

Fatigue Properties of Rubber Modified SMA Asphalt Mixture

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Abstract: To evaluate fatigue properties of rubber modified SMA asphalt mixture, based on optimizing the preparation process of rubber asphalt, the splitting fatigue tests of three kinds of asphalt mixture is carried out including ordinary asphalt, modified asphalt with rubber powder and SBS modified asphalt. And the freezing and thawing conditions were considered in the tests. The results show that rubber powder can improve the fatigue properties of SMA asphalt mixture, but the modified effect of rubber powder is not as good as SBS modifier, the fatigue properties of asphalt mixture are deteriorated by freeze-thaw conditions, the deterioration degree of rubber modified asphalt mixture is less than SBS modified asphalt mixture, but rubber modified asphalt mixture has better freeze-thaw durability.

1 Introduction

The accumulation of waste tire not only occupies land, but also seriously pollutes environment. At present, rubber bitumen as a kind of environmental-friendly bitumen has been widely used^[1-3]. The results of relevant research indicate that adding rubber powder grinded from waste tire into asphalt mixture can obviously improve pavement performance and prolong useful life of asphalt pavement^[4-6].

Due to the existence of crumb rubber, the compatibility between rubber bitumen and gradation should be considered during its use. Li Peili^[7] carried out volumetric parameters test and pavement performance test for gap gradation, continuous gradation and American gradation. Through comparison and selection, gap-graded rubber asphalt mixture has better pavement performance because of its excellent skeleton interlocking structure. SMA asphalt mixture has been widely used in the surface layer of bituminous pavement because of its excellent pavement performance. Therefore, gap-graded SMA asphalt mixture which rubber powder is mixed into has a good application

prospect.

Relevant research results show that ^[8,9] rubber modified SMA asphalt mixture shows excellent performance. But the durability of rubber modified SMA asphalt mixture is referred less, and there is no relevant report on the effect of freeze-thaw conditions on its fatigue properties. Therefore, considering freeze-thaw conditions, the influence of rubber powder on the fatigue properties was evaluated by comparing SMA asphalt mixture which rubber powder is added into or not.

2 Design of Test Plan

In order to fully evaluate the influence of rubber powder on the fatigue properties of SMA asphalt mixture, the performance comparison of three kinds of asphalt mixtures, including ordinary SMA-13 asphalt mixture, ordinary SMA-13 asphalt mixture with rubber powder and SBS modified SMA-13 asphalt mixture are carried out. Firstly the reasonable manufacturing technique is determined by considering the stirring temperature and mixing time of rubber bitumen. Then the optimum asphalt

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content of three asphalt mixtures is determined by Marshall method, and the stress-controlled indirect tensile

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fatigue test of Marshall specimens is carried out under the optimum asphalt content.

To consider the influence of freeze-thaw conditions on the fatigue properties of various asphalt mixtures, the fatigue tests were conducted after 0 (non-condition), 1, 3 and 5 freeze-thaw cycles respectively. The freeze-thaw circulation conditions are as follows: the specimen is put into a plastic bag after vacuum water-retention; 10 mL water is added; the specimen is put into the mouth of the bag and kept in thermostatic water tank at -18°C for 16 hours. Then the specimen is taken out, immediately put into the 60°C thermostatic water tank, removed the plastic bag, and kept warm for 24 hours.

3 Manufacturing Technology of Rubber bitumen

Stirring process of rubber bitumen can be divided into dry method and wet method. The performance of rubber asphalt mixture prepared by wet method is better than that by dry method. Therefore, this study employed wet method to prepare rubber bitumen. When using high-speed shearing equipment to produce rubber bitumen, the viscosity of rubber bitumen will decrease with the increase of stirring time. At the high-speed shearing process, the shearing equipment will further refine the rubber powder, making crumb rubber continue to decline, so the viscosity continues to decline. Therefore, high-

speed shearing equipment is not suitable for rubber bitumen production. Simple blade stirring is used in this study. The rotational speed is 250r/min when stirring.

