The effects of geogrid on reduction of reflection cracking in asphalt overlay

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ABSTRACT: An experimental study on the use of geosynthetic in asphaltic resurfacing of fractured pavements is presented in this article. In the current investigation, an attempt was made to better understand the physical mechanisms associated with geosynthetic reinforced AC overlays. The objectives of this study were to assess the effects of geosynthetics inclusion and its placement location for retarding reflection crack. This study revealed that geosynthetic reinforced specimens improved resistance to reflection cracking. Placing the geogrid at the one third depth of overlay thickness from bottom provided the maximum service life. Results indicate a significant reduction in the rate of crack propagation in reinforced samples compared to unreinforced samples.

1 INTRODUCTION

Asphaltic resurfacing is a way of rehabilitating deteriorated and fractured roads, providing a partial solution based mainly on economic considerations. Nevertheless, this solution is restrained, among other secondary factors, by the premature emergence of cracks on the new layer surface, as a consequence of reflection cracking from the original pavement.

One of the more serious problems associated with the use of thin overlays is reflective cracking. This phenomenon is commonly defined as the propagation of cracks due to the movement of the underlying pavement or base course into and through the new overlay as a result of load-induced and/or temperature-induced stresses (Cleveland et al. 2002).

The reflection crack has two major driving forces: (1) the applied external wheel load contributes to high stress and strain levels in the overlay above the existing crack. The discontinuity in the existing pavement reduces the bending stiffness of the rehabilitated pavement section and creates a stress concentration. When conditions are such that the stress state exceeds the fracture resistance of the overlay, a reflective crack can be initiated and / or propagated. A combination of mode I (opening) and mode II (shearing) stress leads to crack propagation through the overlay (De bondt 1998), (2) another force driving reflective cracking involves daily temperature variations and resulting thermal contractions. Furthermore, the contraction of the discontinuous underlying pavement leads to additional concentrated tensile stresses in the overlay above the existing crack or joint. This phenomenon is almost exclusively linked to the pure mode I crack opening mechanism (Kim & Buttlar 2002).

No solution for completely preventing these cracks propagation has been suggested yet, because of a number of variables involved in the nature of reflection cracking. Only retardation of crack progress is the best solution strategy adopted so far. Inclusion of geosynthetic interlayer may enhance the resistance to reflection cracking either by a stress-relief or a reinforcement mechanism, or by a combination of both.

2 BRIEF REVIEW

During the past decade or so, various researchers have proposed solution to retard reflection cracking based on field, laboratory and numerical investigation (Jayawickrama & Lytton 1987). The field performance of geogrid- reinforced overlay was varied because it depends on construction procedures, position of geogrid, interfacial treatment between layers, and weather conditions (Kuo & Hsu 2003).

In 1999, Kim et al. conducted lab test to study mode I reflection cracking in asphalt overlay with polymer- modified asphalt mixture and Glass Grid or polypropylene film. To simulate an asphalt pavement overlaid on top of a crack in concrete pavement, an asphalt mixture specimen was placed on top of two discontinuous concrete blocks. Their result showed that when modified asphalt mixture was reinforced with the glass grid at the bottom of the asphalt layer, its fatigue life increased by a factor of 16.7. Brown et al. (1989), Chang et al. (1998) and Sobhan et al. (2005) placed asphalt beam specimens on two pieces of plywood that had a 10 mm gap at center to simulate an existing joint or crack underneath the overlay, with the whole system placed on a rubber base representing the soil foundation. Reddy et al. (1999) studied the propagation of reflection cracks by placing asphalt beam specimens on small concrete blocks (at different gap intervals) simulating the broken PCC resting on an elastic foundation prepared with compression springs. Goulias and Ishai (1999) used a wheel-tracking device to test an overlay with a pre- sawn crack or notch underneath the specimens.

