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Reflective Cracking in Asphalt Overlays Reinforced with Geotextiles

Paulina Leiva-Padilla, Luis Loria-Salazar, Jose Aguiar-Moya and Fabricio Leiva-Villacorta

Abstract The use of overlays in pavement rehabilitation is one of the most common techniques in pavement management systems. It can be used when a pavement structure is still in adequate structural condition and the observable distresses can be corrected, ensuring that pavement condition can be maintained for an additional service period. The main issue related to the performance of this technique is the reflection of existing cracks. In order to delay the propagation process, interlayer systems can be used (e.g. geosynthetics). Although research on this area has been conducted previously, it is still necessary to better understand the mechanical behavior of the hybrid system to improve the efficiency of its performance. The following paper shows the results obtained from the measurements and modeling based on core samples extracted from an experimental test section built using geotextiles as an interlayer system prior to overlaying. The samples were evaluated in the laboratory by means of the Overlay Tester. The fracture mechanics and viscoelasticity properties were determined from Indirect Traction Tests, in order to define the Cohesive Zone Model (damage), and Dynamic Modulus Tests (viscoelastic Prony Series parameters). The results helped describe the mechanical behavior associated with the reduction in the reflective cracking process when geotextile materials are used as interlayer system: (i) increase in fatigue life (up to 260 %, due to the energy dissipation capabilities of the material), and (ii) crack propagation trend (which generally follows geotextile-asphalt layer interface, and depends on the amount of binder content, testing conditions and existing material).

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1 Introduction and Motivation

Since 1982, during the "Resurfacing Portland Cement Concrete Pavements" symposium organized by the Highway Research Board (Sherman 1982), reflective cracking was recognized one of the most influent factors affecting the effectiveness of asphalt mix overlay systems.

This process is associated with the propagation of cracks from the existent asphalt layer to the constructed overlay, as a result of traffic loading and environmental changes.

According to Marchand and Goacolou (1982) crack propagation in overlay systems is dependent upon the direction of crack growth (vertical or horizontal) and the bound material. Based on the previous two types of cracked structures can be defined: bonded interface and debonded interface (with centered or displaced crack).

Although the use of geosynthetics is one of the most common techniques used to delay crack propagation between an existing and a new layer, there is no unified criteria for the design and the construction. The previous confirms the need for further research in this area.

The following paper shows results obtained from cores evaluated using the Texas Overlay test [OT, (Ma 2014)], proposed by Claros and Lytton in 1970 (Lytton 1989; Zhou 2007). The cores were extracted from a rehabilitated pavement section that incorporated the use of geotextiles. Additionally, asphalt mixture properties were characterized in the laboratory based on the dynamic modulus test, indirect tensile test and in field with a falling weight deflectometer (FWD). The geotextile properties were obtained based on a tensile test.

Based on the measured material properties, a finite element model of the OT sample was developed to study the mechanical performance of the geosynthetic in the overlay systems.

2 Dissipated Energy Theory

The dissipated energy concept started to be used in 1975, after Van Dijk proposed a mathematical relationship between accumulated energy and failure condition. This unique relationship does not depend on loading mode, stresses level, frequency or resting period (Ma 2014).

In dynamic loading tests, dissipated energy (DE) can be computed as the integral of the curve stress-strain (Eq. 1). In linear-elastic range, these curves are constant, because the material do not dissipate energy; however, outside of this range, the curves are hysteretic cycles, and the area within the curve corresponds to the dissipated energy that is transferred as heat or damage (Shen and Carpenter 2007).

$$DE = \pi \sigma_i \varepsilon_i sen\phi_i \quad (1)$$

where, σ_i: stress at cycle i, ε_i: strain at cycle i, and ϕ_i: phase angle from stress and strain during the ith cycle.

In 2000, Ghuzlan and Carpenter proposed the use of dissipated energy ratio (RDEC) to analyze damage and performance in asphalt mixtures. RDEC is the ratio between the change in dissipated energy from cycle i to cycle $i + 1$ (ΔDE) and dissipated energy up to cycle i (DE in i cycle) (Eq. 2) Ghuzlan and Carpenter (2000).

$$RDEC_a = \frac{DE_a - DE_b}{DE_a * (b - a)} \quad (2)$$

where, $RDEC_a$: average energy ratio during cycle a, and; DE_a, DE_b: dissipated energy in cycle a and b.

During testing, RDEC decreases up to a constant Plateau Value (PV, Eq. 3), because of the micro-structural realignment of the material. Once the material fails (with failure defined as a 50 % reduction in stiffness), the PV increases.

$$PV = \left[1 - \left(1 + 100/N_{f,50}\right)^f\right]/100 \quad (3)$$

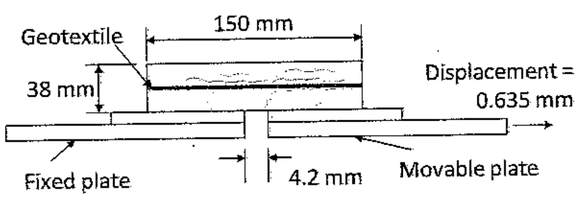
where, $N_{f,50}$: number of cycles to 50 % reduction in stiffness; and, f: slope from linear relationship between DE and number of cycles over $N_{f,50}$.

