Static and dynamic mechanical properties of warm mixed asphalt mixture before and after aging

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Abstract. In order to study the effect of warm mix agent on the mechanical properties of warm mix asphalt mixture before and after aging, this article uses the uniaxial compression test and the uniaxial dynamic modulus test which were carried out on the unaged, short-term aging and long-term aging conditions of the matrix and SBS modified asphalt mixture mixed with RH and Evotherm warm mix agent respectively. The results show: the performance of each asphalt mixture at low temperature and high frequency is equivalent, indicating that dynamic mechanics is not suitable for evaluating the low temperature performance of asphalt mixture; high temperature and low frequency can be used as an evaluation index for high temperature anti-rutting of asphalt mixture. By analyzing the rebound modulus, uniaxial dynamic modulus and other results, it shows that the addition of the warm mix agent improves the low temperature performance of the asphalt mixture, alleviates the aging of the asphalt mixture, and the aging of the aging also brings about a decrease in high temperature stability. The beneficial effect of the Evotherm is weak, and the low temperature performance of the asphalt mixture after aging and the high temperature stability of the warm asphalt mixture after long-term aging are improved. From the comprehensive analysis of static and dynamic mechanical properties, the elastic modulus and dynamic modulus of asphalt mixture are not much different, and the dynamic static modulus of the mixture after aging is quite different, which provides a theoretical basis for the dynamic and static modulus transformation.

1. Introduction

Hot mix asphalt mixture satisfies its proper performance, but it also increases the problem of accelerated aging of asphalt and energy consumption, warm mix asphalt mixture technology came into being under such circumstances[1]. Warm mix asphalt mixture as an new energy-saving and environment-friendly material has good performance and construction workability[2-3]. In 2005, China laid the first warm asphalt mixture pavement and achieved good paving effect[4]. Nowadays, the problem of early damage of pavement is becoming more and more serious, and the most obvious one is aging[5]. Aging will lead to weakening of road surface deformation ability, and it is easier to crack under the action of vehicle load and temperature stress. The static and dynamic mechanical properties of warm mix asphalt mixture before and after aging are important for improving the quality and life of asphalt pavement[6]. In this article, two kinds of warm mix agents were used to assess
uniaxial compression and uniaxial dynamic compression experiments on asphalt mixture under different aging effects. In this paper, we adopt studying the relationship between modulus and dynamic and static modulus, the effect of warm mix agent on the high and low temperature performance of asphalt mixture under different aging effects and the theoretical basis for the dynamic design of asphalt pavement structure design are obtained.

2. Test materials

2.1. Warm mix agent

This paper selects two kinds of warm mix agent, RH and Evotherm. Some technical indicators of the two warm mix agents are shown in Table 1.

Table 1. Warm mixer technical index

| Text projects | RH | Evotherm |
|---------------|----|----------|
| Appearance    | White particles | Dark Yellow liquid |
| Viscosity 20℃/(MPa•s) | - | 720 |
| Density 25℃/(g.cm-3) | 0.894 | 0.916 |
| Amine value/(mgKOH•g-1) | - | 573 |
| Water content/% | 0.1 | 20 |
| Ash/% | 0 | 0 |
| pH | - | 3.4 |
| Water solubility | Insoluble | Soluble |

2.2. Asphalt

The test asphalt is 90# matrix asphalt (JZ) and SBS modified asphalt (SB), both from the Shandong Road and Bridge Mixing Station in Hohhot. The warm mix asphalt is prepared by adding the RH warm mix agent with a recommended parameter of 3% and 0.6% of the Evotherm warm mix agent in the 90# matrix asphalt and SBS, respectively, and then stirring for 30 min to obtain the matrix-RH asphalt (JR), matrix-Evotherm Road Asphalt (JE), SBS-RH Asphalt (SR), SBS-Evotherm Asphalt (SE). The technical specifications of each asphalt are shown in Table 2 and Table 3.

