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The effect of geosynthetics materials in preventing asphalt pavements from reflective cracking

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ABSTRACT: Based on fatigue fracture mechanics theory the analysis is carried out for the fatigue cracking of reinforcing asphalt concrete pavements under traffic loads by using FEM. By comparing, it is pointed out that the bonding condition between reinforcement and semi-rigid base course and the characteristics of reinforcement influence the fatigue cracking life of reinforced asphalt concrete pavements apparently.

1 INTRODUCTION

Reflective cracking is one kind of main diseases causing damages of asphalt pavements. Some methods have been used to prevent the initiating of reflective cracks or delay the time when the cracks expand to the surfaces. Study and practice have proved it is a valid method that reinforcement materials such as fabrics and geogrids are placed between semi-rigid base courses and bituminous surfaces to prevent the cracks in semi-rigid base courses from developing upwards and prolong the service life of bituminous surfaces.

The characteristics of reinforcement materials strengthening asphalt pavements should be the one which the reinforcement phase in composite material acts as, and they should be of interfacial characteristics more stronger which reflect remarkable on the interrelation between the forces and displacements of the reinforcement materials and fillings (paving materials) on the interface. The interfacial bonded condition will influence directly whether the reinforcement materials improve the characteristics of bituminous surface and enhance its strength resisting cracking. Although it has been proved that the reinforcement materials should be ensured bonded with fillings well, but it is difficult to do so in practice. For example, as the geogrid is placed on the surface of semi-rigid base course, even if the surface is cleaned and binder is sprayed on it, the geogrid will still move or fold and can't bond with layers(up and down) completely when asphalt binder is sprayed and compactor rolls. Under traffic loading, the geogrid may be connected with layers frictionally or slidingly to change the reinforcing effect. And this is one kind of interfacial effects.

It has been shown that the mechanical effects of the reinforcement materials on the pavement systems should mainly include(Vanelstraete, A. & Francken L. 1996, Scarpas A. 1996, Zhou Zhi-gang et al. 2000): i)as the crack develops into the surface, the reinforcement will act as a bridge to pull the opened crack edges together and weaken the tension stress concentration around the crack tips;)the reinforcement will strengthen the interlock of the crack edges and weaken the shear stress concentration around the crack tips;)some geosynthetics materials such as geotextile may act as separating layers or SAMIs and increase the potentiality of the vertical crack in half-rigid base course developing along the interface between the surface and half-rigid base course, and so to delay the time when the crack reflects to the top of surface.

In this paper, it is analyzed for the reinforcing effect and interfacial effect of reinforcement materials on preventing asphalt pavements from cracking by using plane FEM based on LEFM. And the fatigue cracking life of reinforced asphalt pavement and factors effecting it are analyzed by using fatigue fracture mechanics method based on the results of laboratory tests. Some suggestions are put forward for reference.

2 FEM FOR THE REINFORCED ASPHALT PAVEMENT

2.1 *FEM method*

Calculation and analysis will be carried out by using plane strain finite element method. The 8-node quadrilateral isoparametric element is chose as the finite element. For the problem analyzed, four kinds of special elements are used here. They are singular element and transition element which reflect the singularity at the crack tip (see Fig.1), bar type element for modeling the reinforcement material, and interfacial element for modeling the contacted condition on the interface[3].

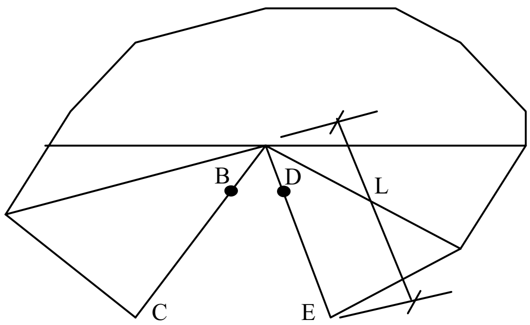

Figure.1 The singular element and transition element

By regression for the horizontal and vertical displacements along the crack edges (see equation (1)), stress intensity factors (K for the tension type crack and K for the shear type crack) can be obtained.

$$\Delta u = \frac{1+K}{G\sqrt{2\pi}} K_I \sqrt{r} + A_1 r + A_{3/2} r^{3/2} + \cdots$$
$$\Delta w = \frac{1+K}{G\sqrt{2\pi}} K_{II} \sqrt{r} + B_1 r + B_{3/2} r^{3/2} + \cdots \quad (1)$$

Because under unaxial symmetrical loading the crack in asphalt pavement is the complex type, so the rule of maximum tension stress is used to calculate the propagating angle θ and complex stress intensity factor K^* for the complex type crack. If $K_1<0.0$, then $K_1=0.0$ while calculating.

