Performance Evaluation of Rubber Asphalt and Desulfurized Rubber Asphalt

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Abstract. The waste crumb rubber (CR) has been utilized to improve asphalt performance but it shows poor compatibility with matrix asphalt. The approaches of desulfurization and degradation of rubber are proposed to solve the above difficulties. The modified asphalts were prepared with using crumb rubber and desulfurized rubber as modifiers, and matrix asphalt was taken as control group to evaluate the physical properties, high-temperature rutting resistance and low-temperature crack resistance of three asphalts. The results show that both CR and DCR contribute to the positive modification to matrix asphalt, CR modified asphalt exhibits excellent high-temperature rutting resistance and low-temperature cracking resistance. The desulfurization of crumb rubber improves compatibility in asphalt due to the declined molecular weight, thereby enhancing the low-temperature performance of asphalt.

Keywords: crumb rubber, desulfurized rubber asphalt, modified asphalt, rheological properties.

1 Introduction

The modification of matrix asphalt using crumb rubber (CR) effectively optimize the pavement performance of asphalt, also taking full use of waste rubber tires [1]. In the past decades, rubber asphalt as a representative technology of crumb rubber modified asphalt, has been the focus of research and development. CR modified asphalt involves the physical swelling of crumb rubber in asphalt, causing that the asphalt presents good high-temperature stability, low-temperature cracking resistance and fatigue resistance [2]. Nevertheless, due to the limited preparation process, as well as poor compatibility between rubber and asphalt, resulting in CR modified asphalt exhibits limited in storage, production, transportation and usage are inconvenient [3].

The concepts of desulfurization and degradation of rubber are proposed to solve the above difficulties [4]. This declines the rubber sizes, thereby improving the compatibility in asphalt, simultaneously solving the problems of poor storage stability of rubber asphalt. Wu et al. [5] discovered that the depolymerization reactions of rubber in the high temperatures caused a decrease in the viscosity of rubber asphalt, but the aging actions led to an increase in viscosity. Bahia et al. [6] revealed that desulfurized rubber exhibited poorer modification in the improvement on high-temperature performance of

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asphalt. Morrison [7] proposed that CR modified asphalt exhibits weaker low-temperature performance than that of desulfurized rubber asphalt. Dong et al. [8] demonstrated that waste cooking oil pre-desulfurized rubber caused changes in components in asphalt, decreasing viscosity at high temperatures and increasing elasticity of asphalt. The above studies have contributed to the advancement of rubberized asphalt, but there is no comprehensive and systematic evaluation of CR and DCR modified asphalt. Consequently, this paper aims to comprehensively evaluate the performance of rubber asphalt and desulfurized rubber asphalt, to investigate the differences in physical properties and explore the mechanisms. The physical properties tests are conducted on matrix asphalt, CR, and DCR modified asphalt. The rheological properties of asphalt samples are analyzed by Multiple Stress Creep and Recovery (MSCR) tests and Bending Beam Rheometer (BBR) tests to comprehensively evaluate the performance of rubber asphalt and desulfurized rubber asphalt.

2 Materials and Methods

2.1 Materials

Raw Materials. This binder of 70 penetration grade was selected as matrix asphalt, and the fundamental technical indicators were provided in Table. 1. The 60-mesh crumb rubber (CR) from waste truck bias tires and desulfurized crumb rubber (DCR) obtained by mechanical screw extrusion desulfurization were used for the preparation of 20 % CR modified asphalt and 20 % DCR modified asphalt, respectively. Table 2 described the results of physicochemical indexes tests for CR and DCR.

Table 1. Technical index of 70# matrix asphalt.

Indexes	Unit	Test result	Standard
Penetration (25 °C, 100 g, 5 s)	0.1 mm	72.8	60~80
Softening point (25 °C)	°C	47.1	≥46
Ductility (5 mm/min, 15 °C)	cm	29	≥15
Viscosity (135 °C)	Pa·s	0.482	-

Table 2. Main chemical composition of CR and DCR.

