Experimental evaluation of a polyester geogrid as anti-reflective cracking interlayer on overlays

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ABSTRACT: Dynamic fatigue test results are presented as part of a laboratory study for evaluation of the effect of a geogrid as an interlayer reinforcement between a cracked asphalt concrete layer and a non cracked one. Tests were performed with and without the grid, in order to ascertain its effects on crack control for both bending and shearing modes of loading. Prismatic beams supported by an elastic base were tested in a MTS equipment, at a loading frequency of 20 Hz. Significant increases in the design life due to reflective cracking and a different pattern of cracking were observed with the inclusion of the polyester geogrid used in the research, which indicates a remarkable reinforcing effect and a clear redistribution of stresses and dissipated energy.

1 INTRODUCTION

The rehabilitation of cracked pavements by placing over it a new asphalt concrete (AC) layer must be properly designed against the reflective cracking phenomenon. If the interface conditions between the new AC layer and the cracked pavement are not considered on design, stress concentrations at the crack tips may lead to a fast cracking of the new AC layer.

In order to study this phenomenon, dynamic supported flexure tests were performed. Supported flexure is able to more reliably duplicate in-situ stress and mode-of-loading conditions. Several researchers have used circular slab specimens supported on a rubber mat (Majidzadeh et al., 1971). A circular shaped repeated load is applied to the center of the slab resulting in a stress state in the slab which is very similar to that occurring in the pavement structure. Additionally, beam fatigue tests were used by Barksdale (1977) to evaluate the fatigue characteristics of asphalt-concrete bases. In his methodology, asphalt-concrete beams were placed on a rubber mat to simulate the field support conditions.

2 FATIGUE TEST

Pavement structures are subjected to two types of mechanical solicitations: thermal and traffic loading. Critical solicitations due to traffic loading are shown in Figure 1(bending mode of traffic load, Fig. 1b, and the shearing mode, Figs. 1a, 1c). This situation occurs during a wheel load passage at a discontinuity in the old pavement surfacing layer.

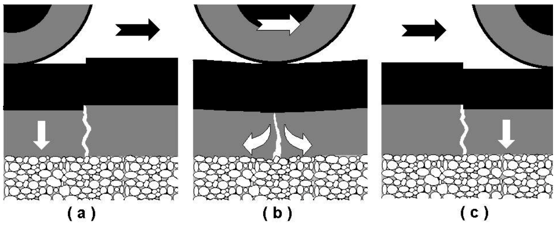

Figure 1- Critical load solicitations in a pavement

Prismatic beams supported on an elastic base were employed, with tests conducted at a sinusoidal load pulse and frequency of 20 Hz on a MTS equipment (Fig. 2).

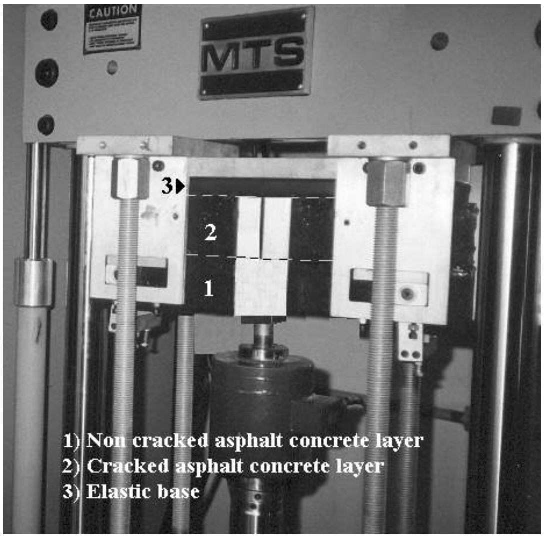

Figure 2 – Fatigue Test with MTS equipment.

The reinforced and unreinforced asphalt concrete test specimens were prepared with dimensions of 460 x 150 x 75 mm. The lower part of the beam had a crack with an opening of 3 mm (layer 2, Fig. 3). The geogrid was placed inside the overlay (layer 1, Fig. 3), 2 cm above the crack tip. The geogrid used as reinforcement was Hatelit® C 40/17, made of high tenacity polyester filaments with bituminous coating, with a mesh size of 40 x 40 mm and nominal tensile strength of 50 kN/m @ 12% strain.

