Study on Rheological Properties of BRA Modified Asphalt

ZHOU Zhihai
China Merchants Chongqing Communications Research & Design Institute Co., Ltd., Chongqing 400067, China
*Corresponding author’s e-mail: 56174286@qq.com

Abstract. Different amounts of BRA modified asphalt was prepared and evaluated for road performance. The basic indexes of different BRA was studied, including: penetration, ductility, softening point and viscosity. The viscosity-temperature characteristics of BRA were studied by Brookfield rotational viscosity test. The high temperature and low temperature rheological properties of BRA was studied by dynamic shear rheological test (DSR) and low temperature bending beam rheological test (BBR). The results show that the penetration of asphalt modified by BRA is decreased, but the softening point and viscosity are improved. BRA could significantly improve the viscosity of asphalt and maintain good construction workability. The rutting factor of BRA is larger than matrix asphalt and asphalt cement. The PG high temperature grade of unaged BRA is higher than that of RTFOT aging. BRA will reduce the low temperature performance of asphalt binder, but it has little effect on asphalt cement.

1. Introduction
Under the coupling of vehicle load and natural environment, the defects such as rutting, cracks and pits caused by the rheological properties of asphalt cement are the main damage of asphalt pavement. Such diseases do not only occur in the upper layer of the road surface, but usually extend to the middle layer, which increases the difficulty of road maintenance. Therefore, in order to improve the durability of asphalt pavement and prevent common pavement diseases, domestic and foreign scholars have carried out a lot of research, such as the modification of matrix asphalt [1]. The modification method of asphalt can be mainly divided into two categories: high molecular polymer modification and natural asphalt modification. Among them, high molecular polymer modified asphalt mainly includes: waste rubber powder, SBS, SBR, PE modified asphalt. The high molecular polymer modified asphalt has excellent high temperature performance, but recent studies have shown that SBS modified asphalt also has many shortcomings, such as easy delamination and separation, high requirements for mixing equipment, etc.

Natural asphalt modified asphalt mainly includes: rock asphalt modified asphalt and Budun rock asphalt modified asphalt. BRA is a natural asphalt modifier. It has been widely used in the road field in recent years due to its excellent modification to matrix asphalt [2]. At normal temperature, BRA is a light brown fine particle powder with a bitumen content of about 20-30%, and the rest is limestone minerals with a maximum particle size of less than 3 mm. Studies have shown that the minerals in BRA have a strong ability to absorb bitumen, which can enhance the adhesion of asphalt and mineral materials [3]. At present, some basic research on the basic road performance of BRA modified asphalt mixture has been studied, but there are few studies on its rheological properties. Based on the above background, this paper studies the basic indexes and rheological properties of BRA.
2. Raw materials and test methods

2.1 Test raw material

2.1.1 Matrix asphalt. The Binzhou AH-90 road petroleum asphalt is used. The test results of asphalt technical performance are shown in Table 1. It can be seen from Table 1 that all performance indicators meet the technical requirements of the Technical Specifications for Highway Asphalt Pavement Construction (JTG F40-2004).

| Pilot projects | Asphalt type | Requirements  |
|----------------|--------------|---------------|
| Penetration (100g, 5s, 25℃, 0.1mm) | AH-90 | 86 | 80~100 |
| Ductility (5cm/min, 15℃) cm | >150 | >100 |
| Softening Point (℃) | 44.3 | 42~52 |
| Rotating film heating test (160℃, 5h) | Quality loss (%) | 0.31 | <1 |
| Penetration ratio (%) | 57.4 | >50 |
| Ductility (25℃, cm) | >150 | >75 |
| Ductility (15℃, cm) | >150 | Measured record |

2.1.2 Modifier. The modifier is BRA, which is a natural asphalt modifier. The main technical indicators are shown in Table 2.

| Indicator | test results | First group | Second Group |
|-----------|--------------|-------------|--------------|
| Asphalt content (%) | 24 | 19.80 |
| Trichloroethylene solubility (%) | 24.0 | 19.80 |
| Density (g/cm3) | 1.84 | 1.76 |
| Flash point (℃) | 270 | 300 |
| Heating loss (%) | 0.55 | 0.58 |
| Water content (%) | 0.64 | 0.20 |

