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Analysis of the Effect of the Cement Mortar Admixture on the Fatigue Resistance of the Semi-Flexible Pavement

Xiayi LIANG [a,b,1] and Binglei XIE [b]
[a] *School of Architecture, Harbin Institute of Technology, Shenzhen, 518071, China*
[b] *Shenzhen Government Investment Project Evaluation Center, Shenzhen, 518036, China*

Abstract. The internal structure of semi-flexible pavement (SFP) is prone to fatigue damage, which affects its service life. The cement mortar admixture has a crucial influence on the fatigue resistance of SFP. In order to explore and study the fatigue resistance performance of SFP, Waterborne Epoxy Resin, emulsified asphalt and Carboxyl Latex were selected as cement mortar admixtures to prepare special cement mortar, and the effect of admixtures on the fatigue resistance of SFP was evaluated by indirect tensile fatigue test. The tests show that Waterborne Epoxy Resin undermines the fatigue resistance of SFP, while emulsified asphalt and Carboxyl Latex can improve it.

Keywords. Semi-flexible pavement, cement mortar, admixture, fatigue resistance

1. Introduction

Semi-flexible pavement (SFP) is a rigid-flexible pavement material that features advantages such as strong high-temperature stability, comfortable driving, and strong wear resistance [1-4]. Due to the huge difference between the volume stability of the cement mortar and the matrix, the internal structure of SFP is prone to fatigue damage that affects its service life. The properties of cement mortar have different effects on the fatigue resistance of SFP. At present, there have been some research achievements on the performance of SFP. Qiu Y, Cai X et al. [5] analyzed the effect of polyvinyl alcohol fiber cement mortar on the self-healing durability of SFP materials using semicircular bending and tensile test. Bao Huan, Wang D, Liang X et al. [6] analyzed the effect of Carboxyl Latex emulsion on the mechanical properties of cement mortar and SFP road performance.

To improve the fatigue resistance of SFP, Waterborne Epoxy Resin, emulsified asphalt and Carboxyl Latex were selected as cement mortar admixtures to prepare special cement mortar. The effect of cement mortar additives on anti-fatigue performance of SFP materials was studied by indirect tensile fatigue test.

[1] Xiayi Liang, Corresponding author, School of Architecture, Harbin Institute of Technology, Shenzhen, 518071, China; Shenzhen Government Investment Project Evaluation Center, Shenzhen, 518036, China; E-mail: 561784034@qq.com.

2. Materials

In this test, P.C32.5 Portland cement, limestone mineral filler and standard sand were used to prepare cement mortar, 70# Shell asphalt and basalt aggregate were used to prepare SFP matrix, and their performance were tested to meet the requirements of technical specifications. The performance indices of cement mortar additives are shown in tables 1 and 2.

Table 1. The technical indices of modified emulsified asphalt.

Testing indexes		Technical requirement	Test results
Amount remaining on sieve (%)		≤0.1	0.04
Viscosity (Asphalt standard viscometer $C_{25,3}$,s)		12~60	24
Evaporation residue	Solid content (%)	≥62	63.5
	Penetration (25℃, 0.1mm)	40~100	70
	Softening point $T_{R\&B}$ (℃)	≥57	58.8
	Ductility (5℃,cm)	≥20	23
	Solubility (%)	≥97.5	99.1

Table 2. The technical indices of waterborne epoxy resin and carboxyl latex.

Test Indices	Requirements	Waterborne Epoxy Resin	Carboxyl Latex
Viscosity (mPa·s, 20℃)	80~350	252(Part A) 93(Part B)	120
pH	7~8	7.5(Part A) 7.5(Part B)	7.5
Solid content (%)	50±2	93(Part A) 50.7(Part B)	49.0

3. Special Type of Cement Mortar

Referring to the existing research methods [7], the performance requirements of cement mortar are: Cement mortar is cured for 7d under standard conditions; the compressive strength is 10-30MPa; the flexural strength is > 3.0MPa; the fluidity is 10-14s.