2.2 *Asphalt pavement structure*

The four elastic layers system is chosen as asphalt pavement structure(see Fig.2 and Table 1). The semi-rigid base course contains one penetrated crack.

Table 1 Asphalt pavement structure

layer	Modulus(Mpa)	Poisson rate	thickness(cm)
surface	1800	0.25	15
base course	1400	0.25	20
subbase	300	0.30	25
subgrade	40	0.35	

The traffic loads acting on the surface of asphalt pavement include eccentric vertical load with horizontal load simultaneously. The perpendicular load value is 0.7MPa, horizontal load value is 0.21MPa. The sizes of loading area are 2r=2×15.0cm.

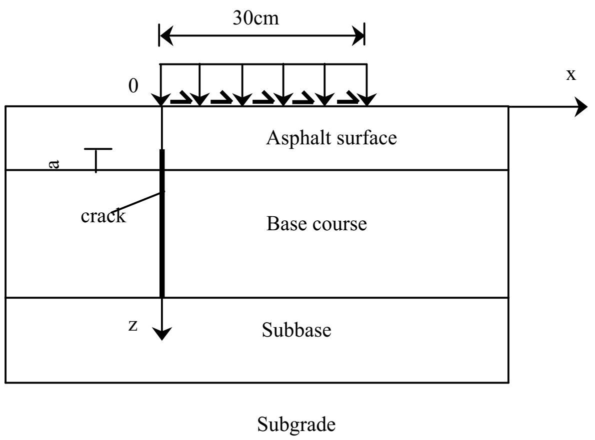

Figure 2 Pavement structure

2.3 *Interfacial contacting condition*

The interfacial codition can be represented by interface element (elastic spring model) between reinforcement and layers. For plane problem, the relations between forces and displacements in the interface element are

$$\begin{Bmatrix} F_s \\ F_n \end{Bmatrix} = \begin{bmatrix} k_s & 0 \\ 0 & k_n \end{bmatrix} \begin{Bmatrix} \Delta u \\ \Delta w \end{Bmatrix} \quad (2)$$

where respectively, Fs, Fn are shear and normal forces between up and down layers, ks, kn are stiffness factors of shear and normal springs, and Δu, Δw are their relative displacements in the two directions. For different types of reinforcement materials, the values of ks will not be equal to each other. For geotextile, the interaction between reinforcement and filling is due to the limited friction on the interface, so the ks value will be small. But for geogrid, the interaction will include the friction force between its longitudinal strip and filling, the reaction force of transverse ribs to filling and its torsion moment, so the ks value will be large.

3 REINFORCING EFFECT OF REINFORCEMENT

The results listed in Table 2 show that the reinforcement placed under the bottom of bituminous surface can weaken the concentration level of stress at crack tip for some degree, but the reinforcing effect is determined largely by the mechanical characteristics of reinforcement selected. For example, the geosynthetics with tension stiffness Eg=2.0MN/m value of tension stiffness can act as reinforcement, but that one with Eg=0.5MN/m value of tension stiffness can't do it.

Table 2. Stress intensity factors and maximum tension force

Eg(MN/m)	0.0		0.5				2.0			
Inter. Cond.	①	④	①	②	③	④	①	②	③	④
$K_1(MN/m^{3/2})$	0.13	0.47	0.13	0.50	0.49	0.50	0.12	0.48	0.45	0.50
$T_{max}(KN/m)$			2.14	-40.33	2.69	-1.30	6.58	-77.42	9.44	-2.17
$K_2(MN/m^{3/2})$	0.12	0.03	0.12	0.03	0.04	0.03	0.12	0.03	0.04	0.03
$T_{max}(KN/m)$			0.14	-0.39	0.50	0.03	0.45	-0.74	1.76	0.00
θ(°)	52.41	7.64	51.84	7.29	8.50	7.18	53.17	7.65	10.39	7.28
$K^*(MN/m^{3/2})$	0.22	0.48	0.22	0.50	0.49	0.50	0.22	0.49	0.46	0.50

*① $K_{s1}=K_{s2}=10^6 MP_a/m$ ② $K_{s1}=10.0, K_{s2}=10^6 MP_a/m$
③ $K_{s1}=10^6, K_{s2}=10.0 MP_a/m$ ④ $K_{s1}=K_{s2}=10.0 MP_a/m$

The reinforcing effect mainly influences stress intensity factor K_1, but hardly for K_2. This is consistent with the characteristics that the reinforcement is only able to resist tension and has not powerful resisting shear ability. But the reinforcement will improve the distribution of shear stress of bituminous surface along the interface. Also the reinforcement will increase the propagating angle θ of crack to prolong the propagating route and delay the time crack developing to the surface.

