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Experimental study of pavement performance of basalt fiber-modified asphalt mixture

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Abstract: To discuss the pavement performance of basalt fiber-modified asphalt mixtures, the optimum dosages of asphalt and fibers are studied by the Marshall test and the rutting test. The results demonstrate that the optimum dosages of asphalt and fibers are 4.63% and 0.3%, respectively. Then the pavement performances of basalt (polyester, xylogen) fiber-modified asphalt mixtures are investigated through high temperature stability tests, water stability tests and low temperature crack resistance tests. It indicates that the pavement performances of the fiber-modified asphalt mixtures such as rutting dynamic stability, freezing splitting tensile strength, low temperature crack resistance and so on are improved compared with control asphalt mixture. The results show that the pavement performances of asphalt mixtures can be improved by fiber-modifiers. Besides, the improvement effects of basalt fiber are superior to polyester fiber and xylogen fiber.

Key words: asphalt mixture; basalt fiber; Marshall test; high temperature stability test; pavement performance

Asphalt pavement has been widely used in express highways for its merits of smoothness, comfortable travel, low noise and so on. However, early damage of asphalt pavement becomes more and more serious with the increase in axle load and traffic[1-3]. Therefore, asphalt mixtures should be modified in some way to promote their pavement performance. Among the modifiers of asphalt mixtures, fibers have obtained more and more attention for their excellent improvement effects. The improvement effects of various types of fiber modifiers such as methyl cellulose, polyester and so on, have been investigated and widely used in asphalt mixtures[4-5]. As a kind of new additive and stabilizer of asphalt mixtures, basalt fiber has obtained wide attention for its excellent technical characteristics. Basalt fiber not only makes up for the drawbacks of low strength, elastic ratios and weak high temperature resistance of organic fibers, but also overcomes the drawbacks of environmental pollution of mineral fibers such as asbestos fiber[6]. However, researches on the pavement performance of basalt fiber-modified asphalt binders are still limited. Tang et al.[7] investigated the influence of basalt fiber on the water stability of asphalt mixtures and found that basalt fiber could improve the water stability of asphalt mixtures. Peng et al.[8] investigated the mechanical properties of the short-cut basalt fiber-reinforced asphalt mixtures. The results indicated that short-cut basalt fiber significantly reinforced the mechanical properties of asphalt mixtures. This paper aims to study the pavement performance of the basalt fiber-modified asphalt mixtures by high temperature stability tests, water stability tests and low temperature crack resistance tests.

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1 Material and Mineral Mixtures Grading

The traditional dense gradation asphalt mixture is a kind of suspension dense framework and it is widely used in road pavement for its characteristics of better water stability, durability, convenience and so on. So, studies on the fiber improvement effects of this kind of asphalt binder are of great practical significance.

1.1 Asphalt

The test asphalt is AH-70 asphalt, which is produced in Liaohe, China. The major technical indices are shown in Tab. 1.

Tab. 1 Major technical indices of AH-70

Items	Penetration/(0.1 mm)			Ductility (15 ℃)/cm	Softening point/℃	Penetration index
	15 ℃	25 ℃	30 ℃			
Test value	37	75	112	135	49	−0.96
Standard value	30 to 45	60 to 80	100 to 130	≥100	≥45	−1.5 to +1.0

1.2 Mineral mixtures selection and grading

Limestone and limestone mineral admixtures are produced by Yongli Quarry (Liaoyang, China). The selected mix gradation is AC-16 as shown in Tab. 2.

Tab. 2 Mineral mixtures grading(mass percent) %

Items	Sieve/mm										
	0.075	19	16	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15
Upper limit	100	100	90	80	62	48	36	26	18	14	8
Lower limit	100	95	75	58	42	32	22	16	11	7	4
Selected gradation	100	98	85	66	50	42	31	22	15.2	8.5	6.5

1.3 Major indices of fibers

The major technical indices of experimental fibers are shown in Tab. 3.