Table 2. Properties of Matrix asphalt

| Text projects | Technical standard | Text result |
|---------------|--------------------|-------------|
| Needle penetration (25℃,100g,5s)/0.1mm | 80~100 | 90.83 |
| Ductility (10℃,50mm/min)/cm | ≤30 | >100 |
| Softening point (R&B)/℃ | ≤44 | 46.3 |
| Flash point (COC)/℃ | ≤245 | 308 |
| Dynamic viscosity (60℃)/(Pa.s) | ≤140 | 144.3 |
| RTFOT (163℃) quality loss/% | ≤0.8 | -0.01 |

Table 3. Properties of SBS modified asphalt

| Text projects | Technical standard | Text result |
|---------------|--------------------|-------------|
| Needle penetration (25℃,100g,5s)/0.1mm | 60~80 | 69.9 |
| Ductility (10℃,50mm/min)/cm | ≤30 | 34.8 |
| Softening point (R&B)/℃ | ≤55 | 67.9 |
| Flash point (COC)/℃ | ≤230 | 332 |
| Dynamic viscosity (60℃) | ≥3 | 2.6 |
| RTFOT (163℃) quality loss/% | ≤1.0 | -0.01 |

2.3. Aggregate and mix grading

The coarse and fine aggregates are made of basalt and limestone ore, respectively, which are from the Shandong Road and Bridge Mixing Station in Hohhot. The properties of the mineral materials meet the requirements; the mix is AC-13 graded. Compared with the hot mix asphalt mixture, all the mixes have a small change in the content (mass fraction), effective bitumen content and asphalt film thickness of the bitumen aggregate in the warm mix asphalt mixture, that is, the asphalt after adding
the warm mix. The oil-stone ratio of the mixture has no effect[7]. Finally, the optimum ratio of the oil-stone ratio is 5.2% for the matrix mixture and 5.0% for the SBS mixture.

3. Static and dynamic mechanical properties test method

3.1. Aging plan
The short-term aging adopts the time-delay mixing method (the mixed mixture is placed on the hopper surface for 2 h, and the mixture is mixed every 30 min); long-term aging is a method in which the test piece is placed in a high-low temperature alternating box at 85 °C for 5 days on a short-term aging basis and naturally lowered to room temperature. The short-term aging is referred to as D, and the long-term aging is expressed as L (For example, the short-term aging of the matrix asphalt mixture is expressed as JZD, and the long-term aging of the SBS asphalt mixture is expressed as SBL).

3.2. Uniaxial compression test
The uniaxial compression test can calculate the rebound modulus $E'$ through the test results. The rebound modulus can effectively express the mechanical properties of the mixture under different conditions, and is an evaluation index that can better evaluate the static mechanical properties. Substituting the failure load $P$ of the test piece into the equation (1), the strength under each load can be obtained, and the relationship curve is plotted. The corrected coordinate axis is read and substituted (2) to obtain the compressive rebound modulus.

$$q_i = \frac{AP_i}{\pi d^2}$$

(1)

$$E' = \frac{q_5 \times h}{\Delta L_5}$$

(2)

In the formula, $q_i$ is the load at each level; $P_i$ is the pressure under the action (MPa); $E'$ is the compressive modulus of resilience (MPa); $q_5$ is the pressure under the action of the fifth stage load (0.5P) (MPa); $h$ is the height of the test piece (mm); $\Delta L_5$ is corrected rebound deformation (mm) for the fifth stage load.

3.3. Uniaxial dynamic modulus test
The uniaxial dynamic modulus test can obtain the dynamic modulus $|E^*|$ by applying an uninterrupted sinusoidal load to the test piece by collecting the relationship between stress and strain which changes with time. The dynamic modulus is the absolute value of the complex modulus of the material calculated from the ratio of the peak value of the stress and the peak of the strain during a complete sinusoidal load. It is used to describe the material's resistance to deformation. The expression is as shown in equation (3):

$$|E^*| = \frac{\sigma_{amp}}{\varepsilon_{amp}}$$

(3)

In the formula, $\sigma_{amp}$ is the stress peak; $\varepsilon_{amp}$ is the strain peak.