The studies described below were based on finite element analyses to simulate crack propagation in asphalt overlay. The cracking mechanism and growth inspired plenty of studies in order to remedy the problem. Rigo et al. (1993) utilized a two–dimensional (2-D) finite element program to model overlay pavement subjected to truck wheels and temperature variation. The cracks were traced by iterative FEM analysis by removing the elements of maximum stress. Castell et al. (2000) predicted crack growth rate with maximum strains and found bottom –up cracking is more likely to be found than top-down cracking. Thick overlay was once considered to prevent bottom-up reflective cracks. Yet, Uhlmeyer et al. (2000) investigated thick overlay and found crack starting at surface and propagate down ward. Sha (1993) also noticed top-down reflection cracking happened for thick overlay according to field observation in China. Kuo and Hsu (2003) used the ABAQUS finite element program to model geogrid- reinforced asphalt overlay on the old PCC pavement with joint/crack. Old pavement support was modeled with continues springs as Winkler foundation. They concluded that placing the geogrid at one third depth of asphalt overlay thickness from bottom had the minimum tensile strain above geogrid compared to the specimens with geogrid placed at the bottom or in the middle of asphalt overlay.

In present study, a laboratory experiment program and detailed analysis were employed. The primary objectives of the experimental phase were as follows: (I) to study the effects of placement of geosynthetic in overlay under the condition of mode I (bending) on the growth and propagation of reflection crack, (II) to quantify the effectiveness of geosynthetics in retarding reflection cracking in asphalt overlay with different gap interval of old pavement. In the course of study, an experimental technique was developed for mode I fracture testing using a servo hydraulic dynamic testing machine. This paper presents the methodology and some of significant result obtained from the work.

3 Experimental program

3.1 *Test set up*

The current study evaluated different test configurations based on Kim et al. 1999), Brown et al. (1989) and Sobhan et al. (2005) research and developed a set up shown schematically in Fog: 1. Also ratios of loading plate dimensions and pressure on top pf the specimen to that of the specimen were similar to Kim et al. (1999), Youngqi Li et al. (2002) and Sobhan et al. (2005). Before choosing these dimensions for the samples, numerical study with ANSYS.10 was also performed and the results showed the size effects are in-significant and negligible for these dimensions of the samples. This study consist of the following major components representing a layered pavement structure: (a) an asphalt overlay $380mm^{L} \times 150mm^{W} \times 75mm^{H}$, which may be unreinforced or reinforced in any depth, (b) a block of concrete, simulated discontinuous existing pavement (depth 100 mm) and (c) a resilient subgrade modeled with neoprene rubber with elastic modulus of 11 Mpa.

Simulated-repeated loading was applied to the specimens using a hydraulic dynamic loading frame. Cyclic square loads were applied to the top centre of the beam through a circular loading plate (112 mm diameter) with frequency of 10 Hz. A maximum load of 6.79 kN was applied to the specimen to create 690 kPa or 100 psi pressure on top of the specimen. A 0.196 kN (20 kg) minimum load was used to keep the loading plate in place during dynamic loading. UTM servo-hydraulic machine with computerized test control and data acquisition system was used for conducting the experimental program. The specimens were tested at 20°C. Before the specimens were tested, they were kept in a temperature chamber at the desired temperature for 2 hours.

3.2 *Materials Used*

The AC used in this study to represent the overlay is made of coarse aggregate, and asphalt binder. The grading of mix aggregate with the specification limits given by Iran Highway Asphalt Paving Code (2003) is plotted in Fig. 2, with the specification requirements. Bitumen, AC 60-70 (that corresponds to PG 64-16), the most widely used in Iran, was used as binder for mixture preparation. The optimum asphalt binder content was 5.2% by weight of hot mix asphalt for each specimen.

The coarse aggregate used in the existing concrete pavement was natural gravel with a maximum size of 19 mm and a specific gravity of 2.58. The coarse and fine aggregate gradations met the BS 882 (BSI, 1973). The elastic modulus and compressive strengths for concrete specimens were 2.85×10^7 kN/m^2 and 343×10^2 kN/m^2, respectively.

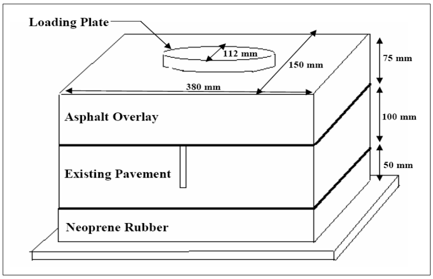

Figure 1. Schematic of test set up

3.3 *Material and property of grid*

The geogrid used was one of the most frequently available and deployed in the country that was 100% polyster with tensile strength of 50 kN/m and 12% strain in machine direction and 14% strain in cross machine direction and its mass per unit area was 240 g/m^2. Grid size was 40 mm × 40 mm.

