Influence of Relative Molecular Mass of SBS on Low-Temperature Performance of Modified Asphalt

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Abstract. Styrene Butadiene Styrene (SBS) is widely used in pavements because it significantly improves the performance of the modified asphalt. The dosage of SBS has an important effect on the low-temperature performance of the modified asphalt. The difference in relative molecular weight influences the magnitude of the change in low-temperature performance. In this paper, low temperature bending beams rheology test of five different relative molecular weight SBS modified asphalt is conducted at -12°C, -18°C and -24°C to evaluate the low-temperature properties of modified asphalt. Then, the experimental results are analysed. The results show that there is a certain correlation between the relative molecular mass of SBS and the low-temperature performance of modified asphalt. The creep stiffness and creep rate of the modified asphalt are influenced by the relative molecular mass of SBS and temperature. As the relative molecular mass increases, the low-temperature performance of the modified asphalt first rises and then decreases.

1. Introduction

As a result of its better driving comfort and low traffic noise, asphalt concrete pavement has the characteristics of short construction period and easy repair, and it also has high reutilization value and becomes the main paving form of highway pavement. However, due to the characteristics of asphalt itself and asphalt concrete structure, under the joint action of vehicle load and climatic factors, asphalt pavement is prone to low temperature cracking and other damage behaviors, and low temperature stability cannot meet the practical requirements. In order to improve the performance of asphalt pavement, various modifiers such as rubber particles, SBS, nano-silica, fiber, etc. are added to the asphalt, and these modifiers can improve the low-temperature performance of the asphalt to some extent, in which SBS modifier can significantly improve the low temperature performance of asphalt, and the modification effect is ideal. With the advancement of scientific research methods, the SBS modified asphalt is gradually deepened, and the degradation law of SBS in SBS modified asphalt is studied [1]. The low temperature performance of SBS modified asphalt after aging is analysed by the rheological behavior of low temperature bending beam [2]. Cao liping [3] studied SBS modified asphalt using phase angle and viscoelastic modulus The low temperature rheological properties, analysis of the effect of modifier content on performance; asphalt temperature sensitivity study shows that when the modifier content is greater than 4%, the permeability index of SBS modified asphalt increases with the content of modifier Linear decline, The temperature sensitivity is increased [4]; the physical equation between the creep stiffness S(t) and the creep rate m(t) at any time t is established by mathematical derivation, and the modification is proposed to have better low temperature performance.
The m value of the agent is proposed to select the asphalt binder according to the S and m values [5]; the creep stiffness (S) and creep rate (m) of the SBS modified asphalt are combined with the raw material performance parameters, and the SBS modified asphalt is analysed. Correlation between raw material performance parameters and low temperature rheological properties [6]; BBR experiments were conducted to analyse the effect of SBS polymer type, SBS content, sulfur content and rubber processing oil addition on the low temperature performance [7].

SBS has great differences in structural composition and parameters, such as its relative molecular mass, Styrene/Butadiene block ratio, Styrene Butadiene diblock content, etc., the difference in structural parameters will be important for the physical and chemical properties of SBS. Influence, so when SBS is added as modifier to asphalt, it will have different effects on the low temperature performance of asphalt due to its own structure, but the research on the influence of SBS relative molecular mass on asphalt performance is rare. The relative molecular mass of SBS used for modification is also selected only by experience. The research on the influence of SBS relative molecular mass on asphalt performance remains in the aspect of basic index change, and its comprehensive influence on asphalt pavement performance and related mechanism are not discussed in depth.

What are the differences in the modification effect of SBS on asphalt with different relative molecular mass levels, and the different effects on the low temperature performance of asphalt? It has important research value for optimizing SBS for road modification and improving pavement performance. The relative molecular mass of linear SBS currently used for road asphalt modification is mainly around 80,000~120,000, and there are also SBS modifiers outside this range, but the relative use is relatively small. Therefore, five kinds of linear SBS modified asphalt with different relative molecular mass (79,000, 87,000, 106,000, 124,000, 138,000) were used to test the rheological properties of low temperature bending beam, and the creep stiffness S value and creep were analyzed. The relationship between the variable rate m value and the relative molecular mass and temperature of SBS, on the one hand, to explore the effect of SBS relative molecular mass on the low temperature performance of modified asphalt, and on the other hand, the preferred SBS for modified asphalt with better low temperature performance. Relative molecular quality levels provide an important reference.