This paper carried out the test research on the fluidity, mechanical properties and shrinkage of cement mortar base on the orthogonal test method. After range analysis, it was determined that the best ratio of common type of cement mortar: Water-cement ratio is 0.65; Mineral filler content 9% and sand content 18%.

On the basis of the common cement mortar, this paper selected three admixtures (Waterborne Epoxy Resin, emulsified asphalt and Carboxyl Latex) to prepare three special types of cement mortar. The test results of special cement mortar are shown in table 3.

Table 3. Test results of special cement mortar.

Test number	Admixture	Percent of admixture added (%)	Fluidity (s)	7 days strength (MPa)		Shrinkage value (0.001mm)
				Flexural strength	Compressive strength	
①	None	0	12.6	3.81	19.5	128
②	Waterborne Epoxy Resin	4	11.8	4.26	22.66	115
③		8	10.5	4.48	23.98	101
④		12	8.70	4.72	26.46	92
⑤	Emulsified asphalt	4	12.1	4.90	18.2	120
⑥		8	15.3	5.12	17.1	111
⑦		12	18.8	5.33	15.9	102
⑧	Carboxyl Latex	4	16.8	5.05	17.11	110
⑨		8	11.5	5.20	15.25	99
⑩		12	8.43	5.45	12.85	90

The data in table 3 indicates that: (1) As the content of Waterborne Epoxy Resin and Carboxyl Latex increases, the fluidity of cement mortar decreases, while as the content of emulsified asphalt increases, the fluidity increases. When the content of Waterborne Epoxy Resin ranges from 0% to 7%, the content of emulsified asphalt ranges from 0 to 6% and the content of Carboxyl Latex ranges from 4% to 9%, the fluidity of cement mortar meets the requirement.

(2) All three special cement mortar meet the strength requirements. The addition of Waterborne Epoxy Resin enhances the strength of cement mortar. The strength of cement mortar increases with the amount of waterborne epoxy resin. After adding emulsified asphalt and Carboxyl Latex, the compressive strength of cement mortar decreases and the flexural strength increases.

(3) The addition of Waterborne Epoxy Resin, emulsified asphalt and Carboxyl Latex reduces the shrinkage of cement mortar. The more the admixture is added, the smaller the shrinkage is, thereby effectively promoting the shrinkage performance of cement mortar. Carboxyl Latex exerts the greatest influence on the shrinkage property of cement mortar, followed by Waterborne Epoxy Resin and emulsified asphalt is the least.

With the comprehensive consideration of the mechanical properties of cement mortar, this paper designed three special types of cement mortar, as shown in the below table 4.

Table 4. The mix of special cement mortar.

Special cement mortar	A Modified (Waterborne Epoxy Resin)	B Modified (Emulsified asphalt)	C Modified (Carboxyl Latex)
Admixture (%)	7	4	8

4. The Mix Design of SFP Matrix

The paper adopted coarse aggregate void-filling method [8] design the gradation. In this study, the target air void 24% was designed. The result is shown in table 5.

Table 5. The gradation of matrix.

Sieve size (mm)	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Percent passing	100	73.4	53.3	15.7	15.7	13.7	12.3	10.6	7.6	4.7	3.0

Referring to design method of OGFC [9], the Schellenberg drain-down and Cantabro test were employed to determine the optimal asphalt content of 3.85%.

5. Fatigue Test and Analysis

5.1. Fatigue Test

In this paper, the fatigue properties of SFP materials are evaluated by indirect tensile fatigue test. The specimens were first tested for splitting tensile strength using MTS testing machine. This paper adopted a stress-controlled fatigue test, in which the stress is kept constant and the fatigue damage is based on the fatigue fracture, and the number of load actions to achieve fatigue failure is the fatigue life. The test stress ratios were 0.2, 0.3 and 0.4, respectively. The test results are shown in the below table 6.

Table 6. Fatigue test results of SFP.

