

Study on High Temperature Properties of Fiber-Free SMA Mixture

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Abstract: The high temperature performance of asphalt mixture is an important factor to determine pavement life. Through rut test, dynamic modulus test and repeated load creep test, the high-temperature properties of two kinds of SMA asphalt mixtures were compared by different indexes, and the performance characteristics of non-fiber SMA asphalt mixtures were evaluated. The dynamic stability of the mixture and the slope of the creep curve showed that the non-fiber SMA mixture had an advantage in rut development rate compared with ordinary SMA. The estimated road life and flow number Fn based on rutting showed that the non-fiber SMA mixture could bear nearly 80% more standard axle load than the normal SMA flow number Fn by 11%. When the permanent deformation of the mixture reaches the failure stage, the non-fiber SMA can bear more loads. The main curves of dynamic moduli of the two SMA mixtures at different reference temperatures are basically the same, and the dynamic moduli characterizing the mechanical properties of the mixtures have little difference. Compared with ordinary SMA mixture, the asphalt film thickness on the surface of non-fiber SMA mixture is thinner, and the skeleton effect between coarse aggregates is more prominent, which is an important reason for the improvement of high temperature stability of the mixture.

Keywords: Fiber-Free SMA Mixture, Dynamic Stability, Dynamic Modulus, Flow Number, High Temperature Performance

1. Introduction

The primary function of fibers in SMA mixture is to adsorb and stabilize asphalt [1]. Fiber can reduce asphalt leakage and oil flooding during construction of SMA mixture. Therefore, fiber is often considered as one of the indispensable components of SMA mixture [2]. The lignin fiber in the market is uneven in quality and strong in water absorption. Once the fiber in the mixture clumps, the stability of SMA property is seriously affected. At the same time, the fiber reduces the production efficiency of the mixture, and significantly increases the viscosity of asphalt margarine [3]. Mixing construction requires higher temperatures, which not only increases energy consumption and harmful gas emissions,

but also exacerbates asphalt aging. Therefore, it is necessary to explore the technical feasibility of SMA mixture without fiber.

In the United States, the state of New Jersey was the first to experiment with a fiber-free SMA mixture [4]. By reducing the construction temperature and improving the viscosity of asphalt, the problems of mixture leakage and oil flooding can be solved. Yu Shufan of Chongqing Transportation Research and Design Institute adjusted SMA mixture grading, Reduce the amount of coarse aggregate, Reduce the clearance rate of mixture and ore (15%), Then reduce the amount of asphalt binder 0.5%~0.8% [5-7]. Solve the leakage problem in the construction process of SMA mixture without fiber.

In this paper, the construction temperature of SMA mixture was reduced by using surface active warm mixing

agent. By changing the viscosity of asphalt during construction, the leakage of fiber free SMA mixture can be avoided [8-9]. The lack of fiber adsorption on asphalt of SMA without fiber, asphalt consumption is bound to reduce, it is necessary to study its high temperature performance.

2. Mixture Design

The Marshall design method was used to design the mix

ratio of non-fiber SMA mixture and ordinary SMA mixture. The two mixtures adopt the same gradation, as shown in Table 1. The fibra-free SMA mixture is composed of 5.6% oil-stone ratio and 0.06% ((by mass of the asphalt) surface active warm mix Evotherm M1. The common SMA mixture consists of 6.0% oil-stone ratio and 0.3% lignin fiber (by mass of the mixture). The volume parameters of the two SMA mixtures determined by Marshall test are shown in Table 2.

Table 1. Gradation of two SMA mixtures.

Sieve (mm)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Mixture grading	100	90.7	63.9	30.3	24.1	20.3	14.5	13.2	11.9	11.4
Grading range	100	90	50	20	15	14	12	10	9	8
	100	100	75	34	26	24	20	16	15	12

Table 2. Marshall test volume parameters of two SMA mixtures.

Mixture	Optimum oil-stone ratio	Void fraction (%)	VMA (%)	VFA (%)	Leakage (155°C)	Stability (KN)
Ordinary SMA	6.00%	3.9	16.9	75.8		7.7
Fiber-free SMA	5.60%	4.1	16.6	75	0.08	7.55

3. High Temperature Performance Analysis Based on Rut Test

The non-fiber SMA mixture is formed at 150°C for the rutting plate, and the ordinary SMA is formed at 170°C. The rut test results are shown in Table 3. The dynamic stability of fiber-free SMA mixture was 8% higher than

that of ordinary SMA. The test results show that the void fraction of different rutting plates has little difference. Void fraction has little effect on rut development in stable creep stage. It can be seen that lignin fiber in ordinary SMA does not contribute much to improving the high temperature performance of the mixture. Less asphalt content is used in the fiber-free SMA mixture, which increases the rutting resistance of the mixture.