2. Materials and Methods

2.1. Materials

2.1.1. Matrix Asphalt. The matrix asphalt used in this paper is Esso 70# asphalt. Refer to the “Test Procedure for Highway Engineering Asphalt and Asphalt Mixture” for the benchmark test of the matrix asphalt. The basic technical indexes of the asphalt are shown in table 1.

| Test index                              | Results of testing | Technical indicators |
|-----------------------------------------|--------------------|----------------------|
| Penetration(25℃, 5s, 100g)(0.1mm)       | 62                 | 60~80                |
| Softening point(℃)                      | 48.5               | >45                  |
| Ductility(15℃, cm)                      | >100               | >100                 |
| Solubility(%)                           | 99.6               | >99.5                |
| Flash point(℃)                          | 260                | >260                 |
| Viscosity(135℃, Pa·s)                   | 0.550              | -                    |

2.1.2. SBS Modifier. The modifiers used in this paper were synthesized by coupling polymerization process. All of them were linear SBS. Five kinds of SBS with different molecular weights were prepared by controlling the ratio of raw materials and polymerization process. The relatives were
determined by Gel Permeation Chromatography (GPC). Molecular mass, the relative molecular mass of SBS modifier used in this paper and the main technical indicators are shown in table 2.

| SBS number | Weight average molecular weight (Mw) | Number average molecular weight (Mn) | Distribution index (Mw/Mn) | Styrene content (%) | SB content (%) |
|------------|-------------------------------------|-------------------------------------|--------------------------|---------------------|----------------|
| SBS-7.9    | 78826                               | 75317                               | 1.05                     | 29.1                | 22.5           |
| SBS-8.7    | 87451                               | 81607                               | 1.07                     | 28.8                | 23.0           |
| SBS-10.6   | 106008                              | 98329                               | 1.08                     | 29.3                | 22.6           |
| SBS-12.4   | 123652                              | 116955                              | 1.06                     | 29.3                | 25.1           |
| SBS-13.8   | 138325                              | 122073                              | 1.13                     | 29.5                | 20.3           |

According to the main parameters of SBS, the content of five kinds of SBS styrene is relatively close, the block ratio is not much different, and the SB content is in the range of 20~25%. The main difference is the difference of relative molecular mass. Since the relative molecular mass of SBS used in road asphalt modifier mostly refers to its weight average relative molecular mass, therefore, the SBS of five different relative molecular masses is numbered by weight average molecular weight, such as SBS-7.9. The average relative molecular mass is 79,000 SBS. The relative molecular masses described herein also refer to their weight average relative molecular masses.

2.2. Standard Experimental Methods

In this paper, low temperature bending beam rheometer is used to test the modified asphalt pitch of matrix asphalt and different SBS relative molecular masses to evaluate the effect of SBS relative molecular mass on the low temperature performance of modified asphalt. During the test, each modified asphalt was poured into a standard mold to form a 127 mm × 12.7 mm × 6.35 mm girder test piece, which was placed in an instrument-controlled greenhouse for heat preservation after low-temperature demoulding, and 980mN±50 was applied to the asphalt trabecular test piece. For a constant force of 50 s, the deformation value is recorded, and the creep stiffness modulus S value and the creep rate m value at 60 s are calculated. The S value characterizes the ability of asphalt to resist deformation at low temperatures. The m value is the rate of change of creep stiffness modulus, indicating the stress relaxation capacity of asphalt. The larger the S value, the greater the asphalt stiffness and the worse the deformation ability at low temperature. The lower the temperature cracking occurs, the smaller the m value is, the lower the stress relaxation performance is. Therefore, in the low temperature environment, the smaller the S value, the larger the m value, indicating that the low temperature performance of the asphalt is better.

In this paper, the BBR test tests the low temperature performance of each modified asphalt sample at -12 °C, -18 °C and -24 °C, and obtains the S value and m value at each temperature to evaluate the relative molecular mass of different SBS. The difference in low temperature properties of asphalt.

3. Experimental Results

Bending Beam Rheometer (BBR) is used to evaluate low temperature performance of the modified asphalt. The low temperature performance evaluation test of modified asphalt with different SBS relative molecular mass was carried out at -12 °C, -18 °C and -24 °C to determine the S and m values of matrix asphalt and modified asphalt. The test results are shown in table 3.
Table 3. Test results of modified asphalt BBR.

| Asphalt type | -12°C | -18°C | -24°C |
|--------------|-------|-------|-------|
|               | S(MPa) | m     | S(MPa) | m     | S(MPa) | m     |
| Matrix asphalt | 163   | 0.404 | 425    | 0.285 | 805    | 0.171 |
| SBS-7.9       | 105   | 0.406 | 285    | 0.305 | 593    | 0.196 |
| SBS-8.7       | 107   | 0.409 | 287    | 0.311 | 573    | 0.208 |
| SBS-10.6      | 111   | 0.400 | 301    | 0.301 | 597    | 0.198 |
| SBS-12.4      | 125   | 0.395 | 330    | 0.281 | 632    | 0.185 |
| SBS-13.8      |       |       |        |       |        |       |

