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Analysis of viscosity and composition properties for crumb rubber modified asphalt

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HIGHLIGHTS

- The viscosity and composition properties for rubber asphalt are analyzed.
- The visco-flow activation energy ($E\eta$) of RA was acquired.
- The viscosity of rubber asphalt is split into three parts: *BE*, *IE* and *PE*.
- The impact of factors on *IE* and *PE* of rubber asphalt was anatomized.
- The viscosity prediction model of rubber asphalt was established.

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ABSTRACT

The preparation of crumb rubber modified asphalt (RA) shall effectively recycle waste rubber and abate environmental contamination. To ascertain the composition and the factors affecting the viscosity of RA, some samples were prepared in the case of different conditions of mixing temperature and processing time for different rubber dosage and rubber size. Brookfield viscosity tests were conducted on RA samples, and the impact exerted by these factors on viscosity of RA was anatomized. The visco-flow activation energy ($E\eta$) of RA was acquired through adopting Arrhenius equation in line with the viscosity values of asphalt in the case of different temperatures. The changing regularity of $E\eta$ was anatomized. The viscosity of rubber asphalt can be split into three parts: the contribution of base asphalt (*BE*), rubber and asphalt interaction effect (*IE*) and crumb rubber particle effect (*PE*), and additionally the viscosity definition is proposed as $\eta_{RA} = \eta_0(1 + IE + PE)$. To isolate the *PE*, the sieving test was designed. Rotary viscosity tests were conducted on RA samples and asphalt samples separated from crumb rubber through adopting Brookfield viscosity meter. The impact exerted by these factors on the viscosity composition parameters *IE* and *PE* of rubber asphalt was anatomized. In line with the viscosity definition, the viscosity prediction model of rubber asphalt was established. It is indicated from the results and analysis that the viscosity values of RA increase by the exponential growth model continuously with the increase of rubber content. There is a certain equivalence for rubber asphalt viscosity between raising mixing temperature and extending the processing time. But too high temperature or excessive time may result in excessive degradation of rubber molecules, which shall cause the decrease of RA viscosity. With the rising of the dosage of crumb rubber, $E\eta$ of RA for origin or aged samples both goes up first and thereupon drops down. And peak $E\eta$ exists in the range of rubber content from 10% to 15%. The $E\eta$ value of aged RA outstrips that of original sample for the same rubber dosage. For the rubber asphalt samples prepared through adopting the same type and size crumb rubber, the *IE* values show linear relation with the dosage of crumb rubber, while *PE* values increase by the exponential growth model continuously with the dosage of crumb rubber. Within a certain temperature range, *IE* and *PE* values both show linear relation with the mixing temperature, and show parabola relationship with the processing time. The proposed prediction model can manifest the viscosity composition of rubber asphalt and has an expected fitting precision.

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1. Introduction

The rubber with excellent property is extensively adopted in industry, transportation, medicine and in other fields, and accordingly the waste of resources and environmental contamination turn out to be increased arising from the waste rubber. How to harness waste rubber and protect the environment has raises the problem to be urgently resolved. The harnessing of waste rubber as a modifier, adding to the asphalt to prepare RA has aroused the extensive concern from the domestic and foreign road workers [1–3]. The crumb rubber in the hot asphalt can optimize the property of asphalt through the swelling, degradation and a series of complex physico-chemical processes [4]. Viscosity is perceived as an important indicator for the evaluation of rubber asphalt property, its variations evidently manifest the rheological properties differences of RA. Abdelrahman [4] started the swelling and degradation behaviors of crumb rubber in RA. Li [5] anatomized the physico-chemical behaviors of crumb rubber in the modified asphalt. Hoang [6] made the viscosity model of material parameters of the polymer. Putman [7], Rui [8], Lougheed [9], Shi [10] studied the viscosity characteristics of RA in different aspects, and thereupon a lot of research results on RA viscosity has made by the impacts exerted by rubber dosage, rubber size, prepared temperature of RA, reaction time and other factors [5–7,11]. However, these factors almost were qualitative analysis, the viscosity characteristics and mechanism of action still are required to be delved into.

