Research on Pavement Performance of High Strength And Toughness Ultra-thin Overlay Asphalt Mixture

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Abstract. Composite modification of SBS modified asphalt, which is widely used in engineering applications, with high strength and toughness modifier, and its application in SMA asphalt mixture. Indoor experimental research was conducted on the composite modified SMA asphalt mixture, and compared with ordinary SBS modified SMA asphalt mixture. Experimental analysis shows that high strength and toughness modifier can replace wood fibers in equal proportions for the stability of asphalt emulsion in SMA asphalt mixtures. High strength and toughness modifier can significantly improve the high-temperature stability, low-temperature crack resistance, water stability, and fatigue resistance of asphalt mixtures, and extend the service life of ultra-thin overlay technology.

Keywords: Ultra-thin overlay; High strength and toughness modifier; SMA asphalt mixture; Pavement performance

1 Introduction

The surface layer of asphalt pavement often experiences early diseases such as fatigue cracking, water damage, rutting, and polishing shortly after opening to traffic due to long-term exposure to natural factors such as wind, sun, and rain, as well as the effects of driving loads and vehicle braking [1,2], resulting in surface functional degradation and actual service life not reaching the design life. In order to meet the functional needs of the surface layer, a high-performance ultra-thin overlay maintenance process is directly added to the surface layer of the old or new road surface, which has been widely promoted and applied in high-grade highways [3-5]. It can effectively improve the surface functions of the road surface such as crack resistance, anti-skid, anti rutting, and smoothness, with a thickness of generally 15-25mm.

SMA asphalt mixture has become one of the most commonly used types of asphalt mixture for ultra-thin overlay due to its excellent road performance[6-8]. However, in extreme temperature, heavy traffic and other service environments, the actual service life of SMA asphalt mixture ultra-thin overlay still cannot meet expectations. On the one hand, the road performance of SMA asphalt mixture cannot meet the requirements

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of the above service environment. On the other hand, the construction and workability of SMA asphalt mixture are insufficient, often leading to diseases such as oil bleeding and rutting on the road surface due to uneven dispersion of fibers, which affects the service life of the road surface [9-11]. Therefore, this article conducts various road performance studies on SMA asphalt mixtures with high strength and toughness modifier, and compares them with conventional SMA asphalt mixtures, providing scientific basis for the selection of high-performance ultra-thin overlay materials.

2 Raw Material and Mix Design

2.1 Properties of Raw Materials

The mineral materials used in this experiment are basalt with a size of 5-10mm, limestone with a size of 0-3mm, and limestone powder produced in Shanxi. The asphalt used is SBS modified asphalt (I-D) produced in Shanxi. The technical indicators are shown in Table 1.

Table 1. Technical index of SBS modified asphalt

Test item		Result	Specification	Test Method
Penetration(25℃), dmm		56	40-60	T0604-2011
Softening point, ℃		78	≥70	T0606-2011
Ductility(5℃), cm		34	≥20	T0605-2011
Elastic Recovery(25℃), %		92	≥75	T0662-2000
Storage Stability, ℃		1.7	≤2.5	T0661-2011
Viscosity (135℃), Pa.s		2.4	≤3.0	T0625-2011
RTFOT(163℃, 85min)	Mass loss, %	0.3	±1.0	T0610-2011
	Penetration of residue, %	71.6	≥65	T0610-2011
	Ductility(5℃), cm	18	≥15	T0610-2011

The high strength and toughness modifier used is an independently developed additive, which is prepared by various additives such as epoxy based oil absorbing resin, polymer elastomer, compatibilizer, etc. through a certain molding process. It is a powder like particle with a moisture content of 0.4%, and its appearance is shown in Figure 1. The fiber used is commercially available wood fiber, with a length of 6mm.

Fig. 1. High strength and toughness modifier and wood fiber

The testing results of all raw materials meet the relevant regulatory requirements.

2.2 Design of Mineral Grading

The mineral aggregate gradation design of ultra-thin overlay asphalt mixture needs to fully consider the anti-skid performance, noise reduction, and water sealing effect on the basis of ensuring the road performance of the asphalt mixture. Based on past engineering experience, the initial designed composite SMA-10 grading curve is shown in Figure 2.