2.1 Texas Overlay Test

The first OT was designed in 1970 by Claros and Lytton. The system consists in gluing a sample (obtained from a 150 mm diameter core with a height of 62 mm) to two steel plates separated by a 2 mm gap as shown in Fig. 1. A constant displacement of 6.35 mm is applied to simulate the opening and closing of cracks.

During testing, three phases of cracking are identified (Zhou and Scullion 2003): (i) Phase 1—Crack initiation and early propagation: During this phase, load and displacement have similar shapes; as maximum displacement is reached, load increases too, (ii) Phase II—Late crack propagation: After the maximum load, crack starts to propagate and load decreases, load and displacement are still in the same

Fig. 1 Overlay test system



phase; and (iii) Phase III—Specimen Failure: In this phase the crack extends to the top of the specimen. The amount of load remaining is associated with the minor adhesion.

Based onTex-248-F testing protocol, failure criteria occurs when a 93 % reduction in the load is achieved (moment where the crack is expected to have traveled thru the full thickness of the specimen).

Ma (2014) proposes the use of ASTM D7460 (Standard Test Method for Determining Fatigue Failure of Compacted Asphalt Concrete Subjected to Repeated Flexural Bending), to analyze fatigue failure. ASTM D7406 defines fatigue failure as the maximum point of the normalized load curve (NLC, Eq. 4) as a function of the number of cycles.

$$NLC_i = P_i N_i P \tag{4}$$

where, NCL_i: normalized load at cycle i, P: maximum load after first cycle, N_i: cycle i, and P_i: maximum load at cycle i.

3 Test Methods

The study consisted of testing and simulating the reflective cracking phenomenon in the OT device under testing protocol Tex-248-F.

Nine cores were extracted from a section of an overlay rehabilitated project where 50 mm of the existent asphalt layer was milled, a nonwoven geotextile was placed as interlayer system, followed by a 50 mm of asphalt mixture overlay. The existing pavement structure was as follows: 80 mm asphalt layer, 100 mm granular base, 150 mm granular subbase over a subgrade soil.

The mechanical properties of the existing materials were described from FWD backcalculation (Table 1). Additional testing was performed on the overlay asphalt mixture: dynamic modulus testing to describe mixture modulus, indirect tensile tests to define CZM (Cohesive Zone Model) properties of the asphalt mixture and traction GRAB tests (ASTM D4632) to compute geotextile modulus.

Using the previous results and geometry dimensions of the OT, a tridimensional finite element model was built. The model consists of 128,336 elements and 69,428 nodes. A displacement of 0.635 mm is applied to the movable face, as shown in Fig. 2.

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Table 1 Material mechanical characterization properties

Material	Material type	Test	Property	
Existent asphalt mixture	Lineal elastic	FWD	Elastic modulus = 2722 MPa (25 °C)	
New asphalt mixture	Viscoelastic	Dynamic modulus	$\tau_{relaxation}$(s)	Prony parameters, Ei (MPa)
			1.00E − 06	2.01E + 00
			1.00E − 05	8.20E + 01
			1.00E − 04	1.04E + 03
			1.00E − 03	2.72E + 03
			1.00E − 02	3.19E + 03
			1.00E − 01	2.97E + 03
			1.00E + 00	4.18E + 03
			1.00E + 02	1.51E + 03
			1.00E + 03	3.41E + 02
			1.00E + 04	2.33E + 02
			1.00E + 05	9.34E + 01
New asphalt mixture	Cohesive zone	Indirect tensile	Elastic modulus = 2722 MPa (25 °C) Max principal stress = 1.3 MPa Displacement at failure = 0.0209	
Nonwoven geotextile	Linear elastic	Traction GRAB	Tension GRAB = 0.9 kN εlong = 0.7 mm/mm Elastic modulus = 184 MPa	

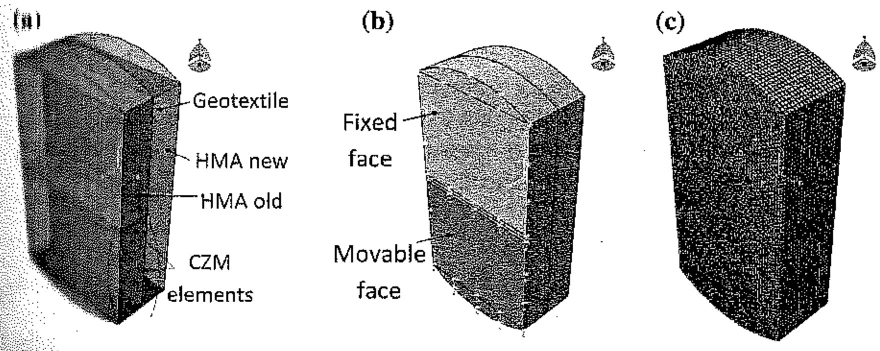

Fig. 2 OT sample finite element model

4 Results

Based on the dissipated energy concept, fatigue performance was analyzed based on the OT. Figure 3a shows how the dissipated energy drops with the number of cycles because of loss of capacity in the material.

