INFLUENCE OF POLYESTER FIBRE ON THE PERFORMANCE OF ASPHALT MIXES

Zhu Haoran, **Yang Jun, Cong Ling, Cui Juan and Wan Jun**

Southeast University, No. 2 Sipailou, Nanjing 210096, P. R. China,
E-mail: yegui8880818@163.com

ABSTRACT

In order to determine the influence of polyester fibre on the performance of asphalt mixes, two types of polyester fibre were selected. One is locally made and the other is imported. Using the wheel tracking test device, the Marshall test device and the material test system (MTS), the high-temperature stability, water stability, low-temperature crack resistance and fatigue resistance of asphalt mixes with the same gradation were studied by means of comparative tests, in which one mix had added polyester fibres and the other mix did not. The results showed that polyester fibres do improve the performance of the asphalt mix. Polyester fibres are able to improve the high-temperature stability, mainly due to their stabilising and multi-directional reinforcing function. They also absorb the bitumen and thicken the bitumen film adhering to the aggregate, which strengthens the resistance of the asphalt mix to environmental disruption and water damage. Polyester fibres remain flexible at low temperatures. By interlacing vertically and horizontally, the fibres increase the elasticity of the asphalt mix and prevent cracks from developing and propagating in the mix at low temperature. Therefore, polyester fibres can improve the low-temperature performance of asphalt mixes significantly. As a result of their three-dimensional random distribution, the polyester fibres are able to block the propagation of cracks, increase the elastic recoverability and delay the loss of material stability and the appearance of rupture, which improves the fatigue resistance of the asphalt mix. Because the polyester fibres could improve the field performance of asphalt mixes comprehensively, they will be of great benefit to the engineering field.

KEYWORDS Polyester fibre, asphalt mix, strength formation mechanism, high-temperature stability, crack, fatigue.

1. INTRODUCTION

With the rapid development of the economy in China, traffic volumes have been increasing exponentially. The fast growth of heavy-load traffic places a huge demand on the nation's highway network, which is covered primarily with hot-mix asphalt concrete. Modifying the asphalt mix by adding additives to the bitumen or asphalt mix has proved to help improve the performance of asphalt pavements efficiently. Today, many types of additive are used in China, including lignin fibres, polyester fibres, organic fibres, mineral fibres, etc. Among these fibres, organic fibres have been found to be fragile and hard to mix during construction, while mineral fibres are harmful to human health and pollute the environment. Based on the overall evaluation of performance, environmental issues and economic issues for all available fibres, lignin fibres and polyester fibres are the most favourable for the purpose. Polyester fibres as a good additive for asphalt mixes have been widely used in asphalt pavements in recent years. This paper demonstrates that polyester fibres help to improve the performance of asphalt mixes by means of comparative tests on asphalt mixes with and without added polyester fibres. All the results will provide a useful reference for engineers.

2. MATERIALS

2.1 Bitumen binder

The bitumen SHELL AH-70 was used in the tests. Its properties are shown in Table 1.

Table 1. Properties of bitumen used in the tests

Item	Penetration (0.1 mm) (25 °C, 100 g, 5 s)	Ductility (cm) (5 cm/min, 15°C)	Softening point (°C) (R&B)	Density (g/cm^3) (15 °C)
Value	75	>100	49.6	1.035

2.2 Mineral aggregate

The technical properties of the mineral aggregate and filler are shown in Table 2.

Table 2. Technical properties of mineral aggregate and filler used in the tests

Item	**Apparent density (g/cm^3)**	**Crush value (%)**	**L.A. Abrasion value (%)**	**Degree of adhesion**
Basalt	2.956	13.2	14.2	5
Lime	2.786	19.8	22.4	5
Filler	2.800	–	–	–

2.3 Fibre

Two types of fibre were used in this test, namely Crackstop fibre made at ADFIL Corp. in Denmark and Roadfort fibre made in China. Their properties are presented in Table 3.

Table 3. Mechanical properties of fibres used in the tests

Type	Crackstop	Roadfort
Raw material	Polymerised polyester	Polymerised polyester
Colour	Natural (white)	Natural (white)
Length (mm)	6 ± 1.5	6 ± 1.5
Diameter (mm)	0.014 ± 0.005	0.014 ± 0.005
Density (g/cm^3)	1.36	1.36 ± 0.04
Melting point (°C)	>250	>265
Burning point (°C)	>540	>540
Tensile strength (MPa)	>500	>500
Break elongation (%)	50	33 ± 9

2.4 Mix gradations

The mixes AK-13A and the modified AC-20I developed in Jiangsu Province were selected. The gradation curves are shown in Figures 1 and 2.