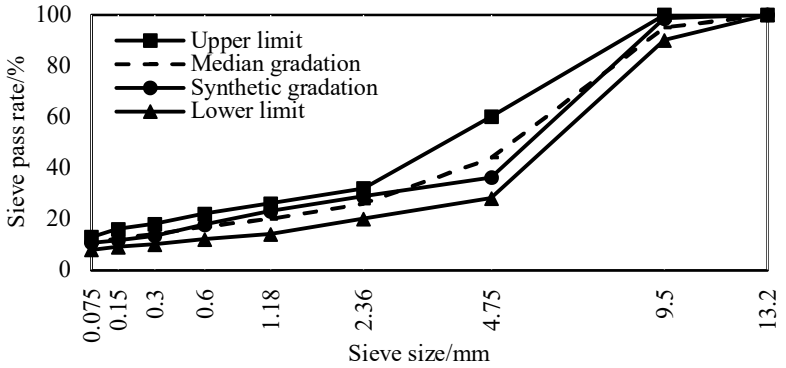

Fig. 2. Synthetic SMA-10 grading curve

2.3 Determine the Optimal Oil Stone Ratio

According to the designed mineral aggregate composite gradation, different asphalt dosages were selected for Marshall compaction tests. SBS modified asphalt mixture was mixed with 0.4% wood fiber, and high strength and toughness asphalt mixture was mixed with 0.4% high strength and toughness modifier. The forming conditions for Marshall specimens are: mixing temperature of 175℃-185℃, compaction forming temperature of 165℃-175℃, and double-sided compaction times of 50 times. The test results of two types of asphalt mixtures are shown in Table 2.

Table 2. Test results of two SMA asphalt mixtures

Test item	SBS modified asphalt mixture	High strength and tough asphalt mixture	Specification
Optimum oil stone ratio, %	6.2	6.8	/
Voidage, %	3.2	3.6	3~4
Voids of Mineral Aggregate, %	17.3	18.6	≥17.0
Asphalt saturation, %	79.8	80.6	75~85
Marshall stability, kN	8.2	10.9	≥6.0
Schellenberg leakage loss, %	0.03	0.04	≤0.1
Water-immersion dispersion Loss, %	7.8	1.5	≤15

The optimal asphalt stone ratio for SBS modified asphalt mixture and high strength and toughness asphalt mixture is 6.2% and 6.8%, respectively. The various volumes of Marshall specimens meet the relevant specification requirements. The high strength and toughness asphalt mixture still has a high asphalt content without relying on fibers, indicating that the oil absorbing component in the high strength and toughness modifier has played a role and achieved the expected effect. It is worth mentioning that the latter's immersion and scattering loss rate is much lower than the standard requirements and SBS modified asphalt mixture, greatly reducing the possibility of scattering and particle damage on ultra-thin overlay.

3 Performance test

3.1 High Temperature Stability

This article uses dynamic stability rutting tests at 60 ℃ and 0.7MPa to test the high-temperature stability of the two asphalt mixtures mentioned above. The test uses a wheel roller forming machine to roll the specimens back and forth 8 times to form them. The variation curve of rutting depth with rolling time is shown in Figure 3.

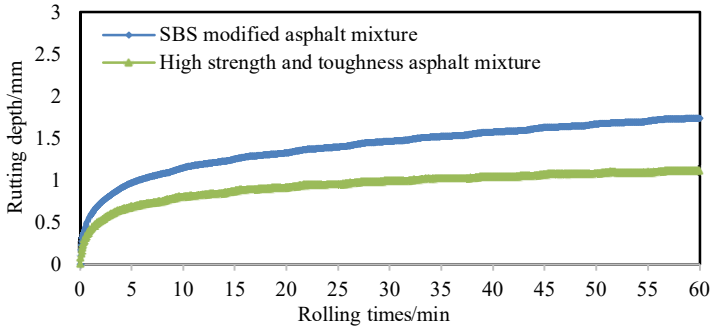

Fig. 3. The variation curve of rut depth with rolling time

From Figure 3, it can be seen that the rut depth of both asphalt mixtures gradually increases with the increase of rolling time, but the rut depth of high strength and toughness asphalt mixtures increases more slowly. The dynamic stability test results of two types of asphalt mixtures are shown in Table 3.

Table 3. Dynamic stability test results of two types of asphalt mixtures

Test item	SBS modified asphalt mixture	High strength and tough asphalt mixture
Rutting depth (mm)	1.741	1.114
Dynamic stability (times/mm)	5575	13404

The results in Table 3 also indicate that compared with SBS modified asphalt mixture, the final rut depth of high strength and toughness asphalt mixture is reduced by

36%, and the dynamic stability is 2.4 times that of the former, which can effectively resist the occurrence of pavement rut diseases under the action of driving loads. The main reason for this phenomenon may be the modification effect of epoxy based components in high strength and toughness modifier on asphalt, thereby improving the shear strength of asphalt mixtures.

3.2 Low Temperature Stability

In order to better evaluate the crack resistance of asphalt mixtures in low-temperature environments, this paper adopts two testing methods: three-point beam bending test at -10℃ and SCB semi-circular bending test. The SCB semi-circular bending test is conducted according to AASHTO TP124-2016, with a diameter of 150mm, a thickness of 50mm, and a pre cut depth of 15mm for the semi-circular specimen. The fracture energy index is mainly used to evaluate the crack resistance of asphalt mixtures.