Indexes	Unit	CR	DCR
Rubber hydrocarbon content	%	56.2	51.2
Acetone Extracts	%	8.8	11
Carbon black content	%	30.5	29.7
Ash content	%	4.5	8

Preparation of Asphalt. The modifiers were added to the molten matrix asphalt, heated to 180 °C and stirred at a rate of 300 r/min for 30 min to ensure the modifiers sufficiently swollen. The mixture of modifiers and asphalt was sheared at 4000 r/min for 50 min, where the temperature always was maintained at 180 ± 5 °C. The resulting compound modified asphalt was subsequently cured and developed in an oven at 180 °C for 30 min.

2.2 Methods

General Properties. The asphalt samples were tested for softening point and penetration at 25 °C, ductility at 5 °C to describe the general properties, according to ASTM D36, ASTM D5 and ASTM D113, respectively.

Rheological Properties. The rutting resistance at high temperatures of asphalt samples was evaluated for creep and recovery at two stress conditions of 0.1 kPa and 3.2 kPa, at the test temperature of 64 °C in accordance with ASTM D7405. Cycles at each stress level included loading deformation for 1 s and unloading recovery for 9 s. According to ASTM D6648, BBR was employed to measure creep stiffness (S) and creep speed (m) at -12 °C, -18 °C and -24 °C to investigate the low-temperature performance of asphalt.

3 Results and Discussion

3.1 General Properties Analysis

From Fig. 1, the softening point of CR modified asphalt reaches 65.5 °C, showing the strongest improved high-temperature performance. The penetration of modified asphalt significantly reduces, indicating that modifiers reduce the asphalt flexibility. The ductility values are in descending order of DCR, CR, matrix asphalt. This is because CR absorbs the light components in asphalt, making rubber particles and connecting tightly with asphalt together. Therefore, the viscosity of CR/asphalt system increases significantly, improving the softening point and decreasing the penetration. DCR also absorbs the light components, the lower molecular weight and no rubber cores of DCR solve the poor compatibility in asphalt, thus presents softer and higher penetration value, enhancing the interfacial bonding force be-tween modifiers and asphalt, subsequently increasing the ductility of asphalt. Meanwhile, the broken molecular structures in DCR leads to the loose structure in the asphalt system become loose, so the softening point is lower and the ductility is higher in comparison with CR modified asphalt.

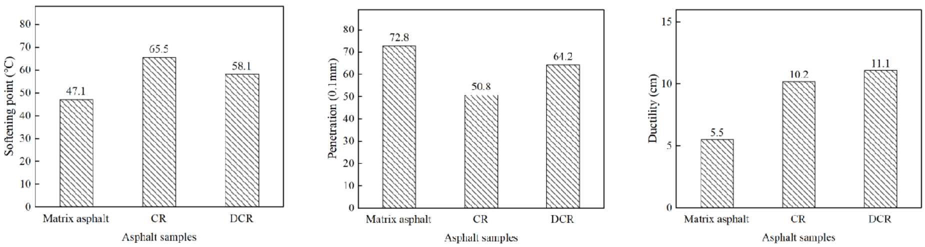


Fig. 1. Physical properties of asphalt samples.

3.2 High-temperature Performance Analysis

From Fig. 2(a), Comparing R values of asphalt samples under 0.1 kPa and 3.2 kPa stress conditions, concluding that the higher stress causes more unrecoverable deformation of asphalt and the lower R value, which corresponds to the fact that the larger tire pressure on the actual pavement produces deeper permanent deformations. Matrix asphalt shows negative R values in the two stress conditions, considering that it is damaged or destroyed. Moreover, the loose internal structure of DCR leads to the decrease in strain recovery percentage in DCR modified asphalt. From Fig. 2(b), Jnr characterizes the contents of unrecoverable residual strains, reflecting the permanent deformation of asphalt. The smaller value indicates that the smaller residual strain and the better deformation resistance of asphalt. Jnr values increase when the stress level is increased from 0.1 kPa to 3.2 kPa, indicating that the residual strain becomes larger and the deformation resistance decreases. Additionally, CR modified asphalt exhibits excellent rutting resistance at high temperatures, which is consistent with the softening point result.