2.2 Experiment method

2.2.1 BRA modified asphalt preparation. The amount of 10%, 20%, 30% of the BRA particles was added to the substrate pitch preheated to 170℃ along the sidewall of the beaker. The motor speed was set to 2500 r/min, and stirred at 175℃ for 30 min. After the stirring, the rotation speed was adjusted to 5000 r/min and sheared for 30 min, so that the BRA modifier was fully swelled, and the whole mixture system was stirred at 165℃ and 2500 r/min for 30 min. After stopping, the BRA modified asphalt is slowly and uniformly stirred by a glass rod. After a large amount of air bubbles in the asphalt is removed, it is poured into a pre-prepared container for use in subsequent tests.

2.2.2 Penetration, ductility, softening point and tack toughness test. The penetration, ductility, softening point and visco-toughness tests were carried out in strict accordance with the test method in JTB E20-2011 (JT E20-2011).

2.2.3 Brookfield Rotational Viscosity Test. The rotor of the Brookfield Rotational Viscosity Test was selected for No. 21 at a speed of 50 rpm and the viscosity of the asphalt was tested at 135℃.
2.2.4 *Dynamic shear rheological test.* The dynamic shear rheological test adopts the strain control mode. The strain value of the original sample is $\gamma=10\%$, the strain value of the sample after RTFOT is $\gamma=8\%$, and the strain value of the sample after PAV aging is $\gamma=\%$. The test frequency is $\omega=10\text{rad/s}$. The original, RTFOT dynamic shear test uses a sample with a diameter of 25 mm and a thickness of 1 mm. After the PAV dynamic shear test, a sample with a diameter of 8 mm and a thickness of 2 mm is used.

2.2.5 *Low temperature bending beam rheological test.* The asphalt girders with a size of 125 mmx12.5 mmx6.25 mm are placed on the two supports. And a 3 to 4 g preload is manually added to ensure that the trabecular beam was in close contact with the support. A 100 g load was applied to the test piece by a computer, and the action time was 1 second to position the test piece. Then unload to preload and let it recover for 20s. At the end of 20s, a load of 100g was applied and held for 240s. The deflection-time curve of the asphalt trabecular was recorded. The curve of deflection versus time was plotted by computer, and the creep stiffness and m value at $t=60$ s were calculated.

3. Test results and analysis

3.1 *Basic indicator*

Asphalt penetration is a shear creep test, the physical meaning of which is apparent viscosity, reflecting the deformation ability of asphalt under load [4]. It can be seen from Table 3 that the penetration of the BRA modified asphalt is lower than that of the matrix asphalt at the same temperature. As the amount of BRA increased, the extent of the decline was more pronounced, indicating that the addition of BRA can harden the asphalt and enhance its resistance to deformation.

The ductility reflects the plasticity of the asphalt material. It can be seen from Table 3 that the ductility of the BRA is significantly lowered, which is unfavorable for its low temperature performance. According to the analysis, BRA contains more mineral particles. When the tensile length reaches a certain value, the mineral particles in the BRA will cause cracking. However, this cracking is not a crack caused by the material reaching the plastic limit. Therefore, it is not appropriate to use the ductility index to evaluate the low temperature performance of BRA binder, which should be further verified by the asphalt mixture test.

Table 3. Performance of different BRA modified asphalt.

| BRA dosage | Penetration | Ductility | Softening Point | Viscous toughness |
|------------|-------------|-----------|-----------------|-------------------|
| 0          | 86          | 25$^\circ$C | 44              | 3.935             |
| 10%        | 84          | >150      | 45              | 7.303             |
| 20%        | 77          | 84        | 47              | 7.619             |
| 30%        | 73          | 59        | 50              | 8.345             |

In terms of softening point, BRA can enhance the high temperature resistance of asphalt. The modified asphalt blended with 10% BRA has substantially the same softening point as the matrix asphalt. When the dosage is increased to 20%, the softening point of the asphalt is remarkably increased. The softening point of 20% and 30% BRA-doped modified asphalt increased by 7% and 13.6%. In addition, after adding BRA, the viscosity of asphalt is also greatly improved. The viscosity of 30% BRA is 2.12 times that of matrix asphalt, and the increase is very obvious. According to the analysis, BRA contains high elements such as nitrogen, oxygen and sulfur, and exists in the form of functional groups. The functional groups can improve the wettability of the asphalt and the resistance to free oxidation groups, thereby enhancing the high temperature softening resistance of the asphalt.