Two series of tests were performed, one for each critical wheel load position in relation to the crack location on the cracked layer (Fig. 3). The cyclic loads were applied until failure of the overlay. Failure was defined as the moment when the crack reached the overlay surface. When the crack did not reach the overlay surface, failure was defined by the presence of visible cracks and a permanent deformation of 2.5 mm under the loaded area. Applied cyclic load level were 1.68, 1.3 and 1 kN (peak to peak) with corresponding vertical contact pressure of 549, 424.5 and 326.5 kN/m^2.

Advantages of this methodology include:

(a) Better simulation of field conditions is possible.
(b) The test offers a convenient means for examining modes of loading.
(c) Support of specimen is expected to reduce the effects of minor imperfections in the specimens and, hence, reduce the scatter of test results.
(d) The test methodology analyses both fracture and fatigue .
(e) The results can be used to evaluate the effects of bending and shearing loads on the design of pavements to control overlay fatigue cracking.

Disadvantages of methodology include:

(a) For beam specimens, the state of stress is predominantly biaxial.
(b) The test is more time consuming than many other fatigue tests.

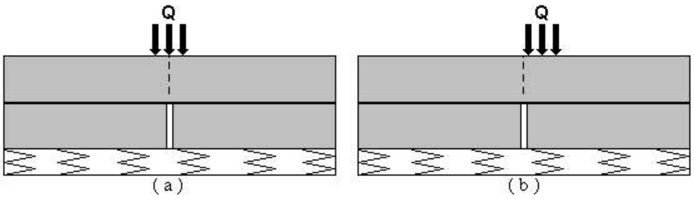

Figure 3 - Position of the loads in the tests. (a) Bending mode, (b) Shearing mode.

3 TEST RESULT

Fatigue tests were performed for the asphalt concrete overlay placed directly over the cracked layer and for the asphalt overlay with anti-reflective cracking system comprised of the geogrid placed over a leveling asphalt concrete interlayer 2 cm thick. Visual observations were made and the number of cycles until failure was measured.

3.1 Visual observation

The following visual observation, comparing beams with and without geogrid, were done:

- In the beams without geogrid, a dominating reflective crack appeared in the overlay and grew vertically upwards (Fig. 4). The cracking in the overlay started earlier and its propagation rate was faster. The tests stopped when the crack reached the overlay surface, breaking the specimen in two pieces.
- In the beams with geogrid, the upward movement was intercepted when the crack reached the geogrid, leading to a new cracking pattern comprised by a series of micro-cracks (Fig. 5, 6 and 7). No major reflection cracking was observed above the geogrid. The tests stopped when a plastic deformation of 2.5 mm under the loaded area was observed, since no crack reached the surface (except the shearing mode test at 549 kN/m^2 contact pressure – Fig. 7).
- In the shearing mode test at higher contact pressure – 549 kN/m^2 – with geogrid (Fig. 7), a lean crack was observed in the edge of the load appliance rigid plate. This is not a reflection crack; it was probably originated by a puncture of the rigid plate on the asphalt surface. Anyway, the test was interrupted when this crack appeared.