Table 4. Low temperature crack resistance test results of two asphalt mixtures

Test item	SBS modified asphalt mixture	High strength and tough asphalt mixture	Test Method
Bending strain(-10℃, με)	2838	3420	T0715-2011
SCB breaking energy (-10℃, J/m^2)	15055	33806	AASHTO TP124-2016

The results in Table 4 indicate that compared to SBS modified asphalt mixture, high strength and toughness asphalt mixture has a larger low-temperature bending strain value, indicating that it has greater low-temperature deformation resistance. The fracture energy index reaches 2.2 times that of the former, indicating that high strength and toughness asphalt mixture can better absorb fracture stress and achieve the effect of resisting low-temperature cracking. The possible reason for this phenomenon is still the joint effect of the oil absorbing component of high strength and toughness modifier and the elastic substrate on SBS modified asphalt.

3.3 Water Stability

This article uses two testing methods, residual stability and freeze-thaw splitting residual strength ratio, to evaluate the water damage resistance of asphalt mixtures. The test results are shown in Table 5.

Table 5. Water stability test results of two types of asphalt mixtures

Test item	SBS modified asphalt mixture	High strength and tough asphalt mixture	Test Method
Residual stability of immersion (%)	93.3	96.5	T0709-2011
Ratio of freeze-thaw splitting strength (%)	84.7	101.7	T0729-2000

From the comparison of the results of the two technical indicators mentioned above, it can be seen that regardless of long-term immersion at high temperatures or freeze-thaw cycles in high and low temperature environments, compared with SBS modified asphalt mixtures, high strength and toughness asphalt mixtures have better water stability performance. The test results of freeze-thaw splitting residual strength ratio exceed 100%, indicating that freeze-thaw cycles still have a certain promoting effect on the strength growth of this type of asphalt mixture.

3.4 Anti-fatigue Performance

This article uses a four point beam bending fatigue test to evaluate the anti fatigue performance of two asphalt mixtures under repeated bending loads. The test temperature is 15℃, the loading frequency is 10Hz, and the loading mode is a continuous sinusoidal mode controlled by 800με. The length, width, and height dimensions of the strain specimens are 380mm, 63.5mm, and 50mm, respectively. The variation curves of the flexural modulus of two asphalt mixtures with fatigue cycles are shown in Figure 4.

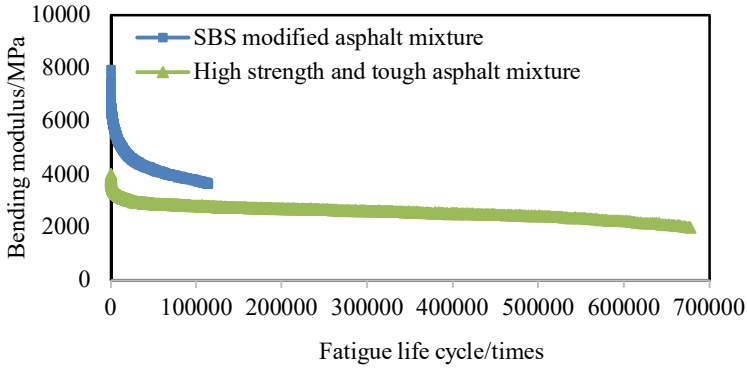

Fig. 4. Bending fatigue test of two asphalt mixtures

From Figure 4, it can be seen that throughout the bending fatigue test loading process, the bending modulus of SBS modified asphalt mixture is always greater than that of high strength and toughness asphalt mixture. However, as the loading continues, the decay rate of the former's bending modulus is much greater than that of the latter, ultimately resulting in a fatigue life of only 17% for the former (114360 cycles) compared to the latter (677550 cycles). The asphalt content has a significant impact on the fatigue resistance of asphalt mixtures, and the excellent fatigue resistance of high-strength and tough asphalt mixtures is still due to the strong adsorption and stabilization effect of high strength and toughness modifier on high content asphalt[12].

4 Conclusions

The results of this study indicate that using high strength and toughness modifier in equal proportions instead of wood fibers for SMA asphalt mixtures, and composite modification with SBS modified asphalt to produce high strength and toughness asphalt mixtures, can significantly improve the high temperature stability, low temperature crack resistance, water damage resistance, and fatigue resistance of asphalt mixtures due to the combined effect of its epoxy based oil absorbing component and elastic substrate on SBS modified asphalt. It can be used as a surface layer material for high-grade highway maintenance projects in extreme high or low temperature climates, heavy traffic and other environments, as well as for the surface wear layer of new roads, extending the service life of the pavement.

Due to the use of expensive high strength and toughness modifier and high asphalt content, the cost of ultra-thin overlay engineering increases for high strength and toughness asphalt mixtures, which is not conducive to the large-scale promotion and application of technology. The next step is to further optimize the mineral gradation of high-strength and tough modifier and asphalt mixtures, and expand them to application scenarios such as steel bridge deck paving.

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