Study on the Rheological Properties of Gussasphalt after Superheat Aging

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Abstract: Gussasphalt mixture has many excellent characteristics such as imperviousness, strong integrity and good flexibility. In recent years, it has been widely used in large and medium-sized bridges, especially steel bridge deck pavements. However, unlike ordinary mixed materials, gussasphalt needs to undergo long-term high temperature aging during mixing and transportation. In order to deeply explore the superheat aging mechanism of gussasphalt, dynamic shear test and bending beam rheological test were mainly used to study the effect of different superheat aging conditions on the high and low temperature rheological properties of gussasphalt in this paper. The test results show that the complex modulus G* of the gussasphalt after aging at 240℃, 220℃ and 200℃ for 6h is 3.6, 3.4 and 2.1 times of 163℃ aging respectively at the test temperature of 48℃. The low-temperature stiffness modulus of gussasphalt shows an increasing trend, while the creep rate shows a decreasing trend, which indicates that the ability to resist low-temperature cracking for gussasphalt is getting worse after higher temperature aging.

1. Introduction
In order to make steel bridge deck pavement with excellent performance and long service life, in addition to reasonable bridge structure, paving structure, mix composition design and construction process, the technical performance of asphalt mixture is important especially that gussasphalt and its mixture can withstand the aging resistance of 240℃. In the whole lifecycle of gussasphalt in the steel bridge deck, the most aging stage is the short-term aging stage in the secondary mixing, transportation and paving process. Excessive aging of the superheat will not only cause the viscosity of the gussasphalt mixture to increase rapidly, but also become difficult to construct, even if the paved layer is constructed, under the violent natural environment temperature difference and the heavy-duty traffic cycle. It is prone to temperature shrinkage cracks and fatigue cracking, which in turn affects the pavement layer's performance and service life [1].

Gussasphalt mixture consists of mixed asphalt, fine aggregate and coarse aggregate. The asphalt or asphalt mortar representing mesoscale has crucial influence on the overall performance of gussasphalt mixture. The meso-scale evaluation of mixed asphalt is short-term. The performance before and after aging is of great help to comprehensively understand and analyze the effect of superheat aging on the macroscopic road performance of gussasphalt concrete [2-5].

Therefore, this paper mainly uses two types of common gussasphalt, and the aging test of the gussasphalt binder at 163℃, 180℃, 200℃, 220℃, 240℃ superheat. The dynamic shear test and the bending beam rheology test of the gussasphalt were carried out to study the effects of different superheated aging conditions on the high temperature performance and low temperature performance of
the gussasphalt with an attempt to reveal the superheat aging mechanism of the gussasphalt in the mesoscopic state. The research results can provide theoretical basis for anti-aging design and development strategy of gussasphalt.

2. Test materials and sample preparation
In order to profoundly reveal the superheat aging mechanism of gussasphalt, Donghai 70# asphalt, SBS modified asphalt and lake asphalt were selected to prepare gussasphalt binder. The various asphalt technical indicators are shown from Tab.1 to Tab.3.

| Indicators                  | Test results | Technical requirement |
|-----------------------------|--------------|-----------------------|
| Penetration (25℃) / 0.1 mm  | 65.2         | 60~80                 |
| Ductility (15℃) / cm        | >100         | ≥100                  |
| Softening point / ℃         | 49.2         | >47                   |
| Penetration index PI        | -0.84        | -1.5~+1.0             |
| Wax content /%              | 1.83         | <2.2                  |
| Solubility /%               | 99.7         | ≥99.5                 |
| Density (15℃) / g · cm⁻³   | 1.03         | -                     |

| Indicators                  | Test results | Technical requirement |
|-----------------------------|--------------|-----------------------|
| Penetration (25℃) / 0.1 mm  | 57           | 40~60                 |
| Ductility (15℃) / cm        | 30.1         | ≥25                   |
| Softening point / ℃         | 81.2         | ≥70                   |
| Penetration index PI        | 0.12         | ≥0                    |
| Solubility /%               | 99.6         | ≥99                   |
| Flash point / ℃             | >242         | ≥230                  |

| Indicators                  | Test results | Technical requirement |
|-----------------------------|--------------|-----------------------|
| Penetration (25℃) / 0.1 mm  | 3            | 1~4                   |
| Softening point / ℃         | 96           | 93~98                 |
| Solubility /%               | 53.6         | 52.5~55.5             |
| Flash point / ℃             | 260          | >240                  |
| Density (25℃) / g · cm⁻³   | 1.40         | 1.38~1.42             |

