Journal of Southeast University (English Edition) Vol. 21, No. 3, pp. 342 – 347 Sept. 2005 ISSN 1003—7985

Measuring crack propagation in reinforced asphalt concretes

Aysar Najd Zheng Chuanchao

(Key Laboratory for Special Area of Highway Engineering of Ministry of Education, Chang'an University, Xi'an 710064, China)

Abstract: Two different reinforcing methodologies are applied: modification of the overlay characteristics by adding chopped glass fibers to the hot mixture asphalt (HMA) and reinforcing asphalt overlay with glass grids. Theory of fracture mechanics (FM) is employed to determine crack growth rates for the suggested anti-cracking overlay systems. Asphalt mixture designing tests, three point bending tests and fatigue crack propagation tests were carried out. The critical stress intensity factors K_{IC} are determined for plain and reinforced asphalt concrete. Depending on the fatigue crack propagation, the crack growth rate is determined for each type of anti-cracking system and the cracking process is also analyzed. One of the significant points in this study is the attempt to give better understanding of the crack propagation for multilayer asphaltic overlay or what are suggested herein to be called composite structure anti-cracking overlay system. The results indicate that the reinforcing materials improve anti-cracking characteristics of the asphalt concrete. Composite structure anti-cracking overlay gives a good solution for the reflective cracking phenomenon over old cracked pavements.

Key words: highway engineering; hot mixture asphalt (HMA); crack propagation; fracture mechanics; critical stress intensity factor

The deterioration of the Syrian highway system, the majority of which was originally constructed during the 1970s, justifies the need for more affective rehabilitation methodologies. This presents a serious challenge. This weak transportation infrastructure system cannot simply be replaced. The monetary cost and the disruption to daily life would be astronomical. From a review of the literature, it can be seen that many of the early field investigations were based on empirical relationships with conclusions which varied from successful to disastrous. Later research has employed the more favorable mechanistic approach of determining fracture properties of the HMA overlays using fracture mechanics theories. The research by Lytton[1] was based on identifying fracture properties of geosynthetic materials. Read[2] has also made efforts to predict the fatigue life of an asphalt mixture. RILEM Conferences on Reflective Cracking in Pavements since 1989 were organized to point out the main factors and mechanisms involved in the initiation and crack propagation[3]. In China, many works have been done in this field. Research on prevention of reflective cracking has been performed since 1986[4,5].

The main objective of this research is to give more insight into the crack growth and crack resistance characteristics of asphalt concrete mixes in general, and into wearing courses over old cracked asphalt pavement in particular. The influences of reinforcing materials on fatigue crack growth are analyzed. Better understanding of the reinforced composite structure asphalt overlay in retarding crack propagation is achieved.

1 Material Properties

Lime stone aggregate, AH – 90 bitumen, chopped glass fibre and glass fibre grid are used in this study. According to asphalt pavement construction and test norm (GBJ 92—93)[6], AC – 10I and AK – 13B asphalt mixtures are used in this paper with gradations shown in Fig. 1. Reinforcing material properties are illustrated in Tabs. 1 and 2.

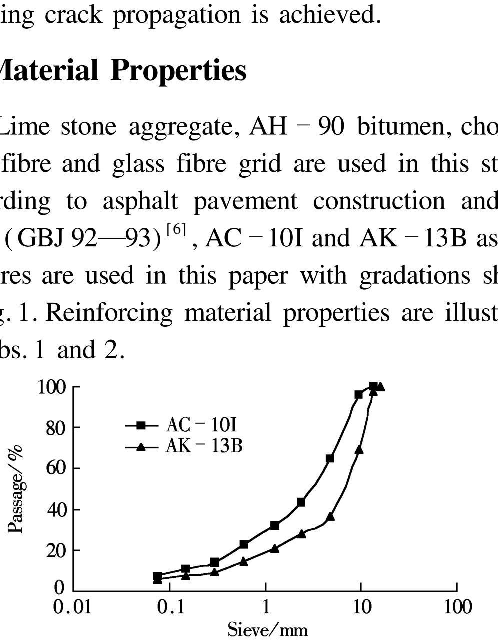


Fig. 1 Gradations of AC – 10I and AK – 13B

Tab. 1 Glass fibre grid properties

Tensile strength/(kN·m⁻¹) Longitudinal direction	Tensile strength/(kN·m⁻¹) Horizontal direction	Elongation /%	Thermal endurance range/℃	Weight/ (g·m⁻²)	Grid size/mm²
35	65	< 5	– 100 to 280	340	12 × 12

Received 2005-03-01.