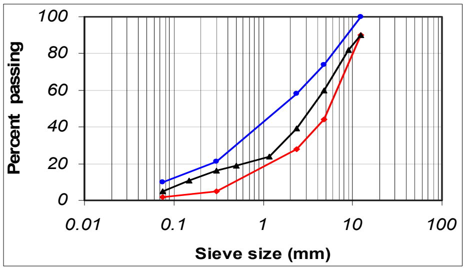

Figure 2. Aggregate gradation used in asphalt concrete

3.4 *Specimen Preparation and Placement Configuration*

To simulate an asphalt overlay on top of a crack in concrete pavement, an asphalt mixture specimen was placed on top of two discontinuous concrete blocks with 100 mm height. The asphalt mixture specimen was bonded using a tack coat on top of the concrete block that had gap cut 2/3 the depth from the top. For each asphalt overlay, aggregate and binder were heated and mixed at a temperature of 150°C. The amount of tack coat used between asphalt layer and concrete block was equal to 0.5 kg/m2 and was AC 85-100 (penetration grade of 85-100). The concrete block was placed in a steel mold with dimensions of $380mm^L \times 150mm^W \times 200mm^H$. A known weight of the hot mixture was poured on concrete block in the steel mold in four layers. The hot mixture was compacted to desired height using hydraulic jack fitted with a flat steel plate 20 mm in thickness.

Table 1 shows the thickness and weight for each layer of overlay. Since the location of geogrid for each type of specimen was different, these thicknesses were selected for all of the specimens in order to reach the same specific density.

The hot mixture was compacted to desired height using hydraulic jack fitted with a flat steel plate 20 mm in thickness. This procedure produced consistent specimens with the desired dimension and density. Specimens were prepared in four lifts at a target unit weight of 2.123 kN/m3. Although the density of the compacted HMA specimen is slightly lower than the typical density used in the field, this density level was selected because it could be consistently achieved with the available hydraulic press in the laboratory. The following four types of specimens were prepared: (I) unreinforced specimens, which served as control specimens, (II) specimens with geogrid embedded on the concrete block, (III) specimens with geogrid embedded in one third depth of asphalt concrete from bottom. This was achieved by placing the geogrid on top of compacted first layer prior to pouring and compacting the loose mix of the next three layer, (IV) specimens with geogrid embedded in the middle of the asphalt overlay, produced by placing the geogrid on top of compacted second layer prior to pouring and compacting the loose mix of the next two layer. In two previous specimen preparations, reinforcement was sandwiched within the overlay.

Each specimen was then placed on the rubber foundation for testing with a hardness of 60 and Elastic Modulus of 11000 kPa. Two replicate specimens were fabricate and tested for each factor combination. Each experiment was recorded in its entirety by a video camera to allow the physical observation of reflection crack formation and propagation. Vertical crack growth was monitored with the camera and measured every 600 cycles from one side which was painted white with a water-based paint. The test was conducted until the vertical crack length reached the full specimen overlay depth (75 mm).

Table 1.Thickness and weight for each layer of asphalt overlay

Layer number	Layer thickness (mm)	Weight (kg)
Layer 1	25.00	2.85
Layer 2	12.50	1.43
Layer3	18.75	2.14
Layer4	18.75	2.14

4 RESULTS AND ANALYSIS

Fig: 3 shows typical failed, one third-embedded geosynthetic reinforced AC with concrete block base that had 10 mm crack/joint and unreinforced sample with asphalt block base that had a 10 mm crack. In the process of the test, crack initiation time (the time until small cracks are observed) and vertical crack propagation were recorded. Crack growth rate was calculated from the slope of the linear regression line to each specimen. Also vertical deformation was measured using the built in actuator of UTM servo-hydraulic machine. The values in Table 2 are an average of the two specimens.