2 Marshall Test

Marshall tests are employed to determine the optimum dosages of various fibers. First, the control asphalt mixture's optimum composition is obtained as a comparison group, and then various fibers are put into the asphalt mixtures in a certain interval of dosage; at the same time, the asphalt

Tab. 3 Major technical indices of experimental fibers

Test items	Basalt fiber	Polyester fiber	Xylogen fiber
Color	Silver gray	White	
Diameter of fiber/μm	15	15	45
Length/mm	12	12	1.2
Specific gravity/($g\cdot cm^{-3}$)	2.56 to 3.05	1.38	0.91
Melting point/℃	1 050	>256	170
Tensile strength/MPa	3 000 to 4 840	500	<300
Young's modulus of elasticity/GPa	>40	16 to 19	3.5
Elongation at break/%	3.2	15 to 30	15 to 25

dosage is also increased by an appropriate amount. Finally, specimens of various fiber dosage asphalt mixtures are made to determine the optimum bitumen-aggregate ratio by Marshall tests.

2.1 Test design

Marshall tests are carried out to determine the optimum bitumen-aggregate ratio, and standard superpave mix procedures are employed to prepare the specimens. The details of the test project are shown in Tab. 4.

Tab. 4 Design of Marshall test

Type	Fiber dosage/%	Bitumen-aggregate ratio/%	Specimen groups
Control	0	4.0 4.5 5.0 5.5 6.0	5
Basalt fiber	0.15	5.0 5.2 5.4 5.6 5.8	5
	0.30	5.0 5.2 5.4 5.6 5.8	5
	0.45	5.0 5.2 5.4 5.6 5.8	5
Polyester fiber	0.15	5.0 5.2 5.4 5.6 5.8	5
	0.30	5.0 5.2 5.4 5.6 5.8	5
	0.45	5.0 5.2 5.4 5.6 5.8	5
Xylogen fiber	0.15	5.0 5.2 5.4 5.6 5.8	5
	0.30	5.0 5.2 5.4 5.6 5.8	5
	0.45	5.0 5.2 5.4 5.6 5.8	5

2.2 Decision of optimum asphalt dosage

Based on the Marshall test results of various fibers under various fiber dosages and asphalt contents, according to the related requirements of Ref. [9], the optimum asphalt dosage and major technical indices of various fibers can be obtained as shown in Tab. 5.

Tab. 5 The results of Marshall tests

Type	Fiber dosage/%	Optimum bitumen-aggregate ratio/%	Density/ ($g\cdot cm^{-3}$)	Porousness VV/%	Saturation VFA/%	Marshall stability value/ kN	Flow value/mm
Control	0	4.45	2.433	3.32	73.7	9.02	2.93
Basalt fiber	0.15	4.58	2.425	3.65	71.3	10.60	3.32
	0.30	4.63	2.417	3.68	72.1	11.30	3.41
	0.45	4.57	2.397	3.71	70.6	10.82	3.56
Polyester fiber	0.15	4.62	2.429	3.66	68.6	10.37	3.49
	0.30	4.61	2.421	3.75	69.5	10.23	3.62
	0.45	4.55	2.410	3.82	68.4	9.92	3.75
Xylogen fiber	0.15	4.45	2.419	3.82	66.4	9.42	3.69
	0.30	4.65	2.407	3.93	66.6	9.59	3.86
	0.45	4.82	2.388	3.98	66.7	9.55	3.99

From Marshall test results it can be seen that the optimum bitumen-aggregate ratios of asphalt mixtures increase with the addition of fibers. The stability improvements of fiber-modified asphalt mixtures are due to the strength enhancement of asphalt mastic which benefits from the fibers' higher strength and better dispersion, and then the Marshall stability correspondingly increases. Under the condition of the optimum bitumen-aggregate ratio, the effect of basalt fiber on reinforcing Marshall stability is more significant than those of polyester fiber and xylogen fiber.

2.3 Decision of optimum fiber dosage

The impacts of Marshall stability and flow value on long-term pavement performance are not apparent. For example, high-temperature rutting damage of asphalt pavement with a qualified flow value is still serious; the traditional dense gradation asphalt mixture is a kind of suspension dense framework, and the density of the framework structure is always inadequate; moreover, the addition of fibers increases the asphalt content, which will result in serious high temperature deformation of asphalt mixtures. Therefore, high temperature stability can be directly assigned as the design control indicators of the dense gradation fiber mixture, and the optimum dosage of fiber can be determined combined with the dynamic stability of the rutting test.