Types	Stress ratio	Tensile stress level (MPa)	Fatigue life (Number of loading)
None	0.2	0.27	60531
A	0.2	0.292	48759
B	0.2	0.252	81337
C	0.2	0.244	96328
None	0.3	0.27	30471
A	0.3	0.292	22542
B	0.3	0.252	40241
C	0.3	0.244	46329
None	0.4	0.272	10742
A	0.4	0.300	7583
B	0.4	0.262	17198
C	0.4	0.252	22007

5.2. Test Analysis

The fatigue equation of stress control is shown in Eq.(1).

$$\mathrm{In}N_{\mathrm{f}} = -\mathrm{n}\,\mathrm{In}\sigma + \mathrm{K} \tag{1}$$

Where: N_f denotes fatigue life; σ denotes tensile stress; n, K denotes the constants of asphalt mixtures. The regression equation is shown in figure 1.

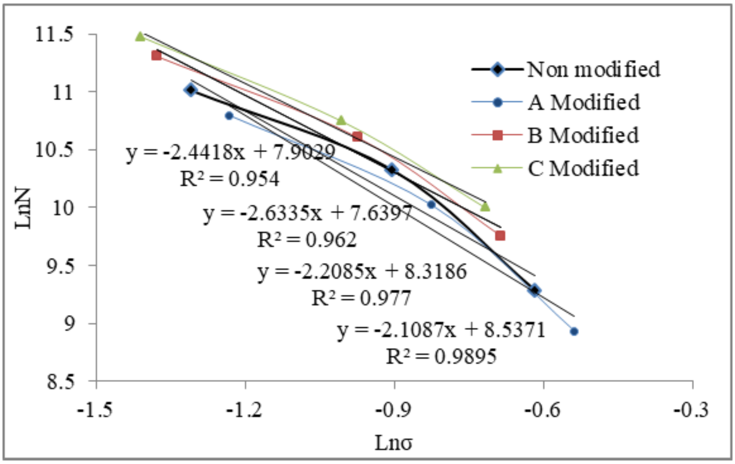

Figure 1. The regression curve of fatigue.

According to the curve analysis in figure 1, the fatigue performance parameters of common, A-type, B-type, C-type SFP are respectively: k=7.90, n=2.44; K_A=7.64, n_A=2.63; K_B=8.32, n_B=2.21; K_C=8.54, n_C=2.11. Compared with the common SFP, the K value of A-type SFP decreases, and the n value increases, thereby reducing the fatigue resistance of the SFP, which indicates that although Waterborne Epoxy Resin can dramatically improve the mechanical properties of cement mortar, it enhances the brittleness of cement mortar and reduces the volume stability inside the SFP and in turn undermines the fatigue resistance.

Compared with the common SFP, the K value of the B-type and C-type SFP increases, while the n value decreases, which enhances the fatigue resistance of SFP. Compared with the common SFP, K_B value increased by 5.3%, n_B decreased by more than 9.5%, K_C value increased by 8.1%, n_C decreased by 14.6%, which indicates that emulsified asphalt and Carboxyl Latex can significantly improve the fatigue performance of SFP, of which Carboxyl Latex is better. After analysis, the addition of emulsified asphalt and Carboxyl latex enhances the flexibility of cement mortar and reduces the stress concentration inside the structure, and has a significant positive effect on fatigue resistance.

6. Conclusion

(1) Waterborne Epoxy Resin, emulsified asphalt and Carboxyl Latex have great influence on the properties of cement mortar. Waterborne Epoxy Resin can enhance the strength and shrinkage performance of cement mortar, while boosting the brittleness; emulsified asphalt and Carboxyl Latex can enhance the flexibility of cement mortar.

(2) The cement mortar admixtures exert various levels of effect on the fatigue resistance of SFP, among which, Waterborne Epoxy Resin undermines the fatigue resistance of SFP; emulsified asphalt and Carboxyl Latex can promote the fatigue resistance of SFP and Carboxyl Latex is better.

(3) According to the levels of effect analysis, it's recommended to apply Carboxyl Latex as the admixture of cement mortar to enhance the fatigue resistance performance of SFP in engineering applications.

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