The crack propagations for specimens with existing concrete pavement were different depending on placement position of geogrid in overlay (at 20℃). In the case with geogrid embedded at the bottom of overlay, cracks occured just over the joint. Then cracks developed under the loading continued to penetrate the entire layer and reached overlay. But in the case of geogrid embedded in middle or one-third depth, top down cracking pattern was identified. Immediately under loading plate, cracks developed from bottom of lower layer of AC overlay. Then the cracking energy was trapped by geogrid. Finally, the upper layer of AC overlay started to crack from top and propagated towards geogrid. This phenomenon was similar to what reported by Kuo and Hsu (2003). Placing geogrid at one-third or middle of overlay thickness divides the overlay into lower layer and upper layer. This design is advantageous with lower layer serving as leveling layer that ensure good seating and bonding of geogrid.

According to Jayawickrama et al. (1987), Kuo and Hsu (2003) and Brown et al. (1989), when geosynthetic was placed inside asphalt overlay, different stress distribution above and blow geosynthetic was produced. So the neutral axis was changed by changing of geosynthetic placement in asphalt overlay.

Fig: 4 shows permanent deformation vs. load cycle and vertical crack growth vs. cycle for geogrid reinforced samples and control without geogrid with 10 mm gap in concrete block. In general, fast vertical deformation occurs initially and then the slop of curves stabilizes. This is due to consolidation of mixtures at the initial stage of load application. It is observed that samples with reinforcement embedded in one-third depth lasted longer than those embedded at the bottom while accumulating less permanent deformation. Fatigue life of reinforced overlay with geogrid placed at one-third depth was 8.1, 3.9 and 1.2 times greater than unreinforced sample, sample with geogrid embedded at bottom and sample with geogrid embedded at middle of overlay respectively. Also Kuo and Hsu (2003) (numerical studies) showed that placing the geogrid at one-third depth of asphalt overlay thickness from bottom with old concrete pavement had the minimum tensile strain above geogrid and therefore had a maximum fatigue life compared with geogrid placed at the bottom or in the middle of asphalt overlay. After this position, placing the geogrid placed at the bottom or in the middle of asphalt overlay was the best placement for retarding the reflection cracking compared with the specimens with geogrid placed at the bottom of overlay. They also noted that placing geogrid inside asphalt overlay, distributes energy into two sub-layers.

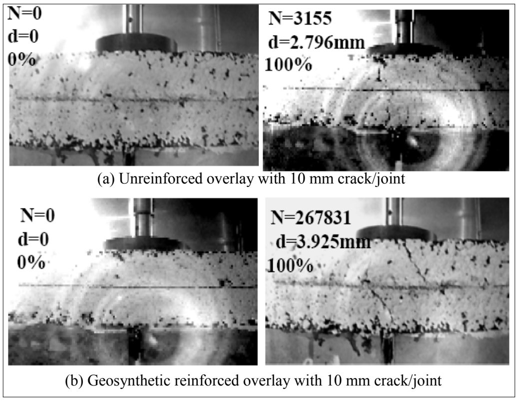

Figure 3. Progression of reflection cracks for (a) unreinforced overlay and (b) geogrid reinforced (embedded at one-third) overlay. Note: N= the number of cycle and d= deflection at this cycle and 0%, 100% corresponds the fatigue life percents.

Table 2. Mode I reflection crack propagation test results

Width of crack (mm)	Geogrid position	Fatigue life (cycles)	Vertical displacement (mm)	Crack initiation (cycles)	Vertical crack growth rate (mm/cycle× 10^{-4})
10	Non	31551	2.796	6310	30
10	Bottom	64311	3.492	11200	14
10	One-third	254653	3.811	38400	3
10	Middle	216732	4.144	33800	4
15	Non	27831	3.028	4200	32
15	One-third	193911	3.914	15600	4
20	Non	19311	3.882	2400	44
20	One-third	168782	3.911	10200	5

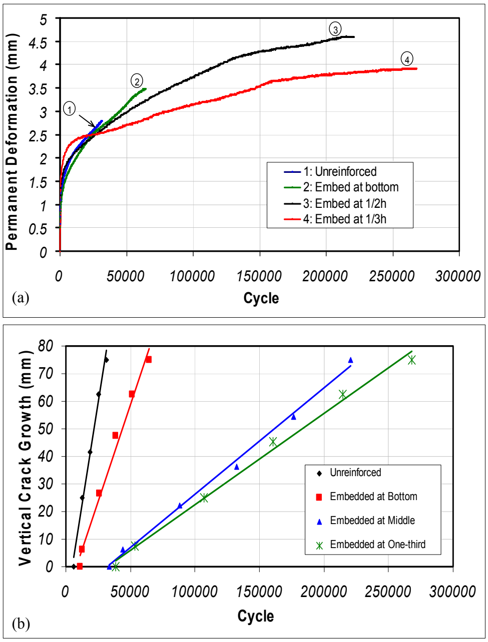

Figure 4. Permanent deformation (a) and vertical crack growth rate (b) for overlays with concrete block base and 10 mm gap at 20°C.