Biography: Aysar Najd (1972—), male, Syrian, graduate, aysar2002@hotmail.com.

Tab. 2 Glass fibres properties

Fibre diameter/μm	Chopped length/mm	Colour	Tensile strength/MPa	Elongation/%	Modulus of elasticity/GPa	Density/ $(g \cdot cm^{-3})$
5.8 to 9.7	6	Silver, white	2 000	5	70	2.54

2 Three Point Bending Test

2.1 Specimens and test condition

Specimen dimensions are 70 mm × 70 mm × 250 mm; span is 210 mm. In order to simulate the crack in the overlay, a metal piece with inverted T shape was used. This piece was put on the middle of the metal mould and heated together to the proper temperature before the asphalt mixture was spread over it. The mixture should be compact and rammed by a small metal stick along the two edges of the metal piece to enhance the density in this area. Initial notch length is 7 mm; crack tip angle $\theta \approx 20°$ (see Fig. 2).

Fig. 2 Notched asphalt concrete specimen

Four specimens were tested for each of the following material groups:

① AK − 13B: skid resistance asphalt mixture (gradation 0/16, bitumen 4%);

② AC − 10I: dense asphalt concrete (gradation 0/13.2, bitumen 5%);

③ GFRAC: glass fibres reinforced asphalt concrete (AC − 10I + glass fibres 0.175%, bitumen 5%);

④ GGRAC: glass grid reinforced asphalt concrete (AC − 10I + glass grid (weight 340 g/m^2, griddling 12 mm × 12 mm).

The testing temperature is 5 ℃.

2.2 Fracture toughness K_{IC}

Based on bending test for notched specimens, fracture toughness can be calculated as[7]

$$K_{IC} = \frac{6M_c a^{1/2}}{bh^2} f\left(\frac{a}{h}\right) \tag{5}$$

where M_c is the critical moment at failure, a is the initial notch length, b is the specimen width, and h is the specimen height.

$$f\left(\frac{a}{h}\right) = 1.99 - 2.74\left(\frac{a}{h}\right) + 12.97\left(\frac{a}{h}\right)^2 - 23.17\left(\frac{a}{h}\right)^3 + 24.80\left(\frac{a}{h}\right)^4 \tag{6}$$

Critical stress intensity factors for various asphalt material types were calculated in Tab. 3.

Tab. 3 Critical stress intensity factors for various asphalt material types

Specimens type	Maximum applied load P_b/N	Critical moment M_c/(kN·mm)	a/h	$f(a/h)$	Critical stress intensity factor K_{IC}/(MPa·$mm^{-1/2}$)
AK − 13B	4 636	245.459	0.099 6	1.852 2	24.339 3
AC − 10I	5 686	304.185	0.099 2	1.852 4	29.860 2
GFRAC	6 535	345.030	0.099 7	1.852 1	34.308 9
GGRAC	6 308	331.170	0.099 2	1.852 4	32.563 4

2.3 Test results analysis

Fig. 3 demonstrates that even though the crack propagation resistance for both the GFRAC and the GGRAC are relatively high, the reinforcing effect is not as high as it is in unnotched specimens. The critical stress intensity factor for GFRAC increased only by 14.9% compared with the plain asphalt concrete, and 9.1% for GGRAC compared with the plain asphalt concrete.