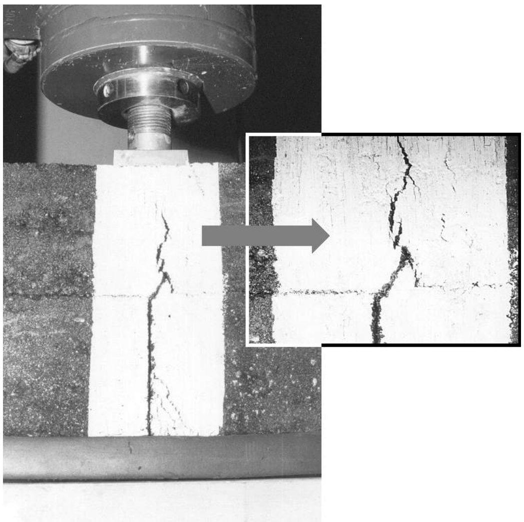

Figure 4 – Crack propagation without geogrid

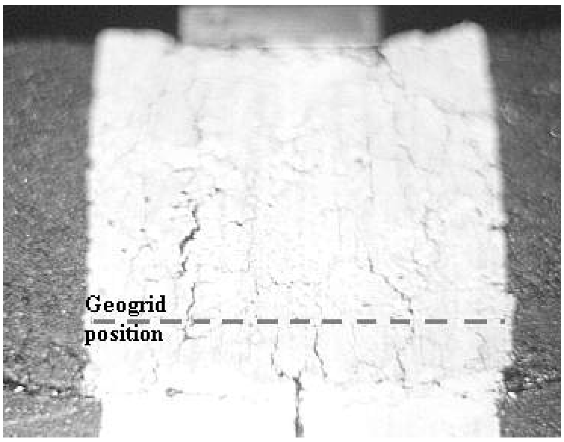

Figure 5 – Beam with geogrid in bending mode

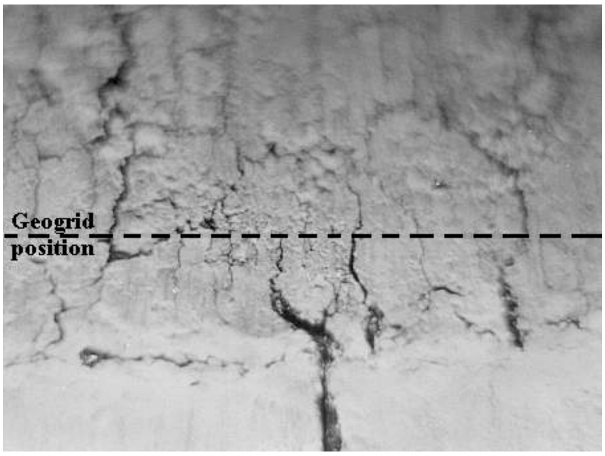

Figure 6 – In bending mode microcracking with geogrid was observed in final stage of the test.

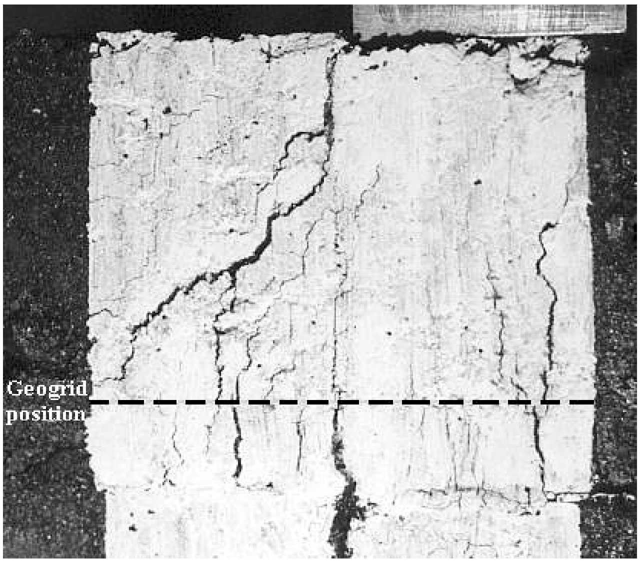

Figure 7 – Beam with geogrid in shearing mode in final stage of the test.

3.2 Numerical results

The fatigue curves for beams with and without geogrid at different loading levels, considering Shearing and Bending modes, can be seen in Figure 8. An effectiveness factor of geogrid (FEG), was calculated as shown on Tables 1, 2 and 3.
This factor is given by: $FEG = N_{f(Geogrid)} / N_{f(Unreinforced)}$ with the fatigue life in each case being calculated as:

$$N_f = \frac{1}{c_f}$$

were c_f , is the fatigue consumption produced by a single wheel load coverage, calculated as:

$$c_{f_1} = \frac{1}{N_{f(B)}} + \frac{2}{N_{f(S)}}$$

where $N_{f(B)}$ = fatigue life in the bending mode and $N_{f(S)}$ = fatigue life in the shearing mode.