In the production of rubber modified bitumen, crumb powder must be fully swelled in bitumen to give full play to the effect of modification. The swelling degree of rubber powder in bitumen is closely related to stirring temperature and mixing time. Therefore, stirring temperature and mixing time are important indexes which affect the performance of rubber bitumen. Although there have been many research results on the production process of rubber modified bitumen^[7-9], considering the compatibility between bitumen and rubber powder, this study evaluated the influence of mixing time and stirring temperature on the performance of rubber modified bitumen, to determine the production process of indoor rubber modified bitumen.

In this study, the AH-70 oil bitumen and 60 mesh oblique tire rubber powder to prepare rubber bitumen is used, in which the rubber powder content was 18%. The three indexes (penetration, softening point and ductility) of rubber modified bitumen prepared under different stirring temperature and mixing time are shown in Figure 1 and Figure 2. When studying the effect of stirring temperature, the same stirring time of 30min was adopted. When studying the effect of mixing time, the same stirring temperature of 180°C was adopted.

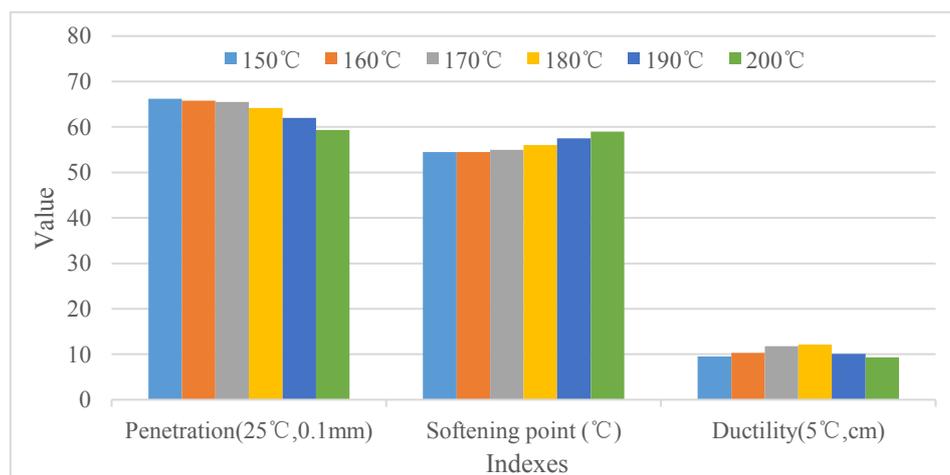


Figure 1 Indexes of rubber modified bitumen produced at different stirring temperatures