Table 3. Rut test results of two SMA mixtures.

Mixture	number	60min Deformation (mm)	Dynamic stability (frequency /mm)	60min Mean deformation (mm)	Average dynamic stability (frequency /mm)
Fiber-free SMA	1	1.617	4701	1.940	6013
	2	1.957	6774		
	3	2.247	6563		
Ordinary SMA	1	2.75	4846	2.577	5568
	2	2.233	5294		
	3	2.749	6565		

The dynamic stability only considers the slope of the stable deformation period, which is an indicator of the rutting development rate of the mixture at the stable stage, but does not consider the initial compaction deformation. It is different from the total rut formed during actual road operation. The rut test results also show that the total accumulated deformation has little relationship with the dynamic stability. The direct result of the rut test is the rut depth of the corresponding number of times, which takes into account the total amount of compaction and creep of the mixture. As can be seen from Table 3, the rut deformation of fiber-free SMA mixture in 60min is significantly smaller, and the deformation is 75% of that of ordinary SMA.

“Research on Asphalt Pavement Structure Design Method Based on Multiple Indexes” considering the influence of ambient temperature, contact stress, loading times and voidage on rut, a rut prediction model based on rut

deformation under standard test conditions was established [10-12], as shown in formula (1).

$$R=0.118K(\mu)^{0.4792}\left(\frac{T}{T_0}\right)^{2.9291}\left(\frac{P}{P_0}\right)^{1.8}\left(\frac{N}{N_0}\right)^{0.4792}\left(\frac{V}{V_0}\right)^{0.8276}\left(\frac{h}{h_0}\right)R_0 \quad (1)$$

In the formula: R- permanent deformation of asphalt layer;
 T_0 -rut test corresponding temperature; T - pavement asphalt layer temperature;

P_0 -rut test contact pressure; P -pavement asphalt layer contact pressure;

N_0 -rut test loading times; N - pavement asphalt layer loading times;

V_0 -rut test void fraction; V - pavement asphalt layer void fraction;

h_0 -rut test thickness; h - pavement asphalt layer thickness;

μ -design lane lateral distribution coefficient

K -correction factor

SMA-13 is widely used in surface layer, and its resistance to permanent deformation is an important index to determine its service life. The reference pavement structure (asphalt surface layer 18cm) is adopted, and the rut depth of the surface layer is 30% (4.5mm) of the allowable rut depth of the highway surface layer (15mm). Combined with the

volume parameters of indoor rutting test, deformation R_0 (as shown in Table 4) and the investigated reference equivalent temperature in different regions of Hebei Province, the service life of the two SMA types used for high-speed surface layers in different regions was calculated based on permanent deformation. As shown in Table 5.

Table 4. Calculation parameters of permanent deformation of asphalt layer.

Mixture	P (MPa)	V_o (%)	V (%)	H (mm)	h_o (mm)	R_0 (mm)
Fiber-free SMA	0.7	3.5	5.9	40	50	1.94
Ordinary SMA	0.7	3.8	5.9	40	50	2.577

Table 5. The service life of two surface SMA based on permanent deformation.

Area	Reference equivalent temperature (°C)	Fiber-free SMA ($\times 10^6$ times)	Ordinary SMA ($\times 10^6$ times)
Zhangjiakou	16.8	165.4	92.1
Chengde	16.6	178.0	99.0
Qinhuangdao	17.6	124.5	69.3
Tangshan	19.2	73.2	40.7
Baoding	20.4	50.6	28.1
Cangzhou	20.8	44.9	25.0
Langfang	20.1	55.4	30.8
Shijiazhuang	21.5	36.7	20.4
Hengshui	20.9	43.6	24.3
Xingtai	21.5	36.7	20.4
Handan	21.6	35.7	19.9

As can be seen from Table 5, the total deformation of non-fiber SMA in rut test is significantly less than that of ordinary SMA. When the surface layer produces the same permanent deformation, non-fiber SMA can bear nearly 80% more standard axle load than ordinary SMA. When the rut depth of the surface layer is the same, ordinary SMA can bear heavy traffic ($> 25 \times 10^6$ axle loads) in the northern part of Hebei Province, and can bear heavy traffic ($12 \times 10^6 \sim 25 \times 10^6$ axle loads) in the central and southern parts of Hebei Province with high temperature and long duration in summer. Fiber-free SMA can bear heavy traffic in all areas of Hebei Province. It can be seen that fiber-free SMA has better durability in terms of permanent deformation.