The prepared matrix asphalt (SBS asphalt) and the lake asphalt are separately heated in an oven, wherein the matrix asphalt heating temperature is 160℃, the modified asphalt heating temperature is 170℃, and the lake asphalt heating temperature is 200℃. The matrix asphalt (SBS asphalt) and lake asphalt were prepared in a mixture ratio of 40%:60%. After the sample preparation is completed, it is placed in a high-speed shearing machine and stirred for 45 minutes to obtain uniformly poured gussasphalt binder.
Taking into account the actual storage state of the gussasphalt mixture, the improved aging oven was used to conduct the aging test for 6 hours, and the aging temperature was set to 5 groups, which were 163°C, 180°C, 200°C, 220°C and 240°C to simulate the high temperature, long mixing and paving process of the gussasphalt mixture. Among them, 163°C is the specified temperature for the short-term aging test of ordinary asphalt, and 240°C is the mixing temperature of the gussasphalt mixture. Temperature gradient is set between the two temperatures for aging test, and the effect of aging temperature on the rheological performance of gussasphalt is observed in this paper.

3. High temperature rheological performance of gussasphalt after superheating

3.1 Test design

The DSR-CV0100 ADS dynamic shear rheometer produced by American BOHLIN Company was used to simulate the sinusoidal strain response of the moving load on the road surface by using the sinusoidal strain load mode in this study. The selected strain level should be in the line viscosity of the material within the elastic range. In order to study the high temperature performance of gussasphalt binder after aging, a metal plate with a diameter of 25 mm was selected, and the thickness of the test piece was 1 mm with a strain level of 0.1%.

Five kinds of gussasphalt binders mixed with 70# asphalt and TLA at different aging temperature were prepared, and five kinds of gussasphalt binders mixed with SBS modified asphalt and TLA were also prepared. DSR tests were carried out for the above 10 samples in which TLA:70#=60:40 and TLA:SBS=60:40. The temperature range of the investigation was from 46°C to 82°C until the complex modulus G* of the asphalt dropped to less than 1 KPa, and the test data were taken as the average of three parallel tests.

3.2 Results and discussion

The results of the DSR test are shown in Fig. 1 and Fig. 2.

(a) Complex shear modulus
(b) Phase angle

Figure 1 Complex shear modulus and phase angle of 70#-TLA mixed asphalt

(a) Complex shear modulus
(b) Phase angle

Figure 2 Complex shear modulus and phase angle of SBS asphalt-TLA mixed asphalt
From Figure 1 and 2, the following conclusions can be drawn: Under same aging condition, the phase angle of 70#-TLA mixed asphalt increases rapidly with the increase of test temperature. When it reaches 80℃, the phase angle under aging condition of 163℃ even reaches 85°, which indicates mixed asphalt almost completely lost the elasticity and entered the viscous flow state. The phase angle of SBS-TLA mixed asphalt has a similar trend, but the phase angle rises faster when the temperature is lower, and the phase angle rises faster when the temperature is higher. This is exactly the opposite of 70#-TLA mixed asphalt, which indicates that the SBS modifier enhances the elasticity of the asphalt to a certain extent and reduces the temperature sensitivity of the asphalt binder.

Regardless of the complex modulus curve or the phase angle curve, the spacing between the curves under different aging conditions is not equally spaced. The 70#-TLA mixed asphalt has the largest reduction in phase angle when the aging temperature is 180℃~200℃. Corresponding complex modulus increases the most. Similarly, SBS-TLA mixed asphalt has the largest reduction in phase angle when the aging temperature is between 180℃ and 200℃, and the same increase of complex shear modulus.

The form of the complex shear modulus curve in each aging state is basically similar. The higher the temperature is, the smaller the complex shear modulus and the larger the phase angle are. When the temperature reaches 60℃, the difference for the complex shear modulus between different aging temperatures becomes smaller and smaller. It indicates that the ratio between viscoelasticity and plasticity changes under different temperature of the mixed asphalt. Under high temperature conditions, the test piece is prone to shear failure due to the large plastic content, especially after 75℃, the complex shear modulus value is almost zero.