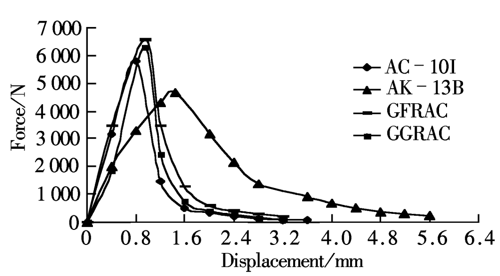


Fig. 3 Force vs. displacement for notched asphalt concrete specimens

3 Fatigue Crack Propagation Test

This test is aimed to measure the crack growth rate value (da/dN) so as to determine the intrinsic parameters of the material, such as A and n in the fatigue strength law, such as Paris' law. $da/dN = A(\Delta K)^n$. Paris' law relates the mean crack propagation per cycle da/dN to the variation of the stress intensity factor $(K_{max} - K_{min})$. In other words, this test enables us to accurately relate the values of the measurable load parameters and the values of the mechanical internal parameter (non measurable), such as the stress intensity factor. In addition to this major goal, this test provides a better understanding of the composite structure asphalt overlay, and of the effectiveness of reinforcing material in retarding crack propagation.

3.1 Composite structure asphalt overlay

Different reinforcement, gradation and structure have been used to create anti-cracking overlay systems. Besides the main types AC－10I, AK－13B, GFRAC and GGRAC (see the point bending test), new kinds of composite structure asphalt specimens have been tested:

① Composite AK－13B/AC－10I (see Fig. 4);

② Composite AK－13B/GFRAC;

③ Composite AK－13B/GGRAC (see Fig. 5).

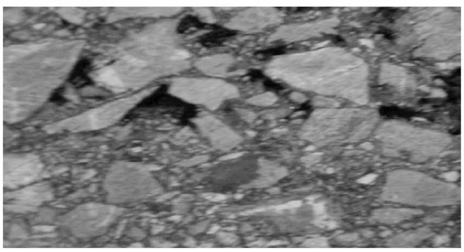


Fig. 4 Composite structure asphalt specimen AK/AC

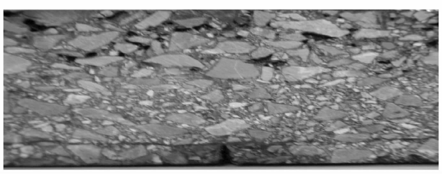


Fig. 5 Glass grid composite structure asphalt specimen AK/GGRAC

As we know, the main function of an asphalt wearing course is to provide suitable skid resistance to the traffic loads and good serviceability. In the case of asphalt overlay on old cracked asphalt pavement, the overlay will quickly develop cracks due to reflection phenomenon from the old cracked layers. Due to the asphalt wearing course's gradation and structure, we cannot reinforce it against crack propagation. Therefore, what we herein suggest is that the composite structure asphalt overlay be used to study the effectiveness of the reinforcements in this system. The specimens were formed in the laboratory in two steps: first, the plain asphalt concrete AC－10I or reinforced asphalt concrete was spread inside a metal mould and compacted to the proper density, then the skid resistance asphalt mixture AK－13B was added above it and then compacted to the proper density.

3.2 Test conditions

The formation method of the specimens is typical as it was in the three point bending test. This test was carried out in the MTS laboratory of Chang'an University. Loading frequency was 10 Hz (loading frequency corresponds to a vehicle speed of 70 km/h). Simisine loading wave was applied. The fatigue crack propagation test was performed for the pure opening mode only. The force controlled mode was used with a maximum load application of 1 155 N. Four specimens were tested for each of the seven studied types. Crack detectors (crack propagation gauges) bonded on the two sides of the specimen were used for measuring the crack propagation under the load repetitions, and checked by the dynamic cracking measuring unit (see Figs. 6 and 7).