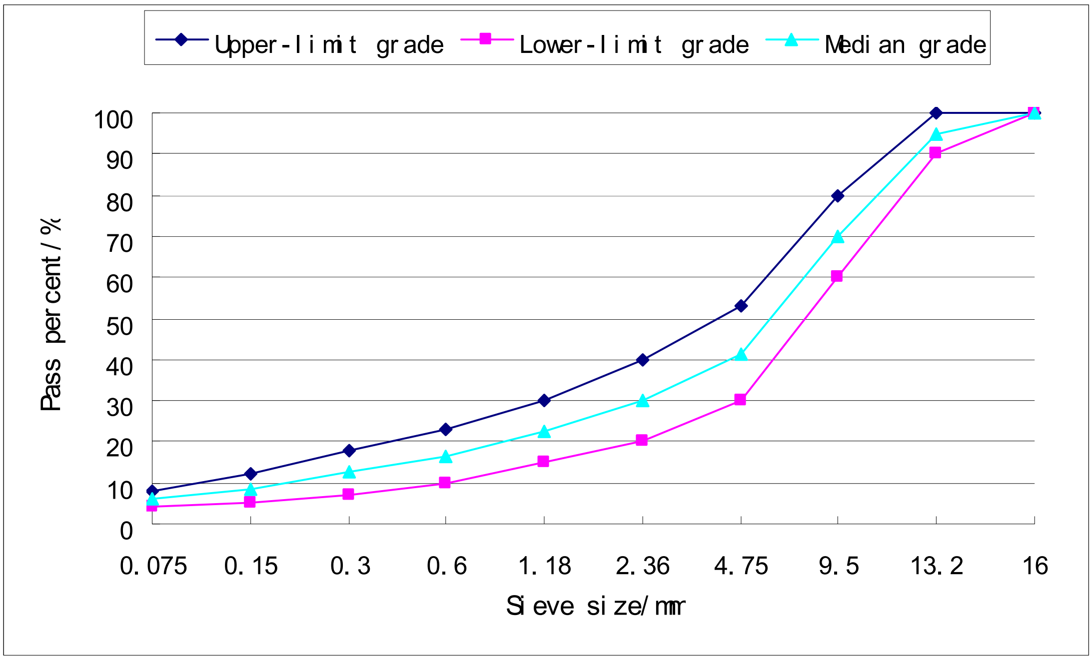

Figure 1. Gradation of mix AK-13A

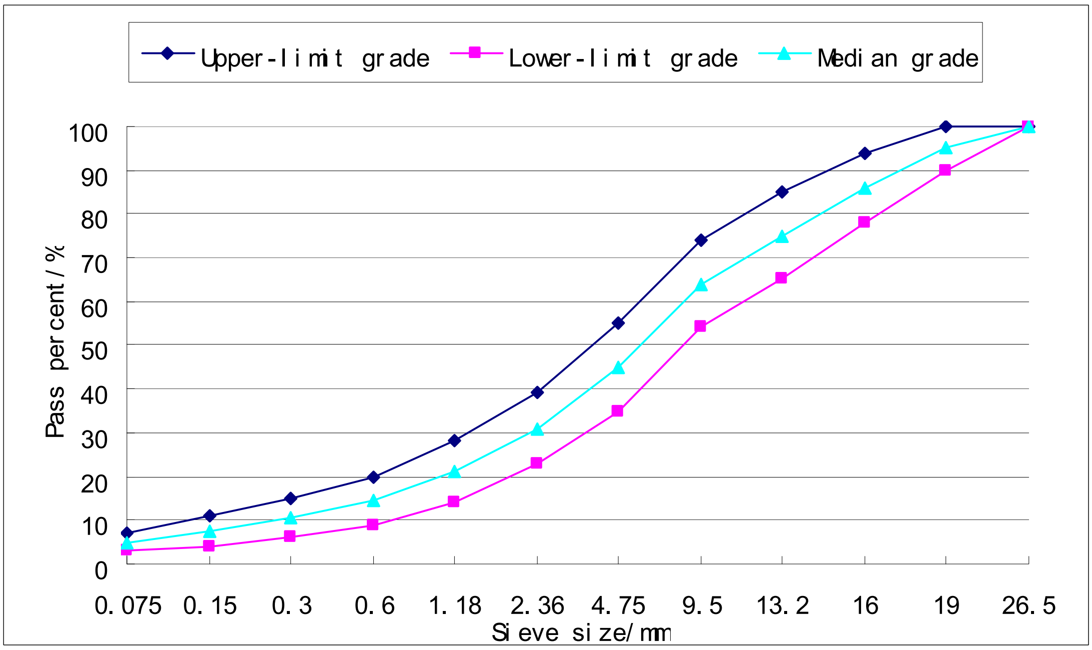

Figure 2. Gradation of mix modified AC-20I

2.5 Scope of research

These mixes with the same gradation and asphalt content were divided into two groups: one with polyester fibre added and the other without. By comparing the two mixes with regard to certain aspects, including high-temperature stability, water stability, low-temperature crack resistance and fatigue resistance, the differences in their performances are discussed.

3. TEST METHODS

The wheel tracking test is an engineering test method for simulating the effect of vehicles passing over the pavement and causing rutting. Due to the good correlation between laboratory test results and field measurements, the wheel tracking test is an important method for evaluating the rutting resistance of asphalt mixes. It was therefore chosen in this research to evaluate the high-temperature stability of asphalt mixes with and without fibres.

The residual stability and freeze-thaw fracture test was used to evaluate the water susceptibility of asphalt mixes with and without added fibres. The tensile strength ratio (TSR) is the ratio of the indirect tensile strength of a Marshall test specimen with and without the freeze-thaw cycle.

The low-temperature indirect tensile strength test was conducted to evaluate the low-temperature properties of the asphalt mixes. It is performed at -10 °C and at a loading rate of 1 mm/min.

Under repetitive loads passing over the pavement, the pavement surface will experience fatigue damage. The Marshall specimens and the indirect fatigue simulation test were employed to evaluate the fatigue resistance of the asphalt mixes with and without fibres.

4. RESULTS AND DISCUSSION

4.1 High-temperature stability

