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Understanding the low temperature properties of Terminal Blend hybrid asphalt through chemical and thermal analysis methods

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HIGHLIGHTS

- Low temperature properties of Terminal Blend(TB) hybrid asphalt are compared with SBS modified asphalt both in binder andmixture.
- Components distribution of TB hybrid asphalt binder is presented.
- During the degradation of crumb rubber,aliphatic component is released which has shorter average chains lengthcompared with that in base binder.
- Increasing amount of aliphatic component leads to a decrease of Tg and improvement in low temperature properties.
- Relaxation property is improved with increase of short chains length aliphatic component.

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ABSTRACT

Terminal Blend (TB) hybrid asphalt binders are composed of crumb rubber, SBS polymer and polyphosphoric acid (PPA). Understanding the relationship between the chemical composition and low temperature properties has a guiding significance for asphalt modification. In this study, BBR (Bending Beam Rheometer) test, GPC (Gel Permeation Chromatography) test, FTIR (Fourier Transform Infrared) test and DSC (Differential Scanning Calorimetry) test were used to evaluate the rheological and chemical properties of TB hybrid binder and TSRST (Thermal Stress Restrained Specimen test) was conducted to estimate the low temperature properties of mixture. The results indicated that crumb rubber and SBS improved low temperature properties, while PPA had an adverse effect. Furthermore, during the degradation of crumb rubber, aliphatic component was released, which played an important role in improving low temperature properties. Finally, TB hybrid asphalt mixture also had better low temperature properties than SBS modified asphalt mixtures according to TSRST results.

1. Introduction

In China, more than 15 million tons of scrap tires rubber are disposed on landfills every year, which creates drastic environmental problems and economic waste. The incorporation of crumb rubber modifier (CRM) into asphalt pavement can improve the fatigue and low temperature performance and has been successfully used in California, Arizona, Texas, Florida et al. for many years [1]. Meanwhile, the utilization of CRM can improve the riding comfort and reduce the noise on highways. In addition, CRM reduces the stiffness of asphalt at low service temperatures which benefits its low temperature performance. However, during application of CRM binder, the engineers still have a concern of lack of storage stability which leads to a segregation between asphalt and crumb rubber [2].

To solve the problem of storage stability and incompatibility, Terminal Blend (TB) rubberized asphalt technology is being used in America, which used heat and shear to promote the degradation during production. As the crumb rubber is fully digested in the asphalt, TB binder shows great storage stability. TB hybrid asphalt binder is produced at the terminal just like other polymer modified asphalt [3]. TB hybrid asphalt is a kind of essentially high cured crumb rubber modified asphalt (CRMA). Bahia and Billiter et al. investigated the effect of CRM on low temperature property of different binders and the result showed that CRM improved the stiffness of binder but degraded its m-value [4]. The change of low temperature property of CRMA is mainly due to the crumb rubber. As Billiter stated that the tire rubber had very low sensitivity to temperature and to keep its elasticity. Abdelrahman et al. [5] investigated the CRM went through different changes during the

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interaction with asphalt. CRM swells in asphalt through absorbing light component in the asphalt at low interaction temperature (i.e. 160 °C) and dissolves in asphalt at higher interaction temperatures (i.e. 220 °C). These interactions affected the composition of liquid phase of asphalt binder, which led to a significant change in low temperature property. Zanzotto et al., [6] stated the production of CRM binders at high temperature led to depolymerization and devulcanization of crumb rubber in asphalt and the released component can improve the low temperature performance. Ghavibazoo and Abdelrahman [7] further investigated the dissolution of CRM and its effect on the low temperature properties of CRM binder. The result showed that when the CRM was at low dissolution levels (below 40%), the low temperature properties are controlled by the CRM particles. When the CRM is at high dissolution level (above 40%), the low temperature properties were based on the liquid phase of CRMA.

Terminal Blend rubberized asphalt is a new technique in producing rubber asphalt binder to improve its workability and storage stability. The crumb rubber fully degrades in asphalt binder which lead to a significant decrease in high temperature. To enhance the high temperature properties of CRMA, Abdelrahman, Attia and Ragab incorporated styrene-butadiene styrene (SBS) copolymer in rubberized asphalt. The polymer modifier can be straightly added to asphalt binder or can be pretreated with crumb rubber [8] .In previously work, PPA modification mostly improves the high-temperature behaviour of base asphalt binders by breaking asphaltenes and turns them to individual particles, which contributes to elastic behaviour.[9] However, the specific modifying effect of PPA for TB rubberized asphalt is not clear.