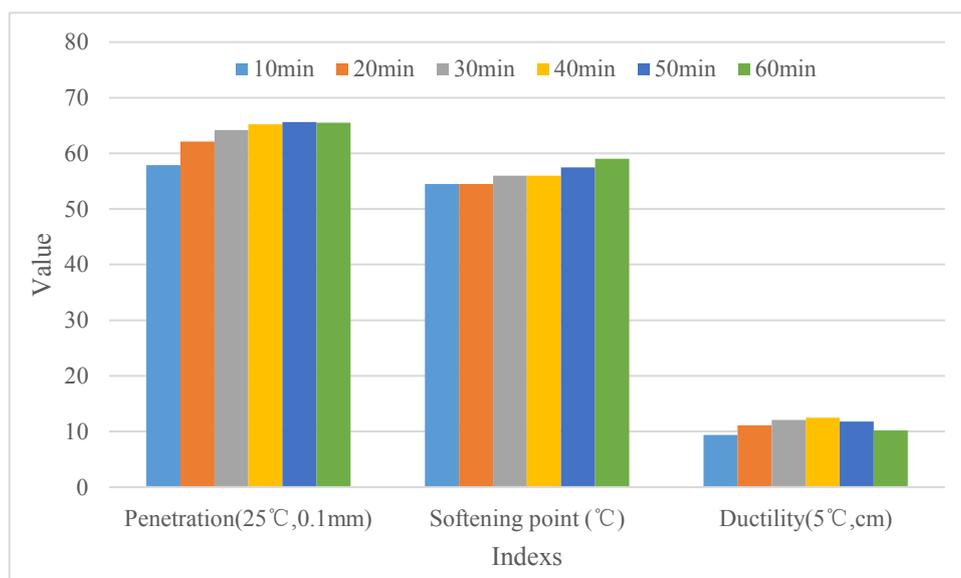


Figure 2 Indexes of rubber modified bitumen produced by different mixing time

It can be seen from the Figure 1 and Figure 2 that stirring temperature and mixing time have certain influence on the three indexes of rubber bitumen. With the increase of stirring temperature and mixing time, penetration and softening point will increase, while ductility will first increase and then decrease, mainly because the appropriate increase of temperature and time can make rubber powder fully swelling and work at full capacity. When the temperature and time increase further, the aging makes ductility of rubber bitumen change, indicating that there is an optimum value in the process of rubber bitumen

production, whether stirring temperature or mixing time. Based on the results of this study, the process of stirring samples at 180°C for 40 min is better.

In addition to the three major indexes, viscosity is a very important technical index of rubber modified bitumen, and the Brinell viscosity value of 170~180°C is usually chosen as index to evaluate the viscosity of rubber bitumen. In this study, the viscosity of rubber bitumen was evaluated by using Brinell viscosity index at 175°C. The viscosity of rubber modified bitumen produced by different processes at 175 °C is shown in Figure 3:

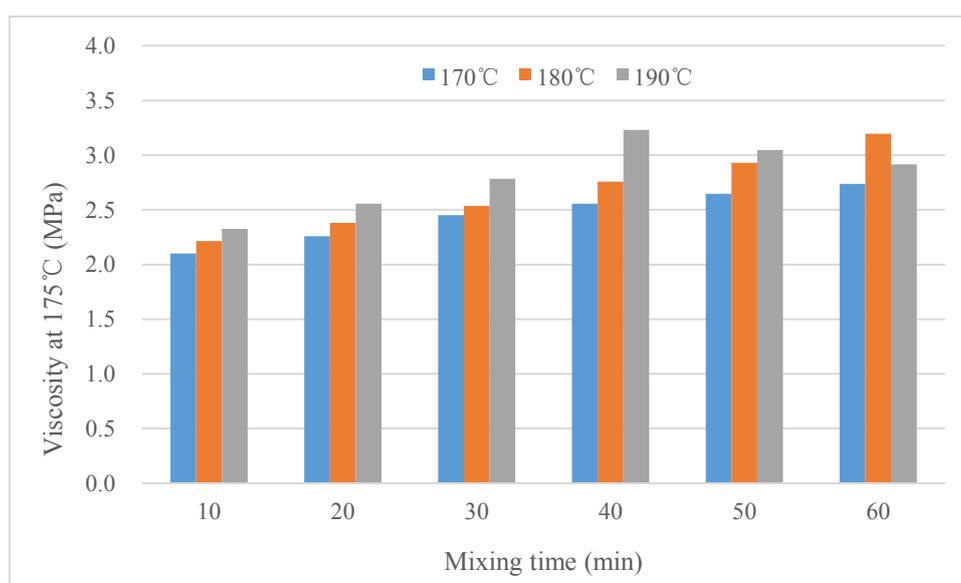


Figure 3 Viscosity of rubber modified bitumen at 175°C (MPa)

It can be seen from Figure 3 that viscosity of rubber modified bitumen increases gradually with the increase of mixing time within 60 minutes at the stirring temperature

of 170°C and 180°C, but the viscosity decreases after 40 minutes at the mixing temperature of 190°C, because the swelling of crumb powder at the early mixing stage is

rapid at the higher mixing temperature. However, with the increase of mixing time, the degradation and desulfurization of crumb powder are accelerated by excessive mixing temperature, which leads to the decrease of viscosity of rubber bitumen.