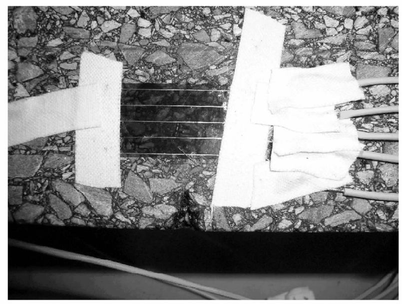
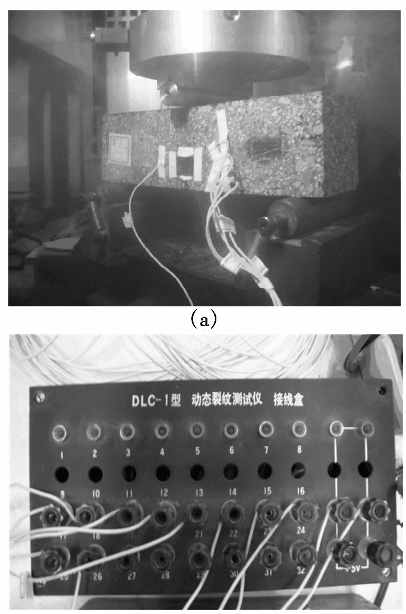


Fig. 6 Crack propagation gauge bonded on the specimen



(a)

(b)

Fig. 7 Specimen inside the fatigue testing machine and the connected dynamic cracking measuring unit

Fig. 5 shows a typical composite specimen reinforced with grid positioned just above the notch.

3.3 Test results analysis

3.3.1 For the basic types (non composite structure overlays)

Because the repeated cycles have a cumulative damaging effect on the material, the crack growth took place under a pulsating load and the fatigue fracture developed under load below the critical value for monotonic action. However, Fig. 8 illustrates the cracking progress for the four basic types of the asphalt overlays under load cycles. Obviously the skid resistance type AK − 13B takes the smallest number of load repetitions before failure, due to the fact that AK − 13B has open gradation, high void percentage and low bitumen content. The crack makes its way between the grains and the repetitions of load, in this case, leading to the debonding mechanism between the aggregates (see Fig. 9).

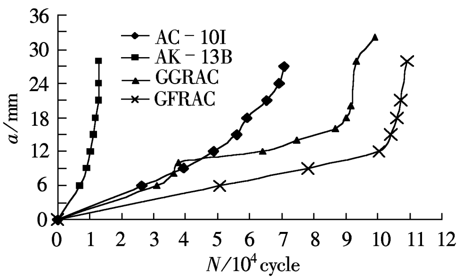


Fig. 8 Crack length vs. load cycles

Fig. 9 Debonding mechanism of AK − 13B fatigue fracture

The crack propagation of the GGRAC displays the same behavior as the plain asphalt concrete at the beginning. This makes it clear that the reinforcing grid does not have an effective role in retarding the concentrated stresses in the crack tip. However, when the crack propagation progresses further upwards and the deformation of the specimen increases, the grid at this stage plays a major role in retarding the crack propagation. The glass grid prevents further opening of the crack due to its low rate of elongation and its high tensile strength. At this point, a transfer of the stresses from the crack tip to the grid occurs and the crack growth rate decreases.

Here a great deal of attention should be paid to the type of grids to be used for retarding crack propagation i. e., the grid in this paper increased the total applied load cycles value by 40% compared with the plain asphalt concrete. The crack propagation of the chopped GFRAC behaves differently from the plain asphalt concrete. Fig. 8 shows that cracking development occurs in steady progress from the beginning until the failure stage, with low crack propagation velocity along the cracking line, except at failure stage. The chopped glass fibers added to the asphalt concrete have a bridging effect. The addition of chopped glass fibers to the asphalt concrete increased the total applied load cycles value by 54% compared with the plain asphalt concrete.

From Fig. 10, the chopped GFRAC can bear high load cycles for the same displacement compared to the other types. High bearing capacity along the crack propagation process, and the failure of the GFRAC happened at a displacement value 37% higher than for the plain asphalt concrete. The behavior of the GGRAC is quite different compared to plain asphalt concrete AC − 10I. The GGRAC suffered large displacement at the beginning under less load cycles, then the rate of displacement decreased rapidly.