4. Static and dynamic mechanical properties test method

4.1. Uniaxial compression test
The test was carried out at five temperatures of 5 °C, 15 °C, 20 °C, 35 °C, and 50 °C for unaged, short-term aging, and long-term aging test specimens. The damage load $P$ obtained by the test is substituted into the formula (1), and the results of the compressive rebound modulus of each asphalt mixture calculated by the formula (2) are shown in Figure 1.
Figure 1. The elastic modulus of the mixture at different temperatures

By comparing the softening points of the two asphalts in Figure 1 (JZ: 46.3 °C, SBS: 67.95 °C) analysis, the results are shown as follow: the rate of change of the rebound modulus increases as the temperature rises and gradually approaches the softening point of the asphalt binder. When the softening point is exceeded, the cohesive force of the binder begins to slowly dissipate. Finally, the frictional resistance generated by the intercalation between the mineral materials provides a rebound. Comparing the modulus of resilience at 5 °C and 50 °C, we can find: RH reduces the high and low temperature performance of the matrix mixture, but Evotherm is improved; both RH and Evotherm can increase the high temperature performance of SBS mixture in a small amount, but the effect is not obvious; RH reduces its low temperature performance, and Evotherm effect increases the low temperature performance. After adding the warm mix agent after short-term aging, it was found that both warm mix agents inhibited the aging effect, and RH compensated for the attenuation of the low-temperature effect brought by the addition of the warm mix agent; Evotherm not only compensated for the attenuation, but also improved the low-temperature performance. After long-term aging, it was found that the low temperature performance was improved and the high temperature performance was decreased by comparing the rebound modulus at 5 °C and 50 °C of the matrix mixture with two kinds of warm mix agents (5 °C: JRL decreased by 11.55%, JEL decreased by 14.34%; 50 °C: JRL decreased by 25.36%, JEL decreased by 12.65%). Analysis of SBS mixture and the addition of warm mix agent can be found: two kinds of warm mix agent can not only alleviate the aging of SBS mixture, but also increase its low temperature performance, and Evotherm effect is better than RH.

4.2. Uniaxial dynamic modulus test

The test was carried out at four temperatures of 5 °C, 20 °C, 35 °C, 50 °C and seven frequencies of 0.1 Hz, 0.5 Hz, 1 Hz, 5 Hz, 10 Hz, 20 Hz, 25 Hz for unaged, short-term aging, and long-term aging test specimens. The uniaxial dynamic modulus of the mixture at different temperatures and frequencies is calculated by equation (3), as shown in Figure 2 (Taking SBS mixture as an example)
Figure 2. Dynamic modulus versus frequency at different temperatures (SBS)

The dynamic modulus of the mixture in Figure 2 gradually decreases with increasing temperature and the decrease gradually decreases. As the frequency increases, the modulus increases gradually, and the dynamic modulus increases with frequency at different temperatures (low temperature low frequency, high temperature high frequency fast). The modulus increases with the frequency increasing and decreases as the frequency decreasing is because that the mixture is nearly fully elastic at low temperature and high frequency, and the dynamic modulus is the elastic modulus of the asphalt mixture; at high temperature and low frequency, the binder in the mixture softens and the cohesive force dissipates, the frictional resistance generated by the intercalation between the mineral materials predominates. At this time, the dynamic modulus is the elastic modulus of a certain grade of ore; when the temperature is low, the mixture is closer to the elastic material. As the frequency increases, the lower the temperature, the closer to the full elasticity; the higher the temperature, the smaller the initial cohesive force, and the dynamic modulus is completely provided by the frictional resistance. The higher the frequency required, the higher the frequency, and the higher the temperature enters the stable phase earlier. The earlier the temperature enters the stable period of high temperature and low frequency, the worse the high temperature performance of the material.