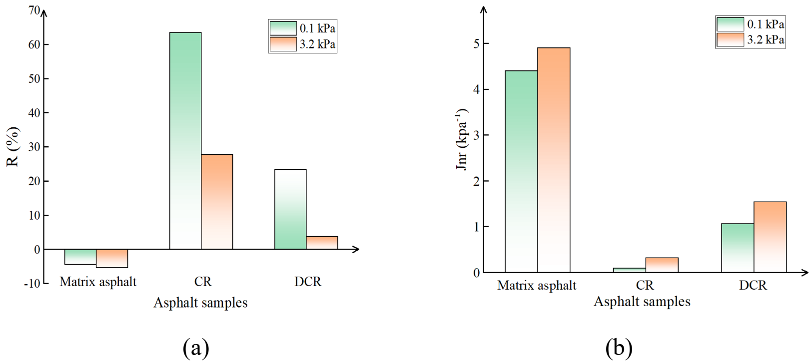
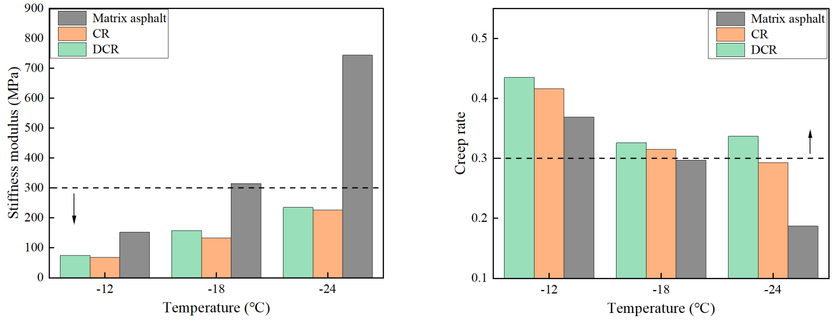


Fig. 2. R and Jnr values of asphalt samples.

3.3 Low-temperature Performance Analysis

As seen in Fig. 3(a), the stiffness modulus S of several asphalts show a growth trend as the temperature decreases in the range of -12 °C to -24 °C, indicating that the falling temperature increases the cracking risk of asphalt. Except for matrix asphalt, the stiffness modulus of modified asphalt meets the requirement of less than 300 MPa in the test temperature range. CR modified asphalt presents low S value at -12 °C to -18 °C temperature, indicating that the asphalt is not easy to crack and brittle fracture under low-temperature loading, showing excellent low-temperature performance. From Fig. 3(b), the creep rate of asphalt gradually decreases as the temperature drops. When the matrix asphalt is modified by RIIR, DCR and CR three rubber modifiers, the creep rate increases at the same temperature, of which the effect of DCR is the most obvious. This is because the inclusion of rubber significantly improves the elasticity of asphalt system, improving ability to respond quickly and relax stresses in the face of thermal stress concentrations, thereby reducing the cracking risks of asphalt. DCR exhibits a stronger interfacial bond with the asphalt and fewer stress concentration points in the asphalt, thus presenting better cracking resistance at low temperatures than CR asphalt.



(a) (b)

Fig. 3. Stiffness modulus and creep rate of asphalt samples.

4 Conclusions

This paper tests the physical properties of CR modified asphalt and DCR modified asphalt, MSCR tests were conducted to determine the deformation resistance of asphalt at high temperatures, and the cracking resistance of asphalt at low temperatures was analyzed by BBR tests. The conclusions are summarized as follows:

1) CR and DCR contribute to the positive modification to matrix asphalt, this is attributed to the dissolution and swelling of rubber.

2) CR modified asphalt exhibits superior high-temperature rutting resistance and low-temperature cracking resistance. DCR improves compatibility in asphalt due to the declined molecular weight, thereby enhancing asphalt performance.

3) The compound modification of CR and DCR is the trend of asphalt research, contributing to perform jointly the advantages of CR asphalt and DCR asphalt.

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