At the same test temperature, different aging states have a great influence on the complex shear modulus of the mixed asphalt. For 70#-TLA mixed asphalt, when the test temperature is 48℃, the complex modulus after aging for 6h at 240℃ is 1810kPa, which is 3.58 times of the complex modulus of 163℃. The complex modulus of asphalt after aging for 6h at 220℃ is 3.38 times of the complex modulus of 163℃. The complex modulus of asphalt for 200℃ aging is 2.08 times of the complex modulus at 163℃. For the same reason, the same trend rule is applied to SBS-TLA mixed asphalt. When the test temperature is 48℃, the complex modulus of asphalt after aging for 6 hours at 240℃ is 7.25 times of the complex modulus of 163℃. The complex modulus after aging for 6 hours at 220℃ is 5.52 times of the complex modulus of 163℃; the complex modulus after aging for 6 h at 200℃ is 3.46 times of the complex modulus of 163℃. It can be seen that for every 20℃ increase in aging temperature, the complex modulus of the mixed asphalt decreases about 1 time, which indicates that the aging temperature of the asphalt has a great influence on the properties of the binder.

4. Low temperature rheological performance of gussasphalt after superheating

4.1 Test design

In the study, TLA-70# asphalt blending ratio of 60:40 mixed asphalt was used for BBR test. The asphalt samples were aged by rotating film oven for 6 hours, and the aging temperatures were 163℃, 180℃, 200℃, 220℃ and 240℃. So the asphalt samples used in the BBR test totaled 5 groups. The test was carried out according to AASHTO T313-02, and the test piece size was 101.6mm×12.7mm×6.4mm with test temperatures -6℃, -12℃ and -18℃. The stiffness modulus S and the creep rate m of the asphalt binder were measured, and S≧300MPa and m≧0.3 were used as evaluation indexes of the binder. The test procedure of the formed test piece is shown in Figure 3.
4.2 Results and discussion

The test results are shown in Fig. 4 and 5.

Figure 4 shows the stiffness modulus S of the gussasphalt binder at different superheat aging temperatures. It can be seen from the curve that the low temperature stiffness of the mixed asphalt increases with the increase of the superheat aging temperature. The value shows an increasing trend. The greater the stiffness modulus is, the smaller the allowable deformation ability is, and the worse the ability to resist low temperature cracking is. Therefore, as the superheat aging temperature increases, the low temperature anti-cracking ability of the gussasphalt binder is significantly reduced. In addition, it can be seen from Fig. 4 that if the stiffness modulus is 300 MPa as the critical temperature, the critical cracking temperature of the 163°C superheat aged asphalt binder is -12.6°C, and the criticality of the modified asphalt is recovered by 240°C superheat aging. The cracking temperature was -9.3°C, which indicates that the critical cracking temperature increased significantly as the temperature of the superheated aging increased.

The creep slope m characterizes the relaxation ability of asphalt. The larger the m value is, the stronger the relaxation ability is. When the temperature drops sharply, it tends to have better low temperature performance. It can be seen from Fig. 5 that with the increase of the superheat aging
temperature, the creep slope of the gussasphalt binder gradually decreases at each test temperature, and the relaxation capacity at low temperature gradually decreases. Its low temperature performance has a significant impact. In addition, the creep rate of mixed asphalt under different superheat aging temperatures is basically consistent with the test temperature, showing a linear correlation.

5. Conclusion
In this paper, the high and low temperature rheological properties of gussasphalt after superheating aging were studied by DSR test and BBR test. The main conclusions are as follows:

1) For 70#-TLA mixed asphalt, when the test temperature is 48°C, the complex modulus after aging for 6h at 240°C is 1810kPa, which is 3.58 times of the complex modulus of 163°C. The complex modulus of asphalt after aging for 6h at 220°C is 3.38 times of the complex modulus of 163°C. The complex modulus of asphalt for 200°C aging is 2.08 times of the complex modulus at 163°C.

2) With the increase of superheating aging temperature, the low temperature stiffness modulus of gussasphalt shows an increasing trend, and the creep rate shows a decreasing trend, indicating that the asphalt has a weaker ability to resist low temperature cracking. Further, if the stiffness modulus is 300 MPa as the critical temperature, the critical cracking temperature at 240°C is increased by 3.3°C from the critical cracking temperature at 163°C.

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