4 INTERFACIAL EFFECT OF REINFORCEMENT

According to the calculating results, the interfacial condition between reinforcement and semi-rigid base course influences the concentration of stresses at crack tip largely. No matter the reinforcement is placed or not, good interfacial connected condition can weaken the concentration level of tension stresses, but sliding frictionlessly can weaken the concentration level of shear stresses. The condition of $K_{s2}=10.0MP_a/m$ is similar to sliding frictionlessly, and that of $K_{s2}=10^6MP_a/m$ can represent the interfacial connected completely condition. Based on the results of complex stress intensity factor and crack propagating angle, the reinforcement should be ensured to connect with semi-rigid base course completely in order to play the role of reinforcement.

If the reinforcement is connect with semi-rigid base course badly, it still can weaken the concentration level of tension stress, but increase that one of shear stress slightly. This is because of tension force in reinforcement transited by increasing shear forces between reinforcement and bottom of bituminous surface. And the tension force will increase too. Because of the multiple effect of different loads, at last the reinforcement still reduces the complex stress intensity factor and increases the crack propagating angle.

The varying law of stresses and stress intensity factors at the crack tip with crack propagating shows that there are two actions effecting the crack propagation(see Fig.3). One is the reinforcing action of reinforcement materials, which is remarkable in the early period of crack propagating. The reinforcement pulls the opened crack edges together as bridge. The another one is the interaction between layers. The restrained forces will weaken the tension stress concentration in the first stage of crack propagating when there is a good bonding interfacial condition. For poor interfacial conditions, it can weaken the shear stress concentration for the sliding freely condition nearly, but as the crack propagates to the top of the surface, the edges of crack will be pressed together, so this kind of interaction will be weakened.

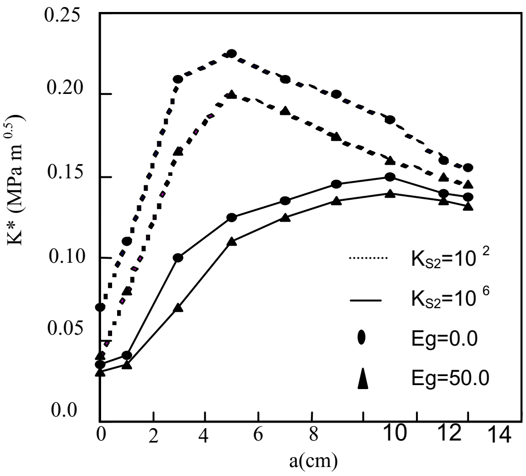

Figure 3 The curve for complex stress intensity factor K* with crack length a

5 FATIGUE CRACKING LIFE OF ASPALT PAVEMENT

By using the empirical power law developed by Paris and Erdogan, the total number of normalized axle loads as the crack in semi-rigid base course reaches the top of surface will be

$$N = \int_0^h A^{-1}(K^*)^{-m}\,da \quad (3)$$

where h is the thickness of surface, A and m are fracture mechanics parameters. According to the results of repeated bending tests on beam specimens made by asphalt mixture, their fracture mechanics parameters are $A=3.0\times10^{-6}$ m=2.38.

Using the equation (3) to calculate the fatigue cracking life of asphalt pavement under different reinforcing conditions. The results in Fig.3 show that there exist the influences of the reinforcing action and interfacial action in the first stage of crack propagating before the crack extends into the surface 3.0cm(a/h<0.2). After the length of crack is longer than 3.0cm, the fatigue curves of crack propagating are almost varied with one accord no matter how about the interfacial condition and which reinforcement material to be used.