4. High Temperature Performance Analysis Based on Dynamic Modulus

The physical and mechanical properties of asphalt mixture are closely related to temperature and load frequency, so the conventional indexes cannot fully reflect the pavement properties of asphalt mixture [13]. The dynamic modulus is close to the working state of pavement, so it becomes the parameter to evaluate the performance index of asphalt mixture and the calculation of pavement structure [14].

Rotary compaction instrument (PCG3) was used to form $\Phi 150\text{mm} \times H 170\text{mm}$ cylindrical specimen, and core drilling machine was used to drill $\Phi 100\text{mm} \times H 150\text{mm}$ specimen. The dynamic modulus test was carried out at 5°C, 20°C, 35°C and 50°C, and the heat was kept in the response temperature incubator for no less than 5h before the test. The test results are shown in Table 6, and the main curves of dynamic moduli with 5°C, 20°C and 50°C as reference temperatures are shown in Figure 1.

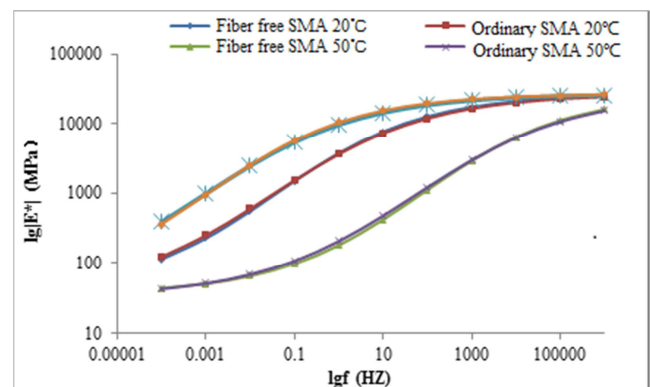


Figure 1. Main curves of dynamic moduli of two SMA at different reference temperatures.

Table 6. Dynamic modulus test results of two SMA mixtures.

Mixture	Test temperature	Dynamic modulus (MPa)					
		0.1HZ	0.5HZ	1HZ	5HZ	10HZ	25HZ
Ordinary SMA	5°C	5839	8377	9460	12225	13230	14592
	20°C	1370	2589	3304	5468	6537	8043
	35°C	296	479	614	1237	1662	2506
	50°C	134	182	211	369	497	733

Mixture	Test temperature	Dynamic modulus (MPa)					
		0.1HZ	0.5HZ	1HZ	5HZ	10HZ	25HZ
Fiber-free SMA	5°C	6172	8839	10034	12974	14181	15744
	20°C	1492	2594	3384	5761	6913	8570
	35°C	223	370	484	1018	1413	2183
	50°C	120	167	199	364	506	772

According to the test results, the dynamic modulus of non-fiber SMA under different frequency loads at 5°C and 20°C is slightly larger than that of ordinary SMA, which may be related to the small size of non-fiber SMA oil stones and the thin thickness of asphalt film between aggregates. The modulus difference of the two mixtures decreases with the increase of temperature. The main curves of dynamic modulus at different reference temperatures are basically consistent, and there is no significant difference between the

two types of SMA dynamic moduli.

Phase Angle is an important index to characterize the viscoelastic properties of materials. For asphalt mixtures with viscoelastic properties, $E^*/\sin\phi$ can better reflect the rut resistance at high temperature, and the higher the value, the better the rut resistance. The phase angles and $E^*/\sin\phi$ of different frequencies of the two SMA mixtures at 50°C are shown in Table 7, and there is no significant difference between the phase angles and $E^*/\sin\phi$ of the two mixtures.

Table 7. Phase angles of different frequencies and $E^*/\sin(\phi)$ of two SMA mixtures at 50°C.

Loading frequency (Hz)		0.1	0.5	1	5	10	25
Phase Angle	Ordinary SMA	21.21	24.9	27.48	31.6	33.28	37.11
	Fiber-free SMA	20.69	24.61	27.46	32.15	33.99	38.11
$E^*/\sin(\psi)$	Ordinary SMA	371.21	432.27	457.48	704.41	905.91	1215.22
	Fiber-free SMA	340.92	401.58	431.12	684.79	904.57	1250.62

5. High Temperature Performance Analysis Based on Repeated Load Creep Test

Asphalt mixture has obvious viscoelastic properties, creep deformation is the internal cause of rutting formation. The creep test can reflect the characteristics of viscoelastic materials well and simulate the deformation mechanism of pavement materials when rutting occurs [15]. Repeated load creep tests were carried out on ordinary SMA and fiber-free SMA mixture respectively. The high temperature stability of the two kinds of SMA was compared by the creep characteristics of the mixture at high temperature.