The calculated values of FEG were 2.61, 3.79 and 3.61 for contact stresses of 549 kN/m^2, 424.5 kN/m^2 and 326.5 kN/m^2, respectively. It should be pointed out that the values obtained for 549 kN/m^2 might be influenced by the superficial puncturing effect of the rigid plate with sharp edges into the AC (Fig. 7). Additional tests shall be performed with a softer contact between plate and AC in order to avoid this effect. Also, the FEG values certainly would be greater if we could accept plastic deformation greater than 2.5 mm.

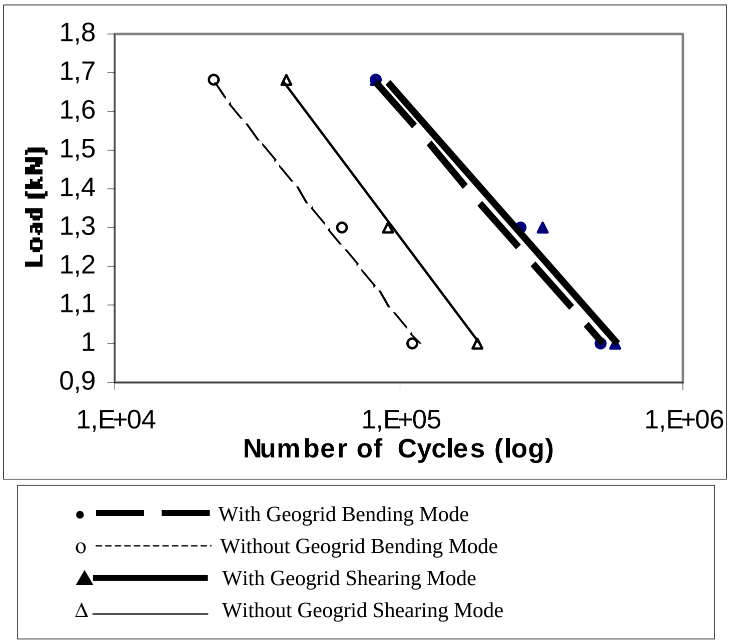

Figure 8 – Fatigue curves.

Table 1 – Effectiveness factor for 549 kN/m^2 (load 1.68 kN)

Beam	$N_{f(F)}$	$N_{f(C)}$	C_{f1}	N_f
Without Geogrid	22350	40270	9.44×10^{-5}	1.10×10^{4}
With Geogrid	83520	82790	3.61×10^{-5}	2.76×10^{4}

[$N_{f(Geogrid)} / N_{f(Conventional)}$] EFFICIENCY OF GEOGRID = 2.61

Table 2 – Effectiveness factor for 424.5 kN/m^2 (load 1.3 kN)

Beam	$N_{f(F)}$	$N_{f(C)}$	C_{f1}	N_f
Without Geogrid	63650	91250	3.76×10^{-5}	2.65×10^{4}
With Geogrid	266780	322740	9.94×10^{-6}	1.00×10^{5}

[$N_{f(Geogrid)} / N_{f(Conventional)}$] EFFICIENCY OF GEOGRID = 3.79

Table 3 – Effectiveness factor for 326.5 kN/m^2 (load 1.0 kN)

Beam	$N_{f(F)}$	$N_{f(C)}$	C_{f1}	N_f
Without Geogrid	111470	187610	1.96×10^{-5}	5.10×10^{4}
With Geogrid	512910	574350	5.43×10^{-6}	1.84×10^{4}