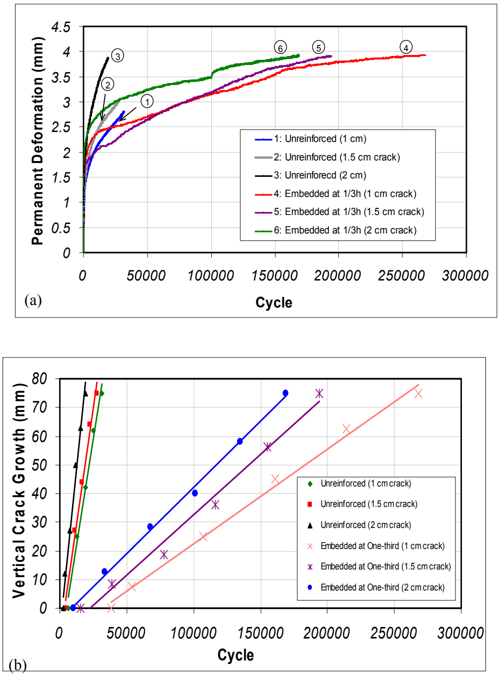

Figure 5. Permanent deformation (a) and vertical crack growth rate (b) for unreinforced and reinforced overlays in one–third depth with concrete block base at 20°C.

It was observed that permanent deformation of unreinforced sample before terminal cracking (at 31551 cycles) was 1.1 times greater than specimen with geogrid embedded at one-third depth at the same cycles.

The vertical crack growth rate of unreinforced sample was the steepest (3×10-3 mm/cycle) of all samples. But vertical crack growth rate for samples with geogrid were less than 1.4×10-3 mm/cycle. The lowest rate was observed in the specimen with geogrid embedded in one-third depth as shown in Fig: 4 with a value of 0.3×10-3 mm/cycle for reinforced overlay in one-third as shown in Table 2. This means that 10 times as many load application are required for crack in the reinforced overlay with geogrid in one-third depth to grow the same length as that in the unreinforced specimen.

Because the best location for geosynthetic in overlay with concrete block that had 10 mm gap interval was one third depth from bottom of overlay, the other reinforced samples with reinforcement in one-third depth with different gap interval were made to compare with unreinforced samples with different gaps in concrete block. By increasing the concrete block gaps, crack propagation was faster than sample with 10 mm joint/crack. As shown in Fig: 5 and Table 2, reinforced overlay on concrete block with 20 mm gap interval had 66% of fatigue life of reinforced overlay on PCC with 10 mm joint/crack. However, specimen with geogrid embedded in one-third depth with 20 mm joint had service life and crack initiation time 8.7 and 4.2 times that of unreinforced specimen with 20 mm gap respectively.

5 CONCLUSION

Data collected from these experiments verifies that geogrid inclusion in asphalt sample lead to significant increase in overlay performance. Specimen with embedded geogrid outperformed non- reinforced samples both in terms of resistance to cracking as well as rutting. Although placing geogrid at one-third depth forces the contractors to pour the overlay in two separate layers and hence encounter some extra cost, this position is most effective in retarding reflection cracking. This design is advantageous with lower layer serving as leveling layer that ensure good seating and bonding of geosynthetic.

The effect of geogrid for overlay reinforcing with increasing crack/joint from 10 mm to 20 mm in existing pavement was not decreased. Also this study showed that top down cracking pattern in overlay with existing concrete block is depending on Geogrid position in asphalt overlay (middle or one-third depth).

Future test should focus on thermal cracking tests on reinforced specimens with different geogrid position in overlay to study the effect of subsequent shrinkage and expansion of old concrete pavement in bottom of overlay for optimizing the placement of geosynthetic in overlay.