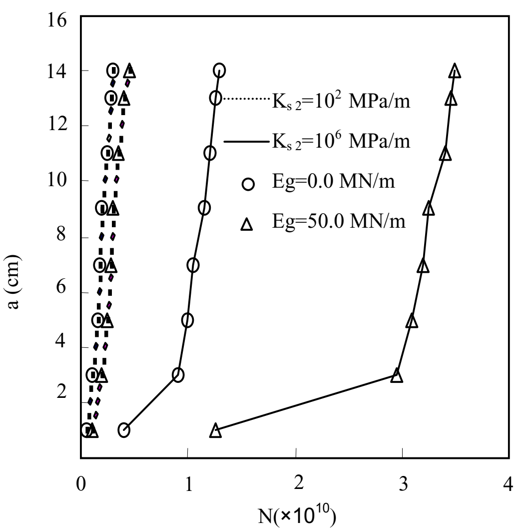

Figure 3.The value of N with crack length a

The influencing scale of interfacial condition is about $k_{s2}<10^3$MPa/m, or $k_{s2}>10^5$MPa/m(see Table 3, in which the N_0 is the fatigue cracking life under well bonding condition and without reinforcement material, and $N_0=1.302\times10^{10}$). For the first condition, the fatigue cracking life of bituminous surface is lower than that one for the well connected condition distinctly. For the second condition, the fatigue cracking life increases remarkably. For the condition between the two ones, the fatigue cracking life doesn't change obviously.

Only as the tension stiffness of reinforcement Eg>1.0MN/m, can it act as one reinforcement really(see Fig.4). For the well bonding condition, if Eg=50.0MN/m, the bituminous surface can be used for double fatigue cracking life.

Table 3 Relative life $f=N/N_0$ under different conditions

Eg(MN/m)	0.0	0.1	1.0	10.0	50.0j
$K_{s2}=10^2$MPa/m	.2260	.2919	.2975	.2980	.3549
10^3	.8525	.8528	.8568	.9015	1.1019
10^4	.8549	.8552	.8582	.9150	1.2201
10^5	.9725	.9725	.9725	.9827	1.3417
10^6	1.000	1.000	1.0057	1.1426	2.0731

Certainly, using stronger reinforcement can slow down cracking speed, but it must be strong enough. The tension stiffness (Eg) of reinforcement should be larger than 10.0MN/m for traffic loads, and the fatigue cracking life can be prolonged more 0.14 to 1.07 times than that one without reinforcement(see Fig.4, in which the N_0 is the fatigue cracking life under well bonding condition and without reinforcement material, and $N_0=1.302\times10^{10}$) . If Eg>40.0MN/m, the reinforcing effect will be more obvious, and the tension in it will be larger than 40kN/m. In practice, we can select these reinforcements with tension strength more than 40kN/m.

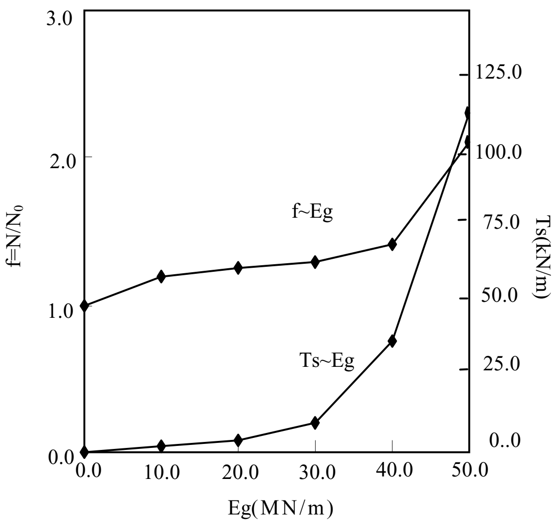

Figure 4. The relative life and tension force with tension stiffness Eg

6 CONCLUSION

According to the analysis above, the following conclusion can be made:

1)Setting reinforcement materials in asphalt pavement system can prolong the surface's fatigue cracking life, but this kind of reinforcing effect depends on the interaction between reinforcement materials and layers, which is related with the reinforcement's geometry, sizes and properties and the interfacial condition such as the rate of tack coat used. The interfacial and reinforcing effects are produced at the first stage of cracking, that is about a/h<0.2.

2)Only the tension stiffness of reinforcement greater than some value(such as 1.0MN/m), is there this kind of reinforcing effect. This value can be used to classify reinforcement and SAMIs.

3)The reinforcement should be bonded with semi-rigid base course as well as possible to increase the interfacial strength and prolong the service life of bituminous surface. Because there are meshes in geogrids and they can interlock hot asphalt mixture well, so geogrids such as Glasphalt can be used in asphalt pavement structures extensively.

7 ACKNOWLEDGEMENTS

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