2. Objectives

The specific objectives of this study are listed as follows:

1. To evaluate and compare the effects of different modifiers and additives on the low temperature properties using BBR test.
2. To analyze the chemical composition change of TB hybrid asphalt binders and SBS modified asphalt binder through FTIR test, GPC test and DSC test.
3. To explore the relationship between the chemical composition and low temperature properties of different asphalt binders through statistical methods.
4. To evaluate the low temperature performance of TB hybrid asphalt mixture with TSRST test.

3. Materials and methods

3.1. Materials and preparation of TB hybrid asphalt binder

In this study, one base binder, one crumb rubber modifier, one SBS modifier, one polyphosphoric acid (PPA) modifier and elemental sulfur were selected to prepare the modified binder in the plant. The base binder used in this study was graded as PG 64-22. SBS 1301 is linear polymer with the average molecule weight of 110,000 g/mol ($\overline{M_w} = 110,000$), containing 30%wt styrene. One ambient processed minus 30 mesh crumb rubber from truck tire, containing 54% natural rubber and synthesis rubber was used to prepare TB hybrid binders. PPA and element sulfur are commercially available from China's market.

Based on the typical production conditions reported by Abdelrahman [5], Billiter [4], Zanzotto [10] and Flanigan [11], the detail of the process were shown as follows. Firstly, fine crumb rubber (30–40 mesh) was added to base binder and blended in a sealed tank for 6 h at 260 °C, when the blend speed was 400 r/min. Secondly, the SBS (and PPA if include) was added into the binder at 180 °C and the binder was sheared at 4000 r/min for 30 min with high speed shearing machine. Then the binder was stirred for 60 min using mechanical stirrer at 400 r/min. Finally, cross-linking agent was added and the binder was stirred for another 90 min.

As storage stability is very important for field application, the separation test was conducted for each sample through keeping an aluminum tube containing 50 ± 0.5 g binder at 163 °C for 48 h according to ASTM D7173 [12]. The top and bottom parts of the tube were collected for softening point test (ASTM D36 [13]) and the difference between the top parts and the bottom parts was used as an index to evaluate the storage stability. In China, if the difference of softpoint between top and bottom of asphalt binder should be less than 2.5 °C, the binder is considered to have good storage stability. The details of modification composition and storage stability test results are presented in Table 1. In a word, increasing interaction temperature and extending curing time help to improve the storage stability.

3.2. Bending beam rheometer (BBR) test

The prepared asphalt samples were first conducted with RTFOT aged process, then were conducted with PAV aged process. At last the aged asphalt samples were conducted with BBR test at different low temperatures (−18 °C and −24 °C) using a bending beam rheometer (BBR, Connon Instrument Company) within two replicates. The details of BBR test process was referred to ASTM D6648 [14]. The stiffness (S) and the creep rate (m-value) of the sample beams were used to determine the rheological and aging behaviour of the modified asphalt.

3.3. Burgers modelling

According to the original data obtained from BBR software, the flexural creep compliance $D(t)$ can be calculated with the following equation.

$$D(t) = \frac{4bh^3\delta(t)}{PL^3} \tag{1}$$

where $D(t)$ is the flexural creep compliance at time t; P is the applied constant load; L is the distance between supports; b is the width of specimen; h is the depth of specimen; $\delta(t)$ is the deflection in middle-span of specimen at time t.

The creep compliance can be expressed by Burgers model [15] using the following equation:

$$D(t) = \frac{1}{E_1} + \frac{t}{\eta_1} + \frac{1}{E_2}(1 - e^{-\frac{E_2}{\eta_2}t}) \tag{2}$$

where E_1 is the instantaneous elastic modulus; η_1 is the viscous coefficient; E_2 and η_2 are viscoelastic indicators.

To estimate the nonlinear fitting parameters of the model, Excel SOLVER tool was used with method of least squares. The four Burgers parameters were obtained according to the modeling results. The parameters obtained from Burgers model could be calculated as follows:

$$\lambda = \frac{\eta_1}{E_1} \tag{3}$$

$$W_s(t) = \sigma_0^2\left[\frac{1}{E_1} + \frac{1}{2E_2}\left(1 - 2e^{-\frac{E_2}{\eta_2}t} + e^{-\frac{2E_2}{\eta_2}t}\right)\right] \tag{4}$$

$$W_d(t) = \sigma_0^2[\frac{t}{\eta_1} + \frac{1}{2E_2}(1 - e^{-\frac{E_2}{\eta_2}t})] \tag{5}$$