3.2 *Brookfield rotational viscosity*

The viscosity of asphalt has obvious temperature sensitivity. The viscosity-temperature relationship of asphalt is one of the basic contents of asphalt rheology research [5]. Good viscosity can enhance the adhesion between the aggregate and the asphalt, thereby improving the resistance of the asphalt
mixture to deformation and water damage. However, the viscosity is not as large as possible, too high viscosity will affect the construction workability of the mixture, which leads to uneven and insufficient filling of the asphalt in the mixing and mixing. In summary, bitumen must have an appropriate viscosity over the temperature range of use, so it is necessary to study the viscosity of BRA. Figure 1 shows the 135℃ viscosity of different amounts of BRA.

![Figure 1. 135°C viscosity value of BRA modified asphalt.](image)

It can be seen from Fig.1 that the viscosity of the modified asphalt is significantly improved after the addition of BRA. At 135℃, the viscosity of BRA at 50% and 100% is 2 and 4 times higher than that of matrix asphalt. BRA has a positive effect on improving the adhesion of asphalt. At the same time, the viscosity of the 50% blended BRA is almost the same as the viscosity of the asphalt cement under the same powder-to-rubber ratio. In addition, the modified asphalt under different BRA dosages has a viscosity value of less than 3 Pa·s at 135 °C, which is in line with China's current technical specifications.

3.3 High temperature rheological properties

The high temperature rheological properties of asphalt binders are closely related to the anti-rutting properties of asphalt mixtures. The rutting factor is an indicator of the rutting resistance of asphalt binders [6]. Table 4 shows the rutting factor $G^* / \sin \delta$ of different BRA at different temperatures.

| Test index | Before aging | After aging |
|------------|--------------|-------------|
|             | Matrix asphalt | Mineral powder | +50% BRA | +100% BRA | Matrix asphalt | Mineral powder | +50% BRA | +100% BRA |
| $G^* / \sin \delta$ (Kpa) | 64°C | 1.43 | -- | -- | 2.90 | -- | -- | -- |
|                  | 70°C | 0.68 | 1.59 | 1.71 | -- | 1.32 | 3.62 | 4.29 | -- |
|                  | 76°C | -- | 0.78 | 0.83 | 2.12 | -- | 1.70 | 2.04 | 4.18 |

As can be seen from Table 4, the $G^* / \sin \delta$ of various pitches decreases as the temperature increases. The rate of drop of different amounts of BRA is comparable, while the rate of decline of matrix asphalt is gentle. At the same temperature, the rutting factor of BRA is significantly larger than that of matrix asphalt, indicating that BRA has the effect of improving asphalt rutting resistance. In addition, for unaged BRA, the PG high temperature grade is higher than that of the matrix asphalt, and each 50% increase is increased by one grade. After RTFOT aging, when the dosage reaches a certain value, the PG high temperature grade will not increase.

3.4 Low temperature rheological properties

The low temperature rheological properties of asphalt binders are the most important factors determining the ability of asphalt pavements to resist low temperature cracking. For asphalt binders, the smaller the creep stiffness, the smaller the elasticity of the material and the greater the viscosity.
The greater the flexibility under low temperature conditions, the better the resistance to deformation [7]. Table 5 and Figure 2 show the creep stiffness and m value of different BRA.