3 High Temperature Rutting Test

In accordance with Ref. [10], the dynamic stabilities of the fiber-modified asphalt mixture at 60 ℃ (under the condition of an optimum bitumen-aggregate ratio, fiber contents are 0.15%, 0.30%, and 0.45%, respectively) are obtained by high temperature rutting tests. The test results are shown in Tab. 6.

The results from Tab. 6 show that compared with the control asphalt mixture, the dynamic stability of the fiber-modified asphalt mixture is significantly improved. While the fiber dosage is 0.30%, the dynamic stabilities of basalt fiber, polyester fiber and xylogen fiber-modified asphalt mixtures increase by 66%, 42% and 24%, respectively. Thus, the addition of fiber can significantly improve high temperature performance of asphalt mixtures.

Tab. 6 Results of dynamic stability of fiber reinforced asphalt mixture

Type	Fiber dosage/%	Optimum bitumen-aggregate ratio/%	Dynamic stability/ (times · mm^{-1})
Control	0	4.95	1 725
Basalt fiber	0.15	5.20	2 485
	0.30	5.35	2 862
	0.45	5.40	2 668
Polyester fiber	0.15	5.27	2 226
	0.30	5.35	2 456
	0.45	5.55	2 371
Xylogen fiber	0.15	5.35	1 935
	0.30	5.52	2 138
	0.45	5.68	2 026

4 Water Resistance Test

4.1 Immersed Marshall test[10]

Marshall specimens are divided into two groups. One group is placed in a tank at a constant temperature of 60 ℃ for about 40 min, and then the Marshall stability value is measured; the other group is placed in constant temperature water at 60 ℃ for 48 h, and then the stability value is calculated. Finally, the residual stability is obtained by

$$S_0 = \frac{S_1}{S} \times 100\% \qquad (1)$$

where S_0 is the residual stability ratio, %; S is the stability of specimens, kN; S_1 is the immersed stability of specimens for 48 h, kN. The results are shown in Tab. 7.

4.2 Freeze-thaw splitting test[10]

Marshall specimens are divided into two groups. One is placed in a tank at a constant temperature of 25 ℃ no less than 2 h, and then the maximum failing load P_{T1} is measured. The other group is immersed for 15 min in a condition of 98.3 to 98.7 kPa vacuum first, and then it is frozen at −18 ℃ for 16 h in a refrigerator after having been put into water for 0.5 h at normal atmosphere. Finally, it is put into a tank at a constant temperature of 60 ℃ for 24 h before being placed in a 25 ℃ constant temperature tank no less than 2 h. Finally, the maximum failing load P_{T2} and the splitting strength are calculated by

$$R_{T1} = 0.006\,287 \frac{P_{T1}}{h} \qquad (2)$$

$$R_{T2} = 0.006\,287 \frac{P_{T2}}{h} \qquad (3)$$

where R_{T1} is the splitting strength without freeze-thaw and R_{T2} the freeze-thaw splitting strength, MPa; h is the specimen height.

The TSR can be calculated by

$$\text{TSR} = \frac{R_{T2}}{R_{T1}} \times 100\% \qquad (4)$$

The calculation results are shown in Tab. 7.

Tab. 7 Test results of water stability of fiber reinforced asphalt mixture

Type	Immersed Marshall test			Freeze-thaw splitting test		
	Stability/kN	Immersed stability/kN	Residual stability/%	Splitting strength without freeze-thaw/MPa	freeze-thaw splitting strength/MPa	TSR/%
Control	8.52	7.27	85.4	0.825	0.670	81.2
Basalt fiber	12.45	11.72	94.2	1.125	1.040	92.5
Polyester fiber	11.06	10.15	91.8	0.952	0.862	90.5
Xylogen fiber	9.83	8.87	90.2	0.905	0.767	84.8

4.3 Analysis of test results

It can be seen from Tab. 7 that the residual stabilities of three fiber-modified asphalt mixtures all meet the requirements[10]. Compared with polyester fiber and xylogen fiber, the improvement of the Marshall stability and the immersed stability of the basalt fiber-modified asphalt mixture is more significant. With the optimum fiber dosage, the immersed Marshall stabilities of basalt fiber, polyester fiber and xylogen fiber asphalt mixtures are increased by 61.2%, 39.6% and 22.2%, and the residual stabilities are increased by 10.3%, 7.5% and 5.7%, respectively.