[$N_{f(Geogrid)} / N_{f(Conventional)}$] EFFICIENCY OF GEOGRID = 3.61

4 PRELIMINARY ANALISYS

Fracture mechanics uses the Stress Intensity Factor (K) as the controlling parameter for fatigue crack progression. Its use with Paris's law has been demonstrated by several studies to be applicable to asphalt concrete mixes. However, its validity requires the existence of a sharp crack which is able to dominate the process, monopolizing the dissipation of energy at its crack tip. With the geogrid tested here, several microcracks appeared instead of a single dominating crack (Fig. 9). This must be the consequence of a redistribution of the dissipated energy over a larger volume in the asphalt concrete mix. A major portion of these microcracks had their progression arrested at a certain point due to the crack geometry developed, while other microcracks could reach the layer surface. The severity of these last ones was, however, lower than that of the single dominating crack in the case where the geogrid was not present, implying in a better expected behavior for the asphalt concrete layer.

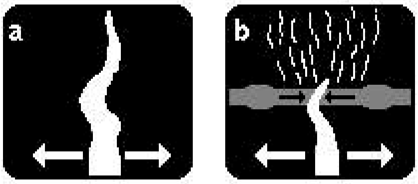

Figure 9 – Crack tip in both cases.

Cai and Horii (1994), proposed a method in order to evaluate the effective deformation properties of a solid with a high crack density. The contribution of each crack is added up and the overall modulus is evaluated. The stress-strain relationship for orthotropic material is expressed with four parameters as

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{Bmatrix} = \begin{bmatrix} 1/E_1 & -\nu/E_1 & 0 \\ -\nu/E_1 & 1/E_2 & 0 \\ 0 & 0 & 1/G \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \end{Bmatrix}$$

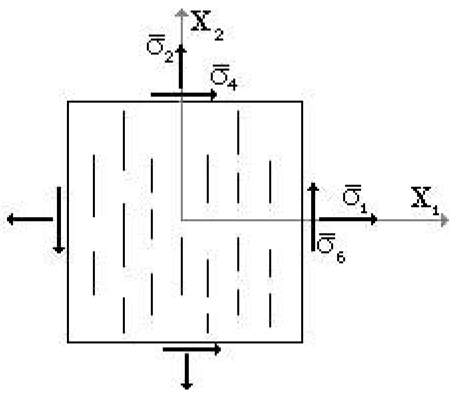

Figure 10 – Unidirectional distribution of slit cracks.

For the single crack embedded in a solid $E_1 = E$, $E_2 = \overline{E}$ and $G = \overline{G}$, where $\overline{E}$, $\overline{G}$ are the effective moduli given by

$$\overline{E} = \left(\frac{1}{1+2\omega} \right) E$$

$$\overline{G} = \left(\frac{1+\nu}{1+\nu+\omega} \right) G$$

where $\omega = \pi N a^2$, (N is the number of cracks per unit volume and a is the half length of the crack). The displacement jumps are calculated by

$$[u_1] = \frac{2\sqrt{2}}{E} \sqrt{\left(\sqrt{\frac{E}{\overline{E}}} + \frac{E}{2\overline{G}} - \nu \right) (a^2 - x^2)} \, \overline{\sigma_6}$$

$$[u_2] = \frac{2\sqrt{2}}{\sqrt{E\overline{E}}} \sqrt{\left(\sqrt{\frac{E}{\overline{E}}} + \frac{E}{2\overline{G}} - \nu \right) (a^2 - x^2)} \, \overline{\sigma_2}$$

These equations will help to develop a performance prediction model that can be employed for overlay design in the case of use of such anti-reflective cracking system. Another objective of this research is to point to the practical situations where the use of the tested geogrid merits attention from an economic point of view.

5 FINAL COMMENTS

Figure 8 shows that the presence of the polyester geogrid had the effect of drastically reducing the influence of the load position on the fatigue life. This is in agreement with the hypothesis that the geogrid redistributed the stresses and strains in the overlay, possibly reducing the distortion energy density (associated with shear stresses) and making the performance of the overlay less dependent upon support conditions. It can be expected, therefore, that the anti-reflective cracking system here studied would be effective also in cases where the existing pavement is severely cracked, to the point where a major pavement reconstruction would be otherwise required.

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