In summary, the preparation process of rubber modified bitumen is as follows: heat the bitumen to 170 ~180°C

and then add the rubber powder with 18% by weight of asphalt mixture, then stir 40min.

After determining the manufacturing technology of rubber modified bitumen, the rubber modified bitumen produced, the base bitumen and SBS modified bitumen used in this study were tested for conventional indicators. The test result is shown in Table 1:

Table 1 Property of three kinds of bitumen

Bitumen type		Base bitumen	Rubber modified bitumen	SBS modified bitumen
Penetration(25°C, 0.1mm)		72.8	64.2	56.1
Softening point (°C)		46.5	56.5	73.5
Ductility(5°C,cm)		6.8	12.3	32.1
Brinell viscosity(Pa.s)		1.8(135°C)	2.8(175°C)	2.1(135°C)
Thin-film heating test(163°C,5h)	Quality loss (%)	0.02	0.10	0.02
	Penetration ratio (%)	68.9	85.2	79.2
	Ductility(5°C,cm)	5.2	11.1	22.5

It can be seen from the test results in Table 1 that the rubber powder increases the softening point and ductility of the base bitumen, and reduces the penetration, indicating that the rubber powder can improve the high temperature performance and cryogenic property of the base bitumen and improve the viscosity of the bitumen.

3 Preparation of specimen

The framework-dense structure of SMA asphalt mixture can ensure that it has good pavement performance. This study selected the gradation as shown in Figure 4 for the preparation of asphalt mixture.

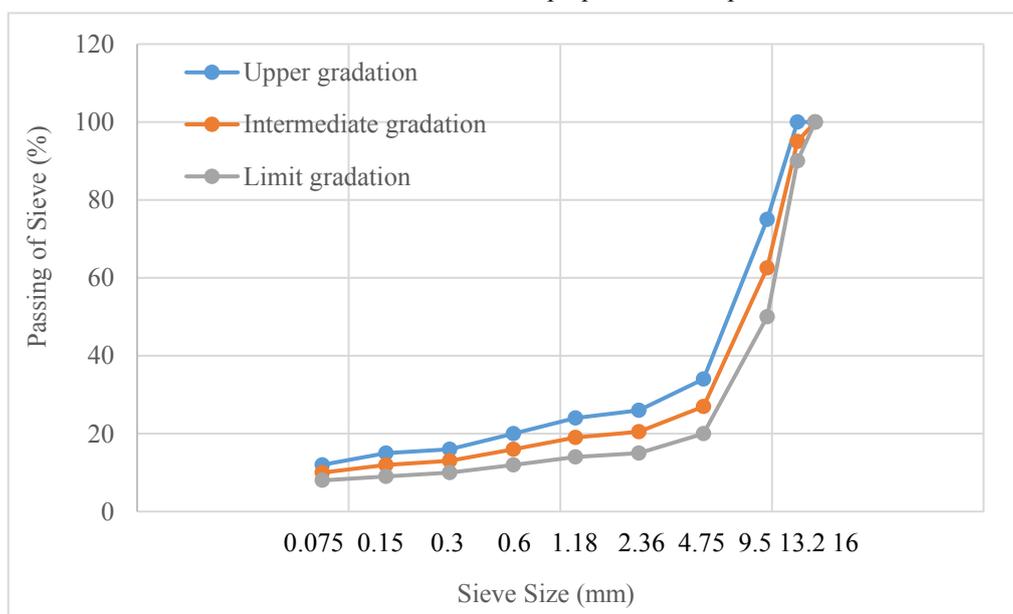


Figure 4 Gradation of SMA-13

Based on the gradation of Figure 4, the composition of SMA-13 asphalt mixture is designed by Marshall test. The

key test indexes are shown in Table 2.