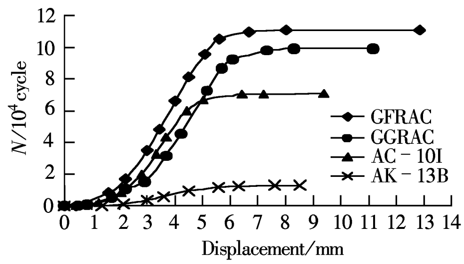


Fig. 10 Load cycles vs. displacement for the basic types

The GGRAC distinguished from the AC − 10I, the failure happened at a displacement value of 12% higher than for the plain asphalt concrete.

3.3.2 For the composite structure anti-cracking overlays systems types

Fig. 11 shows the cracking progress for three composite anti-cracking types of specimens, representing the composite structure anti-cracking asphalt overlays systems.

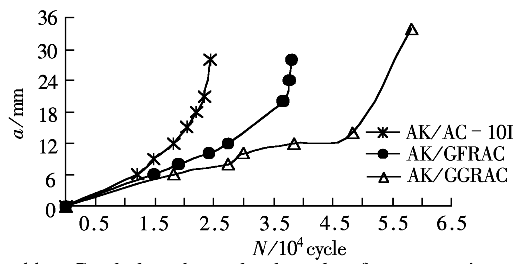


Fig. 11 Crack length vs. load cycles for composite anti-cracking overlays systems

Obviously the plain composite structure AK/AC − 10I type takes the smallest number of load cycles repetition before failure, and the crack growth rate increased rapidly. The composite glass grid reinforced asphalt concrete AK/GGRAC gave the best result in retarding crack propagation among composite structure asphalt overlays. The grid increases the total applied load cycles value by 238% compared with the plain composite structure asphalt overlay AK/AC as illustrated in Fig. 12. This result proves that the high tensile strength reinforcing grid placed in the lower part of the overlay can change the neutral point within the overlay during deflection (see Fig. 13). Due to the tensile stiffness of the glass grid being extremely higher than the tensile stiffness of the asphalt concrete, the reinforcement makes the hinge point or neutral point shift down very close to the reinforcing grid during deflection. The asphalt concrete above the glass grid is mostly in compression. The low stiffness of the upper layer (skid resistance layer AK − 13B) compared with the asphalt concrete AC − 10I, makes the composite specimen deform more under the applied load, which explains why the crack propagation line did not grow vertically from the notch upward. Since the crack tip tensile stresses became compressive stresses, and the propagation stopped, the crack tried to change its way. Fig. 14 shows the cracks lines and the failure of the specimen, the failure of the composite glass grid reinforced asphalt concrete AK/GGRAC was not complete, the ductility was obvious, and the glass grid strands were not broken completely.

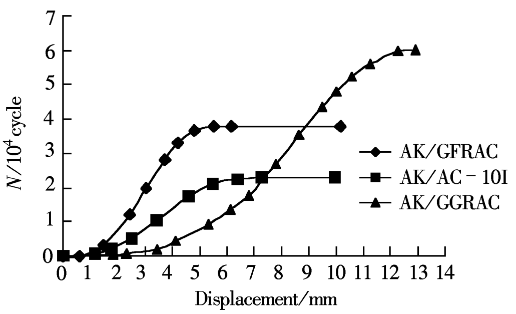


Fig. 12 Load cycles vs. displacement for the composite types

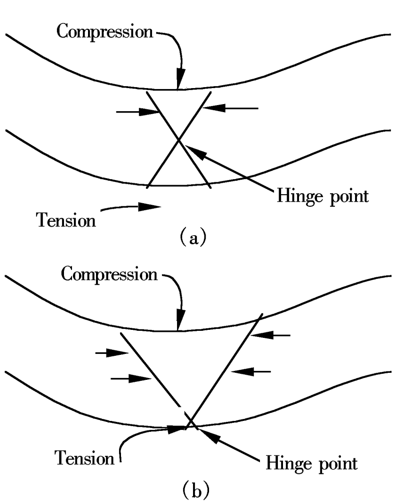


Fig. 13 Hinge point position inside the bending overlay before and after applying glass grid. (a) Without glass grid; (b) With glass grid