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REFERENCES

British standards institution. BS 882, Part 2. 1973. *Coarse and fine aggregates from natural sources*. London, BSI, 1973.

Brown, S,F., Brunton, J.M., & Armitage, R.J.1989. Grid reinforced overlays. Reflective cracking in pavement, Proce., 2nd RILEM conference,Liege, Belgium, March 8-10, pp.63-70.

Castell, M.A., Ingraffea, A.R., & Irwin, L.H.2000. Fatigue crack growth in pavements. Journal of transportation engineering , ASCE, Vol.126, No.4. pp. 283-290.

Chang, D.T.T., Lai, R.Q., Chang, J.Y., & Wang, Y.H. 1989. Effects of geogrid in enhancing the resistance of asphalt concrete to reflection cracks. ASTM STP 1384. American society for testing and materials, pp. 39-51.

Cleveland, G,S., Button, J.,W.,& Lytton, R.,L. 2002. Geosynthetics in flexible and rigid pavement overlay systems to reduce reflection cracking. Report No.FHWA/TX-02/1777, Texas department of transportation research and technology implementation office. pp.1-297.

De Bondt, A.,H. 1998. Anti-reflective cracking design of (reinforced) asphalt overlays. PhD Thesis, Dept. of civil engineering, Delft Univ. of technology, Delft, The Netherlands crack retardation. Journal of testing and evaluation, ASTM, Vol. 27, No. 2, pp.106-113.

Goulias, D.G., and Ishai, I. 1999. Experimental system for simulating crack propagation in asphalt pavements and effectiveness of geosynthetics in crack retardation. Journal of testing and evaluation, ASTM, Vol. 27, No. 2, pp. 106-113.

Iran highway asphalt paving code. 2003. Ministry of road and transportation research and education center, Iran, No. 234. (in Persian).

Jayawickrama, P.,W., & Lytton, R.,L. 1987. Methodology for predicting asphalt concrete overlay life against reflective cracking, Proce., 6th International conference on the structural design of asphalt pavements, Vol. 1.

Kim, J., Buttlar, W.G. 2002. Analysis of reflective crack control system involving reinforcing grid over based-isolating interlayer mixture. Journal of transportation Engineering, Vol. 128, No. 4, July/August, pp. 375-384.

Kim, K.W., Doh,Y.S., Lim, S. 1999. Mode I reflection cracking resistance of strengthened asphalt concrete. Journal of consruction and building MATERIALS , Vol. 13. pp. 243-251.

Kuo, Ch.M., Hsu, T.R. 2003.Traffic induced reflective cracking on pavements with geogrid reinforced asphalt concrete overlay. 82th Annual TRB Meeting, pp.1-23.

Reddy, S.K., Reddy, R., K., & Pandey, B., B. 1999. Cracking in bituminous layers placed over cracked pavements. Presented at the 78th annual meeting of the transportation research board, January, Washington, D.C.

Rigo, J.M., Hendrick, S., Courard, L., Costa, C., Cescotto, S., & Kuck, P.J. 1993. Evaluation of crack propagation in an overlay subjected to traffic and thermal effects, Reflective cracking in pavements: State of the art and design recommendations :Proc., 2nd international RILEM conference, Liege, Belgium.

Sha, Q.,L. 1993. Two kinds of mechanism of reflective cracking. reflective cracking in pavements., Proc., 2nd RILEM conference, Liege, Belgium,pp. 10-12.

Sobhan, K., Genduso, M., & Tandon, V. 2005. Effects of geosynthetic reinforcement on the propagation of reflection cracking and accumulation of permanent deformation in asphalt overlays. Third LACCEI international latin American and Caribbean conference for engineering and Technology (LACCET 2005)"Advances in Engineering and Technology :A global perspective''. 8-10 June 2005 Cartegena, Columbia, pp, 1-9.

Uhlmeyer, J. S., Pierce, L. M., Willoughby, K., & Mahoney, J. P. 2002. Top-down cracking in Washington state asphalt concrete wearing courses," presented in 79th Annual meeting of transportation research board, Washington D.C.

Yongqi Li, P.E., and Metculf, J.B. 2002. Crack initiation model from asphalt slab tests. Journal of materials in civil engineering, Vol 14, No. 4, August 1, pp.303-310