With the decrease of temperature, the creep stiffness modulus S value of matrix asphalt and SBS modified asphalt increases rapidly, the asphalt becomes hard and brittle, and the S value of matrix asphalt is significantly larger than SBS modified asphalt at each temperature, and the m value of asphalt The decrease in temperature is drastically reduced, and the m value of the matrix pitch is reduced more significantly. It is indicated that the matrix asphalt has poor stress relaxation performance and low temperature performance at low temperature. The five different molecular weight SBS studied in this paper have a certain improvement on the low temperature performance of the matrix asphalt.

3.1. Creep Stiffness

![Figure 1. Creep Stiffness Modulus.](image)

It can be seen from figure 1 that with the decrease of temperature, the creep stiffness modulus S value of matrix asphalt and SBS modified asphalt increases rapidly, the asphalt becomes hard and brittle, and the S value of matrix asphalt is significantly larger than SBS modified asphalt at each temperature. It is indicated that the SBS with five different relative molecular masses studied in this paper can improve the low temperature performance of matrix asphalt to a certain extent. Comparing the difference of modified low temperature properties of different SBS relative molecular masses, the S value of five kinds of SBS modified asphalts is not obvious at -12 °C, especially when the relative molecular mass of SBS modifier is less than 124,000, creep stiffness The modulus is relatively close, and when the relative molecular mass reaches 124,000 and above, there is a significant increase. The
SBS-13.8 modified asphalt has the largest stiffness modulus compared with other modified asphalts. When the temperature is lowered to -18 °C, the stiffness modulus of each modified asphalt increases, and the difference of the stiffness of the modified asphalt with different SBS relative molecular mass is slightly obvious. Overall, the modified asphalt creep. The stiffness modulus increases with the increase of the relative molecular mass of SBS modifier, and the creep stiffness modulus of SBS-13.8 modified asphalt is obviously larger. At -24 °C, the creep stiffness of the modified asphalt showed different trends. The stiffness modulus of the modified asphalt of SBS-7.9 increased significantly, which was significantly higher than that of SBS-8.7 and SBS-10.6 modified asphalt at the same temperature. The modifier used in SBS-7.9 modified asphalt has the lowest relative molecular mass, and the effect on the low temperature performance of the matrix asphalt is not obvious. When the temperature is low, the low temperature performance is poor. The creep stiffness modulus of SBS-8.7 modified asphalt is the smallest. When the relative molecular mass continues to increase, the stiffness modulus of SBS-12.4 and SBS-13.8 modified asphalt increases obviously.

3.2. m-Value

![Figure 2. Creep Rate.](image)

It can be seen from figure 2 that the m value of asphalt decreases sharply with the decrease of temperature, and the m value of the matrix asphalt decreases more obviously. At low temperature, the matrix asphalt has poor stress relaxation performance and poor low temperature performance. Under the condition of -12 °C, the m value of each modified asphalt is not much different, but it can be seen that except for SBS-7.9, the modified asphalt with large relative molecular mass has smaller m value and poorer low temperature deformation ability, and the increase in relative molecular mass is more pronounced as the value of m decreases. At -18 °C, there is a similar law. The creep rate of the modified asphalt with a relative molecular mass of more than 87,000 is more obvious. The modified asphalt with a relative molecular mass of only 79,000 has a small creep. Stiffness modulus, but m value is not as good as SBS-8.7 modified asphalt, again indicating that SBS-7.9 has poor modification effect on asphalt, and the effect of improving the low temperature performance of asphalt is not obvious, and when the temperature is lowered to -24 °C When the creep rate m value is reduced to a large extent, the creep rate is lower than the SBS modified asphalt with a relative molecular mass of 8,7000 to 124,000 at -24 °C.

4. Conclusion
In this work, the low temperature properties of SBS modified asphalt with different molecular weights are studied. According to the results, the following conclusions can be drawn:

(1) There is a certain correlation between the relative molecular mass of SBS and the low-temperature performance of modified asphalt.

(2) Temperature has a decisive influence on the Bending Beam Rheometer (BBR) test results, while both s-value and m-value are influenced by relative molecular mass of SBS, which is used as modifier of asphalt. The BBR test results show that when the molecular weight of SBS as a modifier increases, the s-value increases, and the m-value first increases and then decreases.

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