In the test, the wheel track resistance of an asphalt mix at high temperature is shown in the form of dynamic stability, which is tested under the specified temperature and load. Dynamic stability is the rate at which the wheel track deforms while the test wheel runs back and forth over the pavement specimen, which is equal to the number of passes resulting in 1 mm of deformation. The greater the dynamic stability, the better the high-temperature stability of the asphalt mix. In addition, the depth of the wheel track can be measured, which indirectly reflects the high-temperature stability.

Specimens 300 mm long, 300 mm wide and 50 mm thick were fabricated by a tyre-roller machine. The tests were conducted at 60 °C and the pressure of the rubber tyre was 0.7 MPa, with a total load of 78 kg. The tyres ran a distance of 230 mm ± 10mm, at a back-and-forth frequency of 42 passes/min. The dynamic stability (DS) is calculated as follows:

$$DS = \frac{(t_2 - t_1)\times N}{d_2 - d_1} \times C_1 \times C_2 \qquad (1)$$

Where: DS = dynamic stability of asphalt mix (pass/mm)

d_1 = deformation of specimen at time t_1 (mm)

d_2 -= deformation of specimen at time t_2 (mm)

C_1 = correction coefficient for different types of test device, which is 1.0 for the type that runs with a brace pole

C_2 = correction coefficient for the specimen, which is 1.0 for a specimen with a width of 300 mm made in a laboratory

N = number of wheel passes in one minute, i.e. 42 passes/min

The test results are shown in Table 4.

Table 4. Results of the wheel tracking test

Grade	Fibre content (%)	Deformation (mm)	DS (passes/mm)
AK-13A	0	7.780	840
	2 (Crackstop)	4.587	1 630
	2 (Roadfort)	4.667	1 590
Modified AC-20I	0	6.111	850
	2 (Crackstop)	3.817	1 806
	2 (Roadfort)	3.614	1 958

Table 4 shows that the asphalt mix with polyester fibre has a higher dynamic stability, with lower deformation, which suggests that adding polyester fibres could increase the resistance of asphalt mixes to rutting.