Table 5. Creep stiffness and m value of BRA modified asphalt at different temperatures.

| Asphalt                    | Creep stiffness (MPa) | m  |
|-----------------------------|-----------------------|----|
|                            | -6°C   | -12°C | -18°C | -6°C | -12°C | -18°C |
| Matrix asphalt              | --     | 178   | 409   | --   | 0.371 | 0.288 |
| Mineral powder              | 154    | 400   | 892   | 0.433 | 0.345 | 0.241 |
| +BRA50%                     | 159    | 349   | 705   | 0.399 | 0.322 | 0.250 |
| +BRA100%                    | 407    | 720   | --    | 0.348 | 0.274 | --    |

Figure 2. Low temperature rheological index of BRA modified asphalt.

It can be seen from Table 5 and Figure 2 that the creep stiffness of different blending BRA increases with the decrease of temperature, while the m value decreases with the decrease of temperature. At the same time, the modified asphalt after blending with BRA has greater creep stiffness and smaller m value than matrix asphalt. This indicates that the incorporation of BRA reduces the low temperature ductility of the matrix asphalt and the self-healing properties after fatigue failure. However, the 50% BRA has a lower difference between the low temperature rheological index. Therefore, increasing the powder to rubber ratio of the asphalt mixture has a positive effect on improving the low temperature performance of the BRA.

4. Conclusion

(1) The penetration of different amounts of BRA modified asphalt is lower than that of matrix asphalt. As the amount of BRA increased, the extent of the decline was more pronounced. Since BRA contains more mineral particles, it is not advisable to use the ductility index to evaluate the low temperature performance of BRA binder. The high content of nitrogen, oxygen, sulfur and other elements in BRA can improve the high temperature resistance of asphalt.

(2) Brookfield's rotational viscosity test showed that the viscosity of the 50% and 100% blended BRA modified asphalt was 2 and 4 times higher than that of the matrix asphalt at 135 °C. BRA has a positive effect on improving the adhesion of asphalt. The viscosity of modified asphalt under different BRA dosages is less than 3Pa·s, which has good construction workability.

(3) The BRA has little effect on the temperature sensing performance of the matrix asphalt. The rutting factor of BRA at the same temperature is greater than that of matrix asphalt and asphalt cement, and it becomes more and more significant with the increase of BRA content. Unaged BRA, with a PG high temperature rating increased by one level for every 50% of the blend. After the RTFOT aging of the BRA, when the dosage reaches a certain value, the PG high temperature grade will not increase.

(4) For asphalt cements, the incorporation of BRA reduces the low temperature ductility of the matrix asphalt and the self-healing properties after fatigue damage. For asphalt cement, 50% BRA has a low difference between low temperature rheological index and low temperature rheological index of
asphalt cement. BRA has better modification effect on asphalt cement than matrix asphalt.

References
[1] Ying, Y.M. Zhang, X.N. (2010) Research on High Temperature Rheological Characteristics of Asphalt Mastics with Indonesian Buton Rock Asphalt (BRA). JOURNAL OF WUHAN UNIVERSITY OF TECHNOLOGY, 32: 85-90.
[2] Wu, Y.F. Liao, J. Huang, W.Q. Feng, W.K. (2019) Analysis of High-Temperature Performance of Buton Rock Asphalt Modified Asphalt. Journal of Chengdu University (Natural Science Edition), 38: 106-111.
[3] Sun, H. Zhang, L. Cui, X.Z. (2015) Study on Road Performance of Budun Rock Asphalt Modified Asphalt and Mixture. Journal of China & Foreign Highway, 35: 275-280.
[4] Zhang, T.Z. Zhao, P. (2016) Experimental Study on SMA Mixture of Budunsel Rock Asphalt Used as Modifier. Highway, 7: 240-244.
[5] Bao, L. Liu, J.L. Qu, B. Zhan, H.H. (2012) Study on the Factors Affecting the Viscosity of Polymers by Rheometer and Viscometer. ADVANCES IN FINE PETROCHEMICALS, 13: 10-13.
[6] Wang, W.T. Luo, R. Feng, G.L. Wang, L.J. (2016) Impact Factors in Rotational Viscosity Tests. Journal of Wuhan University of Technology (Transportation Science & Engineering), 40: 514-519.
[7] Li, W. Guo, N.S. Jiao, B.Z. W, L. (2018) Rheological properties of rock asphalt composite modified asphalt. Journal of Dalian Maritime University, 44: 79-88.