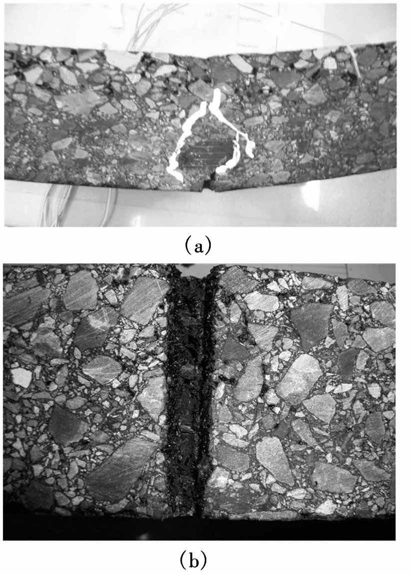


Fig. 14 Failure shape of the composite anti-cracking overlays system. (a) Unbroken grid strands; (b) AK/GGRAC

The addition of chopped glass fibers to the composite overlay AK/GFRAC improves the resistance to crack propagation, but not as much as the reinforcing glass grid does. The chopped glass fibers increase the total applied load cycles value by 155% compared with the plain composite structure asphalt overlay AK/AC − 10I.

4 Conclusion

Glass grid reinforcement prevents further opening of the crack due to its low rate of elongation and its high tensile strength. Chopped glass fibers in asphalt concrete have a bridging effect, and the cracking development occurs in steady progress from the beginning until the failure stage, with low crack propagation velocity along the cracking line. Glass grid composite structure reinforced asphalt concrete AK/GGRAC gives the best result in retarding crack propagation compared with other composite structure asphalt overlay types.

References

[1] Lytton R L. Use of geotextiles for reinforcement and strain relief in asphalt concrete [J]. *Geotextiles and Geomembranes*, 1989, **8**(3): 217 − 238.

[2] Read J M. New method for measuring crack propagation in asphalt concrete [J]. *International Journal for Pavement Engineering*, 2000, **1**(1): 15 − 35.

[3] Rigo J M. General introduction, main conclusions of the 1989 conference on reflective cracking in pavements [A]. In: *The Second International Conference on Reflective*

Cracking in Pavement [C]. Belgium: Liege University, 1993. 3 – 20.

[4] Ye Guozhong. Fatigue shear and fracture behavior of rubber bituminous pavement [A]. In: *The Third International RILEM Conference on Reflective Cracking in Pavements* [C]. Netherlands, 1996. 168 – 175.

[5] Hao Peiwen, Zhang Dengliang, Hu Xining. Evaluation method for low temperature anti-cracking performance of asphalt mixture [J]. *Journal of Xi'an Highway University*, 2000, **20** (3): 1 – 5. (in Chinese)

[6] Department of Scientific Research of the Aminitry of Transportion. *Highway engineering laboratorial norms* [M]. Beijing: China Communications Press, 2001. (in Chinese)

[7] Zhang Dengliang. *Asphalt pavements engineering handbook* [M]. Beijing: China Communications Press, 2003. (in Chinese)

测量加筋沥青混凝土内的裂缝扩展

Aysar Najd　　郑传超

(长安大学特殊地区公路工程教育部重点实验室，西安 710064)

摘要：利用 2 种不同的方法加筋沥青罩面：①在沥青混合料中加入短切玻璃纤维改善沥青混凝土的特性，②采用玻璃格栅加筋沥青混凝土. 应用断裂力学方法分析沥青路面裂缝扩展机理. 采用沥青混合料设计试验、三点弯曲试验和疲劳裂缝扩展试验，确定加筋沥青混凝土的临界应力强度因子 K_{IC}，测量每一种沥青罩面抗裂系统的裂缝扩展速率. 本研究的主要特点是提出复合型抗裂罩面系统，分析了多层加筋沥青罩面裂缝扩展过程，推荐了若干沥青路面抗裂系统. 结果证明，加筋材料可以提高沥青罩面的抗裂特性，复合型抗裂罩面系统能够有效地阻止反射裂缝的扩展.

关键词：道路工程；热拌沥青混和料（HMA）；裂缝扩展；断裂力学；临界应力强度因子

中图分类号：U41