After polyester fibre has been added to the asphalt concrete, it becomes evenly distributed in the asphalt matrix. Because the size of the fibre is very small, the number of fibres is very large. The dispersed fibres form a network structure within the asphalt mix, which can enhance the elastic recovery and decrease the rutting depth and the speed of deformation. In addition, the fibre reinforcement can enhance the shear resistance of the mix. Moreover, the viscosity of the bitumen increases significantly due to the absorption of fibres, which will ultimately improve its strength. Polyester fibres can also improve the stability of the mix as they keep the bitumen film in a very stable state. The air voids in the fibre provide extra space for the expansion of bitumen when it happens, especially at high temperature in summer, which prevents bleeding (Peng, et al., 2003). All these factors contribute to improving the high-temperature stability of the asphalt mix.

4.2 Water susceptibility

The physical and mechanical performance of asphalt mixes is normally lowered when they are under water because of the reduced adherence between the bitumen and aggregate. The residual stability and freeze-thaw fracture tests were used to evaluate the water susceptibility of asphalt mixes with and without fibres.

Marshall specimens with a diameter of 101.6 ± 0.2 mm and a height of 63.5 ± 1.3 mm were used. The Marshall test device is used in the residual stability test, which provides a loading rate of 50 ± 5 mm/min. The specimen is loaded at this rate and the highest load (Marshall stability) is recorded.

$$MS_0 = \frac{MS_1}{MS} \times 100 \qquad (2)$$

Where: MS_0 = residual stability of specimen (%)

MS_1 = Marshall stability of specimen after 48 hours under water (kN)

The freeze-thaw fracture test was used to estimate the water stability of the asphalt mixes by measuring the ratio of the indirect tensile strength of the Marshall specimen with the freeze-thaw cycle. The tests were conducted at 25 °C at a loading rate of 50 mm/min.

$$TSR = (R_{T2} / R_{T1}) \times 100$$

Where: TSR = tensile strength ratio in freeze-thaw fracture test (%)

R_{T2} = splitting tensile strength of specimen after freeze-thaw conditioning cycle (MPa)

R_{T1} = splitting tensile strength of specimen without treatment (MPa)

The results are presented in Table 5.

Table 5. Results of the water stability test

Grade	Fibre content (%)	Residual stability value (%)	TSR (%)
AK-13A	0	84.5	71.1
	2 (Crackstop)	90.3	76.5
	2 (Roadfort)	92.5	74.1
Modified AC-20I	0	84.3	70.4
	2 (Crackstop)	93.2	77.9
	2 (Roadfort)	92.1	74.2

It can be seen from Table 5 that the residual stability and the TSR value both increase when polyester fibre is added to the bitumen, which suggests that polyester fibres could help to protect the asphalt mix from water damage. The theory of water stability is based on adhesion theory. In accordance with the mechanism of adhesion between bitumen and mineral aggregates, lowering the tensile force at the interface between the bitumen and mineral aggregates can result in a decrease in the water damage to the asphalt mix (Wu et al., 2003). Due to the absorption of the bitumen by the fibre, the free bitumen content is reduced and the adhesive strength is enhanced. This is the reason why the asphalt mixes with polyester fibres exhibited higher values for residual stability and TSR, and why the resistance to water damage is improved. It is concluded that the addition of fibres improves the water stability of asphalt mixes by increasing the adhesive strength between the bitumen and mineral aggregate to resist the ingress of water.

4.3 Low-temperature crack resistance

Bitumen is a rather temperature-sensitive material. Temperature variations cause its mechanical performance to vary greatly. When the ambient temperature drops, the strength of the mix increases and its adaptability to deformation decreases significantly, resulting in cracks and making it brittle. The low-temperature indirect tensile strength test is usually conducted to evaluate the low-temperature performance of asphalt mixes. The material test system (MTS) is used in the test at -10 °C and a loading rate of 1 mm/min.

$$R_T = 0.006287 P_T / h$$

$$\varepsilon_T = X_T \times (0.0307 + 0.0936\mu) / (1.35 + 5\mu)$$

Where: R_T = indirect tensile strength (MPa)

ε_T = tensile strain

X_T = horizontal deformation under the largest load (mm)

The results are shown in Table 6.