The creep process of asphalt mixture under load is divided into three stages. The creep curve properties of the mixture at different stages under load can be used to characterize its high temperature deformation characteristics. In the first stage, the compression degree and volume of the creep curve have a great influence, which has a poor correlation with the high temperature deformation capacity of the mixture. The third stage is the characteristic of the mixture after shear failure. The surface layer material should not enter this stage in the pavement design, and its curve characteristics have no reference significance for the evaluation of the performance of the mixture; The second stage reflects the shear deformation resistance of the mixture when the pavement enters the stable stage. The slope of the curve represents the shear deformation rate of the mixture. The number of loads that the mixture can bear before entering the failure stage is the flow number F_n , which can

effectively measure the durability of the asphalt mixture at high temperature.

Rotary compactor (PCG3) was used to shape $\Phi 150\text{mm} \times H170\text{mm}$ cylindrical specimen. The sample $\Phi 100\text{mm} \times H150\text{mm}$ was drilled by a core drilling machine. The creep test was carried out at 50°C without confining pressure by using the basic performance tester of AMPT asphalt mixture produced by IPC of Australia Company.

Table 8. Creep test results of two SMA mixtures.

Mixture	Creep test index			
	F_n (times)	sp (%)	sp/F_n	Slope b
Ordinary SMA	3177	3.82	1.20×10^{-4}	1.67×10^{-3}
Fiber free SMA	3526	2.86	0.81×10^{-4}	1.06×10^{-3}

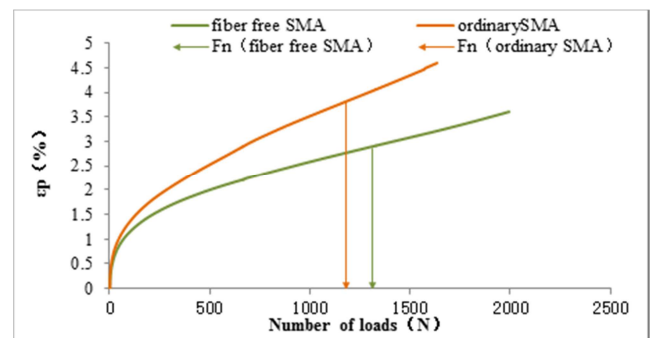


Figure 2. Creep buckling of two SMA mixtures under repeated loading test.

As shown in Table 8 and Figure 2:

- (1) The flow times of fiber free SMA mixture was 11% higher than that of ordinary SMA. It can be seen that under the same high temperature condition, when the permanent deformation of the mixture reaches the third stage, the non-fiber SMA mixture can bear more loads.
- (2) The strain corresponding to the flow number F_n of the

fiber-free SMA mixture is 75% of that of the ordinary SMA, which is the same as the difference of the total deformation of the two mixtures in 60min in the rut test. It can be seen that the permanent deformation of non-fiber SMA is smaller when it reaches the failure stage.

- (3) The slope of creep curve of fiber-free SMA mixture in the stable stage (the second stage) is significantly lower than that of ordinary SMA, indicating that the rut development rate of fiber-free SMA in the stable stage is slower.

6. Conclusion

Through rut test, dynamic modulus test and repeated load creep test, the difference of high temperature performance between fiber-free SMA mixture and ordinary SMA mixture was analyzed, and the following conclusions were drawn:

- (1) The dynamic stability of the mixture and the slope of the creep curve showed that the non-fiber SMA mixture had an advantage in rut development rate compared with ordinary SMA.
- (2) The deformation of F_n in the rut test and repeated creep test of fiber-free SMA mixture is 75% of that of common SMA, showing better deformation resistance.
- (3) Based on the asphalt rutting prediction model, the non-fiber SMA mixture can bear nearly 80% more standard axle load than ordinary SMA under the same climate and pavement structure conditions. The flow frequency of fiber-free SMA mixture was 11% higher than that of ordinary SMA. The fiber-free SMA mixture can withstand more loads before the permanent deformation reaches the failure stage.
- (4) The main curves of dynamic moduli of the two SMA mixtures at different reference temperatures are basically the same, and the dynamic moduli characterizing the mechanical properties of the mixtures have little difference.

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