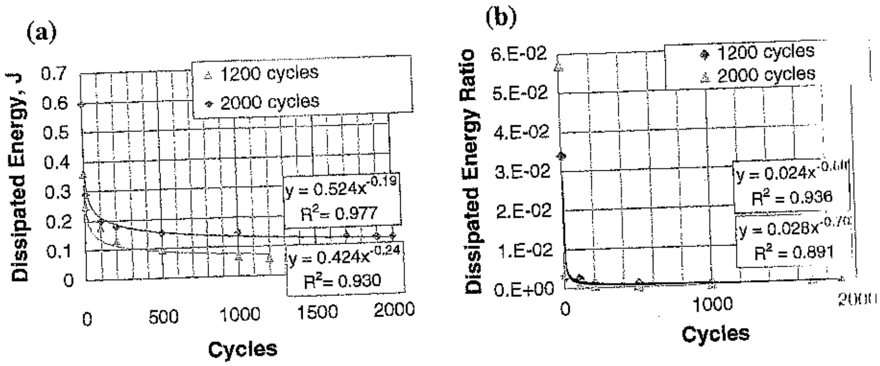

Fig. 3 Overlay tester results **a** dissipated energy and **b** dissipated energy ratio

Additionally, from the RDEC plot shown in Fig. 3b, it is evident that complete failure does not occur during testing. However, the PV is near to zero, which implies a lower damage per cycle and longer fatigue life (Vargas-Nordcbeck et al. 2014; Prowell et al. 2010; Shen and Carpenter 2007).

According to Ma (2014), rich bottom asphalt mixtures require approximately 750 cycles to fail in the OT. Consequently the analyzed specimens have a remaining life of over 260 % prior to reaching failure. This could be associated to the energy absorption by the geotextile.

As a second step, the OT finite element model was developed. Material properties and used geometry are as described in Table 1 and Fig. 2.

Results obtained shows concentration of tensile stresses at the interface between the new and the existent asphalt mix layer (Fig. 4a), causing a gradual loss of the bond capacity between the geotextile and the existent layer. The previous reflects what was observed on laboratory samples (Fig. 4c). The gradual loss of bond capacity generates stretching and higher tensile stresses in the geotextile (Fig. 4b), reducing the tensile stressed that is transmitted to the upper layer, and therefore delaying the development of the reflective cracking mechanism.

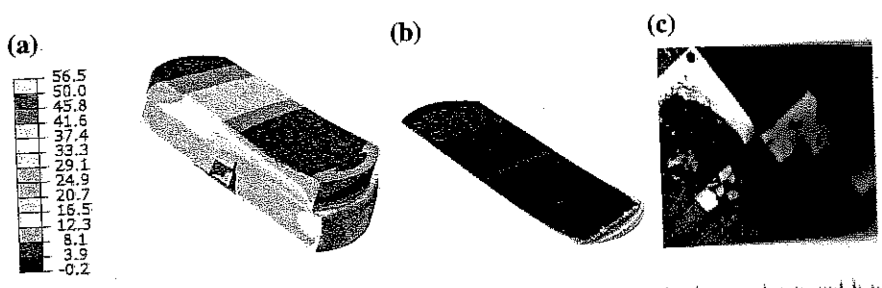

Fig. 4 Finite element modeling results. Maximum principal stresses **a** in the specimen and **b** in the geotextile. **c** Failed OT specimen

5 Conclusions and Recommendations

The main conclusions derived from this study are the following:

- In overlay systems reinforced with geotextile and tested in the OT, crack progression follows the geosynthetic-existent asphalt layer interface. This can be attributed to mechanical work by the geotextile.
- It is important to standardize an adequate correct construction practice to guarantee the adequate functionality of the geotextile: appropriate adhesion between layers and application rate of the bond coats.
- Finite element modeling was able to describe the mechanical performance of the system when geosynthetic are used, showing it could be better to change the settings of the normal test to obtain better results.
- Placing a geosynthetic material in overlay systems improved the overall fatigue resistance in the laboratory. However it is still necessary to transfer the results to field conditions, in order to developed shift or calibration factors to predict structural performance.
- The dissipated energy approach is an useful tool to study fatigue phenomenon in asphalt mixtures. It is recommended to extend the study in order to reach total failure of the system.

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