Table 6. Results of indirect tensile strength test

Grade	Fibre content (%)	Strength (MPa)	Strain (10^{-3})
AK-13A	0	3.053	4.1
	2 (Crackstop)	3.946	4.6
	2 (Roadfort)	3.703	4.4
Modified AC-20I	0	3.349	3.4
	2 (Crackstop)	4.284	4.3
	2 (Roadfort)	4.104	4.7

Table 6 shows that the splitting strength and the deformation properties improved greatly at low temperature in the mix with added polyester fibres. The reason may be that the fibres increase significantly the mix's resistance to splitting at low temperature. The fibres also contribute to flexibility at low temperature. The interlacing of the fibres vertically and horizontally improves the elasticity, which helps to reduce the propagation of cracks.

4.4 Fatigue resistance

Under repetitive loads, the pavement surface will experience fatigue damage. The Marshall specimens and indirect fatigue simulation test were performed to evaluate the fatigue resistance of the asphalt mixes. The MTS was used in the test at 25 °C, adopting a sine wave load with a frequency of 10 Hz. It was specified that the specimen should to be destroyed when its deformation reached 1.5 mm. The test results are presented in Table 7.

Table 7. Results of fatigue tests

Grade	Maximum load (N)	Fibre content (‰)	Fatigue life (passes)
AK-13A	1 500	0	24 100
		2 (Crackstop)	41 005
		2 (Roadfort)	45 231
	2 000	0	11 495
		2 (Crackstop)	21 413
		2 (Roadfort)	23 452
	2 800	0	4 151
		2 (Crackstop)	5 618
		2 (Roadfort)	6 675
Modified AC-20I	1 500	0	23 252
		2 (Crackstop)	41 618
		2 (Roadfort)	46 667
	2 000	0	10 735
		2 (Crackstop)	20 320
		2 (Roadfort)	25 367
	2 800	0	3 581
		2 (Crackstop)	5 773
		2 (Roadfort)	7 524

It can be seen from Table 7 that the polyester fibres were able to improve the fatigue life of the mix. The contribution of polyester fibres to the fatigue performance could be explained by the “silver line” theory and the crack development theory. The silver line theory states that stress concentration occurs where some interface or internal defect exists in an asphalt mix and subsequently induces cracks. As the deformation increases, the line along which stretching is orientated ruptures and changes into small cracks. Under repeated loads, these small cracks propagate and eventually rupture (Li et al., 1998; Li et al, 2004). In the mixes containing fibres, when the silver lines change into cracks, a large number of fibres at the interface block the cracks. In addition, the fibres absorb a lot of the energy that is needed to make the cracks expand. While the silver lines are developing, the fibres would change the direction of development of these lines, slow down the speed of propagation, and delay the destruction of the mixes. All these factors contribute notably to improving the fatigue durability of an asphalt mix.

5. CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

- Polyester fibres could improve the high-temperature stability notably, due to their effects of absorbing bitumen and providing stabilisation and reinforcement.
- Polyester fibres could absorb bitumen and also thicken the bitumen film adhering to the mineral aggregates, which would strengthen the resistance of asphalt mixes to environmental disruption and water damage.
- Asphalt with added polyester fibres appears to be flexible at low temperature. The interlacing of the fibres vertically and horizontally increases the elasticity of the asphalt mix. This prevents the onset and propagation of cracks, which improves the low-temperature performance of the asphalt mix significantly.
- Because of their three-dimensional random distribution in asphalt mixes, polyester fibres could block the propagation of cracks and improve the fatigue resistance of asphalt mixes.

6. REFERENCES

[1] Li, WL, Han, LN and Guan, NF, 2004. Influence of polyester fibre on asphalt mixes. Liaoning Communication Science and Technology, 2 pp 4 – 16 (in Chinese).

[2] Li, WG, Zhang, ZQ, Zhang DL, Zhang, J and Luan, F, 1998. Research on fibre reinforcement of asphalt pavements. Journal of Xi'an Highway University, 7 pp 235 – 238 (in Chinese).

[3] Peng, B, Li, WY and Dai, JL, 2003. Application of fibre in asphalt concrete. Highway Engineering of Central-South China, 6 pp 44 – 46 (in Chinese).

[4] Wu, SP, Xue, YJ and Zhang, DF, 2003. Research on asphalt concrete with polyester fibres. Journal of the Wuhan University of Science and Engineering, 12 pp 47 – 49 (in Chinese).