The main reasons are that the addition of fibers increases the dosage of asphalt in the mixture, which improves the effective film thickness of mineral materials and effectively reduces the possibility of water between the asphalt interface and the mineral aggregate; thus, the residual stability of asphalt mixtures is increased. The freeze-thaw test results show that the freeze-thaw splitting strength and the splitting strength without freeze-thaw of the fiber-modified asphalt mixtures are improved to some extent compared with control mixtures. The splitting strengths without freeze-thaw of basalt, polyester and xylogen fiber-modified asphalt mixtures are increased by 36.4%, 15.4% and 6.2%, and the freeze-thaw splitting strengths are increased by 55.2%, 28.7% and 14.5%.

5 Low Temperature Crack Resistance Test

The low temperature cracking is one of the main cause of damage to asphalt pavement, which seriously affects the pavement service life. The bending test of small beams at a low temperature of −10 ℃ is employed to evaluate low temperature resistance cracking of the fiber-modified asphalt mixtures[10]. The MTS material tester is employed to carry out the test, and the method of loading is concentrated loading. The test results are shown in Tab. 8.

Tab. 8 Test results of low temperature crack resistance of fiber-modified asphalt mixtures

Type	Limiting flexural-tensile strength/MPa	Failure strain ε_μ/10^{-3}	Curving stiffness modulus/MPa
Control	9.134	7.45	8 980.0
Basalt fiber	10.747	10.78	11 925.1
Polyester fiber	10.523	10.15	10 132.5
Xylogen fiber	10.236	9.85	9 835.2

The test results show that the limiting flexural-tensile strength, failure strain and curving stiffness modulus of the fiber-modified asphalt mixtures are all significantly improved compared with those of the control asphalt mixture. It is due to the following reasons: 1) The addition of fiber makes the optimum asphalt dosage increase, which results in the improvement of stress relaxation performance and the bending strength of the asphalt mixtures; 2) The reinforcement effects of fibers on the asphalt mixtures ensure the improvement of the flexural-tensile strength of the asphalt mixtures, and thus, the low temperature crack resistance of the asphalt mixtures can be improved by fibers. Compared with polyester fiber and xylogen fiber, the reinforcement effects of basalt fiber on low temperature crack resistance performance is more obvious. The flexure strength, failure strain and bending strength modulus are improved by 17.7%, 44.7%, 32.8%, respectively.

6 Conclusions

1) The optimum basalt fiber dosage (weight) is 0.3% corresponding with the optimum asphalt ratio of 5.35%.

2) The Marshall stability and rutting stability of the basalt fiber-modified asphalt mixture are increased by 66% and 47%, respectively; the immersion Marshall stability, residual stability, and the TSR of the basalt fiber-modified asphalt mixture are increased by 61.2%, 10.3%, 55.2% and 13.9%, respectively; the flexural-tensile strength, failure strain and curving stiffness modulus of the basalt fiber-modified asphalt mixture are increased by 17.7%, 44.7% and 32.8%, respectively.

3) Compared with polyester fiber and xylogen fiber, the improvement effect of basalt fiber on asphalt mixture pavement performance is better.

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玄武岩纤维改性沥青混合料路用性能试验研究

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摘要:为研究玄武岩纤维在增强沥青混合料路用性能方面的作用,首先通过马歇尔试验与车辙试验确定最佳沥青用量与纤维掺量. 研究表明,玄武岩纤维的最佳掺量为 0.3%,最佳沥青用量为 4.63%. 然后通过高温稳定性试验、水稳性试验及低温抗裂性试验对不添加纤维、添加玄武岩纤维、添加聚酯纤维以及添加木质纤维情况下的沥青混合料的路用性能进行了对比分析. 试验结果表明,相对无纤维增强沥青混合料,纤维沥青混合料提高了最佳沥青用量,其车辙动稳定度、冻融劈裂强度、低温抗裂强度等均得到了一定提高与优化;在保持最佳纤维掺量的情况下,玄武岩纤维改性沥青混合料的路用性能得到明显的提高,且其增强作用优于聚酯纤维和木质纤维.

关键词:沥青混合料;玄武岩纤维;马歇尔试验;高温稳定试验;路用性能

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