Table 2 Test result of SMA-13 asphalt mixture

Type of mixture	Compaction temperature (°C)	Optimal asphalt content (%)	Air void (%)	Marshall stability(kN)	Flow Value (0.1mm)
Ordinary asphalt mixture	145	6.0	3.8	6.21	26.1
SBS modified asphalt mixture	155	6.1	3.9	8.32	30.1
Rubber modified asphalt mixture	165	6.6	3.8	7.51	28.9

As is shown in the Table 2, the optimal asphalt content of rubber modified asphalt mixture is 0.5% higher than that of SBS modified asphalt mixture. The Marshall stability is higher than that of ordinary asphalt mixture, but is lower than that of SBS modified asphalt mixture.

4 Analysis and result of indirect tensile fatigue test

UTM-25 material test machine of Australian IPC Company was employed to the indirect tensile fatigue test. The test temperature was 15°C. The stress control model with half sinusoidal load and total loading time for 1s were adopted in the test. Four specimens are selected for each stress ratio to carry out the test, and fatigue failure is judged by specimen failure. Before the fatigue test, the splitting strength of all kinds of asphalt mixture at 15°C was tested, as shown in Table 3.

Table 3 Splitting strength of various asphalt mixtures (MPa)

Preparation conditions	The type of mixture		
	Ordinary asphalt mixture	SBS modified asphalt mixture	Rubber modified asphalt mixture
No cycle	0.651	0.781	0.692
One freeze-thaw cycle	0.583	0.732	0.675
Three freeze-thaw cycles	0.522	0.692	0.628
Five freeze-thaw cycles	0.412	0.602	0.586

After testing the splitting strength, the stress values at the stress ratios of 0.3, 0.4 and 0.5 are calculated as the control loads in fatigue tests. The double logarithmic relationship of stress ratio and fatigue life under each condition is as follows:

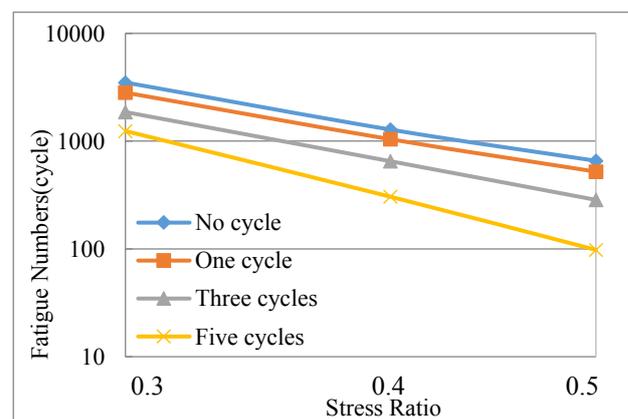


Figure 5 Fatigue characteristic diagram of ordinary asphalt mixture

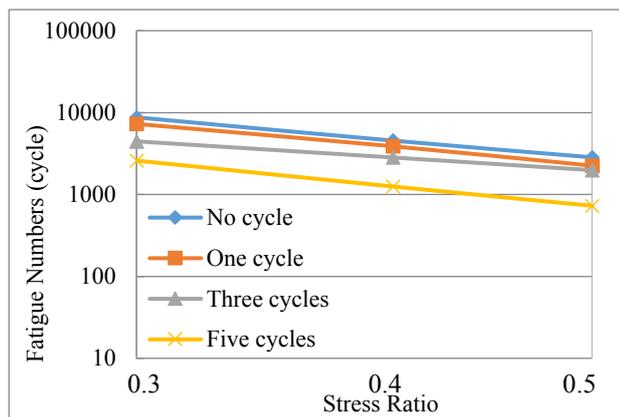


Figure 6 Fatigue characteristic diagram of SBS modified asphalt mixture

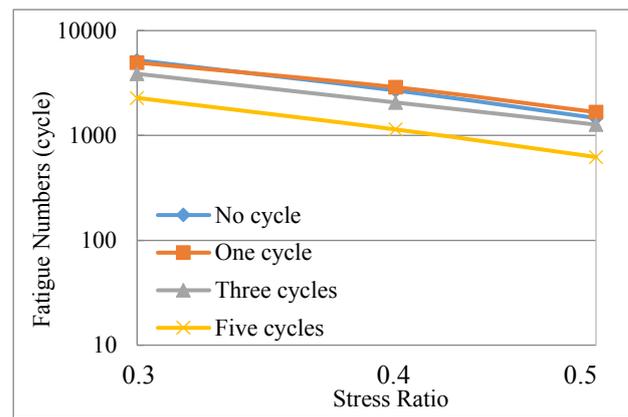


Figure 7 Fatigue characteristic diagram of rubber modified asphalt mixture

As the figures show, there is a good double logarithm relationship ($\lg N_f = A \lg(\frac{\sigma_i}{\sigma}) + B$) between fatigue life and stress ratio of various types of asphalt mixtures after

different preparation conditions in accordance with the relevant research results [10-12]. The characteristic parameters of fatigue equation of different types of asphalt mixtures are arranged as shown in Table 8.

Table 4 Characteristic parameters of fatigue equation of different types of mixture

Preparation conditions	Ordinary asphalt mixture		SBS modified asphalt mixture		Rubber modified asphalt mixture	
	A	B	A	B	A	B
No cycle	-3.285	1.818	-2.203	2.787	-2.478	2.427
One freeze-thaw cycle	-3.311	1.712	-2.291	2.667	-2.120	2.595
Three freeze-thaw cycles	-3.672	1.350	-1.585	2.820	2.186	2.444
Five freeze-thaw cycles	-4.967	0.500	-2.488	2.110	2.534	2.037

As is shown in Figures 5-7 and Table 4, the test results are as follows:

(1) For unconditional specimens, among the three asphalt mixtures, SBS modified asphalt mixture has the best fatigue properties. Rubber modified asphalt mixture takes the second place. Ordinary asphalt mixture is the worst. It shows that rubber powder can improve the fatigue properties of asphalt mixture, but the modified effect is not as good as SBS modifier.

(2) The fatigue life of three kinds of asphalt mixture decreases with the increase of freeze-thaw cycles. The influence of 1 freeze-thaw cycle is small, and the fatigue life is obviously reduced after three freeze-thaw cycles.

(3) The absolute value of characteristic parameter A of the fatigue equation of ordinary asphalt mixture is the largest, indicates that the fatigue life of this kind of asphalt mixture is the most sensitive to load, and the difference between SBS modified asphalt mixture and rubber modified asphalt mixture is not obvious.

(4) The freezing-thawing cycle has the greatest influence on the ordinary asphalt mixture, the bigger on SBS modified asphalt mixture and the smallest on the rubber asphalt mixture. After five freeze-thaw cycles, the fatigue life of rubber modified asphalt mixture is equivalent to that of SBS modified asphalt mixture.

5 Conclusion

In the study, the fatigue characteristic of rubber modified SMA-13 asphalt mixture was investigated and compared with ordinary and SBS modified SMA-13 asphalt mixture. Based on the outcome of the experimental study, the following conclusions can be drawn:

- (1) The rubber modified asphalt produced by mechanical stirring for 40 minutes at the temperature of 170 °C ~180 °C has better technical properties.
- (2) Compared with SBS modified asphalt mixture, the optimal asphalt content of rubber modified asphalt

mixture is increased by 0.5%, and the Marshall stability is higher than that of ordinary asphalt mixture, but lower than that of SBS modified asphalt mixture.

(3) Rubber powder can improve the fatigue performance of asphalt mixture, but the improvement effect is not as good as that of SBS modifier.

(4) Freeze-thaw cycles have adverse effects on the fatigue properties of various asphalt mixtures. The fatigue properties of rubber modified asphalt mixtures reduction significantly especially after 3 freeze-thaw cycles. The reduction degree of rubber modified asphalt mixtures is less than SBS modified asphalt mixtures and rubber modified asphalt mixture has better freeze-thaw durability.

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