analysis of the images taken during the tests showed that this change of pattern coincided with the development further cracking to the initial crack made in the lower beam prior to testing. For reinforcement layers G1 and G2 the change of pattern of the curves took place at values of *N* close to that obtained at the end of the test on the unreinforced beam. This may be associated with the lower tensile stiffness of G1 and poorer adherence of G2 with the asphalt concrete.

Figure 5 presents the numbers of load repetitions (*N*) in each test for a loading plate vertical displacement of 25 mm for different values of plate vertical stress (350 kPa, 450 kPa and 560 kPa). As expected, the greater the vertical stress the lower the value of *N*. The presence of reinforcement G1 increased approximately by 5 times the value of *N* in comparison to that value for unreinforced beam. The beam reinforced with G2 resisted 8 times more load repetitions than the unreinforced beam, whereas the beams reinforced with G3 and G4 resisted 10 and 15 times more load repetitions than the unreinforced beam, respectively.



	Reference	G1	G2	G3	G4
560 kPa	200	800	1343	2100	3759
450 kPa	400	2049	3200	3900	6100
350 kPa	551	3245	4650	6001	8625

Figure 5. Values of *N* for a loading plate displacement of 25 mm.

4. CONCLUSIONS

This paper described and discussed the results of loading tests on overlays on cracked asphalt layers with and without geosynthetic reinforcement. The main conclusions of the work are summarised as follows:

- All reinforcements tested increased the number of load repetitions resisted by the asphalt concrete beams and reduced crack reflection. The increase in the number of load repetitions with regard to the unreinforced situation varied between 5 and 15 times, depending on the reinforcement considered. The best performance was obtained in the test with reinforcement G4.

- The best adherence between reinforcement and asphalt concrete layer was observed for reinforcement G1. That was because of the asphalt coating of this type of product.

- The steel wire mesh used as reinforcement, despite increasing the number of load repetitions with regard to the unreinforced case, showed poor adherence with the asphalt concrete.

5. REFERENCES

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