4.3. Static modulus and dynamic modulus

Table 4 summarizes the 20 °C rebound modulus data compared with 20 °C, 0.1 Hz (static) 10 Hz (dynamic) uniaxial dynamic modulus which aims to obtain the relationship between dynamic and static modulus.

| Asphalts | 20 °C Rebound modulus (MPa) | 20°C 0.1HZ Dynamic modulus (MPa) | Dynamic modulus/Rebound modulus | 20°C 10HZ Dynamic modulus (MPa) | Dynamic modulus/Rebound modulus |
|----------|-----------------------------|----------------------------------|---------------------------------|---------------------------------|---------------------------------|
| JZ       | 1074                        | 1028                             | 0.96                            | 7157                            | 6.66                            |
| JZD      | 1350                        | 1937                             | 1.43                            | 8710                            | 6.45                            |
| JZL      | 1526                        | 2468                             | 1.62                            | 9833                            | 6.44                            |
| JR       | 1102                        | 1333                             | 1.21                            | 7996                            | 7.26                            |
| JRD      | 1258                        | 2230                             | 1.77                            | 9594                            | 7.63                            |
| JRL      | 1270                        | 2169                             | 1.71                            | 9681                            | 7.63                            |
| JE       | 1090                        | 1252                             | 1.15                            | 7926                            | 7.27                            |
| JED      | 1224                        | 1812                             | 1.48                            | 8760                            | 7.16                            |
| JEL      | 1292                        | 2076                             | 1.61                            | 8712                            | 6.74                            |
| SB       | 1130                        | 1155                             | 1.02                            | 6511                            | 5.76                            |
| SBD      | 1600                        | 1766                             | 1.1                             | 8629                            | 5.39                            |
| SBL      | 1685                        | 2411                             | 1.43                            | 9314                            | 5.53                            |
| SR       | 1170                        | 1094                             | 0.93                            | 6373                            | 5.45                            |
The rebound modulus at 20 °C in Table 4 meets the recommended range in the pavement design specification. It is also found that the dynamic modulus of the original mixture measured at 0.1 Hz is not much different from the elastic modulus measured by the uniaxial compression test, but the data difference after aging is large; the dynamic and static ratios tend to be stable at 10 Hz, and there is little change after aging (The dynamic modulus of the matrix asphalt mixture at 10 Hz is about 6.5 times of the rebound modulus, about 7 times after adding the warm mix agent, and the degree of aging is reduced after adding the Evotherm; the SBS mixture is stable at about 5.3 times). This shows that the anti-aging performance of SBS mixture is better than that of matrix mixture. After adding warm mix agent, it can improve the short-term aging resistance of the mixture, and Evotherm can also exert anti-aging effect in long-term aging. This test can provide a basis for the test between dynamic and static modulus and the selection of the modulus of the pavement layer system.

5. Conclusion

(1) Static mechanical properties analysis can be obtained: the high and low temperature performance of the asphalt mixture is improved after adding Evotherm, but RH is reduced except for the high temperature performance of SBS mixture. After the addition of the warm mix agent, the decay rate of the short-term aging performance becomes slower; after aging, the warm mix agent directly affects the high-temperature stability of the mixture, and the mixture added with Evotherm is less affected.

(2) Dynamic mechanical properties analysis can be obtained: the performance of asphalt mixture at low temperature and high frequency is equivalent, indicating that dynamic mechanics is not suitable for evaluating the low temperature performance of asphalt mixture; the high temperature low frequency can evaluate the high temperature performance of the asphalt mixture.

(3) Comprehensive analysis of dynamic and static mechanical properties: after aging, the dynamic and static modulus of the mixture is quite different. It is recommended to consider the modulus change caused by aging in the design process; under normal conditions (20 °C, 10 Hz), the dynamic modulus is 5–6 times of the modulus of resilience, and the dynamic and static modulus are quite different, which provides a basis for the conversion between dynamic and static modulus.

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