In this study, RA were prepared in the case of different conditions of mixing temperature and processing time for different rubber dosage and rubber size. The viscosity of RA in the case of different preparation conditions shall be tested, and thereupon the viscosity characteristics and influencing factors shall be anatomized. RTFOT aging test of RA shall be conducted, and the visco-flow activation energy (E_η) of RA was acquired through adopting Arrhenius equation in line with the viscosity values of RA in the case of different temperatures, and the visco-flow characteristics of RA were anatomized. The viscosity definition is made based on the contribution of base asphalt (*BE*), rubber and asphalt interaction effect (*IE*) and crumb rubber particle effect (*PE*). To isolate the *PE*, the sieving test was designed. Rotary viscosity tests were conducted on RA samples and asphalt samples separated from crumb rubber through adopting Brookfield viscosity meter. The impact exerted by these factors on the viscosity composition parameters IE and PE of RA was anatomized, and the viscosity prediction model of RA was established.

2. Materials and experimental methods

2.1. Materials

A typical virgin asphalt binder was adopted. Its properties were tested and listed in Table 1. A kind of commercially available 20, 40, 60, 80-mesh crumb rubber from the Changda Huachu company was adopted in this investigation. The appearance is black. The physical and chemical parameters are listed in Table 2.

2.2. Rubber asphalt(RA) preparation

To ascertain the viscosity and Composition for rubber asphalt, RA were prepared in the case of the different conditions through heating and stirring. Preparation conditions are listed in Table 3.

2.3. Viscosity test

In line with ASTM D 4402, Brookfield viscometer (DV-II, 27# rotor, 50 r/min) was adopted to measure the viscosity of RA samples in the case of different conditions to analyze the influence on the viscosity of RA and discuss the viscosity composition of RA. The temperature for the viscosity test is 180 °C.

2.4. Aging test

To comparatively analyze the visco-flow properties of RA before and after aging, the RA samples were artificially aged according to the RTFOT procedure (AASHTO T240). The aging simulation conditions are: aging temperature is 163 °C ± 0.5 °C, the rotation speed is 15 r/min ± 0.2 r/min, the hot air flow velocity is 4000 ml/min ± 200 ml/min and aging time is 85 min.

2.5. Sieving test

To analyze the relationship between the swelling degree of crumb rubber and the viscosity of RA, the sieving test was designed to separate the crumb rubber from RA. The rubber asphalt was poured into 200-mesh sieve device and thereupon placed in 150 °C oven for 1 h, to separate the crumb rubber from asphalt in the presence of constant temperature. The sieve device is exhibited in Fig. 1.

2.6. Viscosity composition parameters of RA

The relationship between the different conditions and the interaction effect (*IE*) and the particle effect (*PE*) were anatomized in line with the viscosity of RA and the sieved asphalt from RA in the presence of different conditions. Thereupon the viscosity composition of RA was elucidated.

Putman [10] attained that the impact exerted by crumb rubber on the viscosity of RA was primarily split into two parts: Interaction effect (*IE*) and Particle effect (*PE*). *IE* is produced in the wake of the interaction of the crumb rubber and the asphalt. The crumb rubber shall absorb the light component of the asphalt as the crumb rubber and the asphalt are interacted with each other, and the absorbing shall result in the variation of the asphalt

Table 1
Properties of asphalt binders.

Test Indicators		Values	Test Methods [12–17]
Density (15 °C)/(g/cm^3)		0.978	ASTM D70
Penetration (25 °C, 5 s, 100 g)/(1/10 mm)		88	ASTM D5
Softening Point (R&B)/°C		43	ASTM D36
Ductility (5 °C, 5 cm/min)/cm		>150	ASTM D113
Flash point/°C		271	ASTM D92
Penetration index		−1.477	ASTM D5
Film Heating Test (163 °C, 5 h)	Mass loss/%	−0.064	ASTM D1754
	Penetration ratio/%	61.0	ASTM D1754/D5
	Residual ductility (15 °C, 5 cm/min)/cm	47.3	ASTM D1754/D113

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