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Investigation of rheological and chemical properties asphalt binder rejuvenated with waste vegetable oil

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HIGHLIGHTS

- The rheological and chemical properties of rejuvenated asphalt with waste vegetable oil were studied.
- The workability and fatigue resistance of aged asphalt were improved by addition of W waste vegetable oil.
- The sulfoxide index and the large molecule size (LMS) content decreased due to physical dilution.

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ABSTRACT

To improve the performance of asphalt mixture with high content of reclaimed asphalt pavement (RAP), rejuvenator is usually added. The traditional rejuvenator is non-renewable and contains large amount of carcinogenic polycyclic aromatic hydrocarbons. In this study, the effects of waste vegetable oil (W-oil) on rejuvenating aged asphalt binder were investigated in terms of rheological and chemical properties. The viscosity, complex shear modulus, and fatigue life were measured using Rotational Viscometer (RV) and Dynamic Shear Rheometer (DSR). The chemical properties were characterized by Gel Permeation Chromatography (GPC) and Fourier Transform Infrared Spectroscopy (FTIR). The experimental results indicated that the workability and fatigue resistance of aged asphalt were improved by addition of W-oil. The logarithm values of viscosity of rejuvenated asphalt at specific temperature showed linear relationship with the dosage of W-oil. The fatigue life of rejuvenated asphalt increased exponentially as the dosage of W-oil increased. There was no chemical reaction found between W-oil and aged asphalt. With the increasing content of W-oil, sulfoxide index ($I_{S=O}$) and the large molecule size (LMS) content decreased due to physical dilution. Besides, the workability and fatigue resistance of rejuvenated asphalt were found having close correlations with sulfoxide index and the LMS content.

1. Introduction

In recent years, with the development of highway reconstruction, Reclaimed Asphalt Pavements (RAP) has been employed in new pavement as recycled materials [1]. When 20%–50% of RAP is used in new pavement construction, the costs can be reduced by 14%–34% [2]. At the same time, the use of RAP can reduce the consumption of non-renewable mineral aggregate and virgin asphalt [3]. Therefore, the effective recycling of RAP can save cost and protect environment significantly. The hot-in-plant recycling, as one of asphalt pavement recycling technologies, is most widely adopted in the worldwide [4–6]. However, with the increase of RAP content, the risks of moisture damage, fatigue cracking, and low temperature cracking become greater [7].

The addition of rejuvenator can improve properties of asphalt mixture with the high content of RAP [8,9]. The rejuvenation of aged asphalt is achieved by adjusting chemical composition and colloidal structure [10,11]. Aromatic hydrocarbon oil is the major components of traditional rejuvenators [12], which contain benzene, polycyclic aromatic hydrocarbons, and dioxin and usually cause various diseases [13]. On the other hand, vegetable oil is a kind of environment-friendly, degradable and volatilisable materials. Vegetable oil is mainly composed of fatty acid ester oil, and the addition of vegetable oil in aged asphalt could increase the content of light oil [14].

Recently, researchers have employed waste cooking oil to rejuvenate aged asphalt. Zargar et al. [15] and Asli et al. [16] found that there was no significant difference between virgin asphalt and the

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rejuvenated recycled asphalt, according to analysis of penetration, softening point and viscosity. In addition, the rolling thin film oven test results showed that vegetable oil rejuvenated asphalt had strong anti-aging ability compared with virgin asphalt. Zaumanis et al. [17] studied six rejuvenators (waste vegetable oil, waste vegetable grease, organic oil, distilled tall oil, aromatic extract, waste engine oil) and found that bio-based rejuvenators had better performance compared with petroleum-based rejuvenators. Zhang et al. [18] evaluated the low-temperature performance of asphalt modified with waste edible vegetable oil and recycled tire rubber. It was found that addition of recycled tire rubber could reduce the elastic component as well as improve its low-temperature cracking resistance. The previous studies mainly focused on physical and rheological properties of aged asphalt rejuvenated by waste vegetable oil after cooking, few studies have investigated the effect of waste oil generated in the production process of vegetable oil. In addition, the relationship between rheological properties and chemical properties of rejuvenated asphalt has not been well studied.

2. Objective and scope

The objective of this study is to investigate the feasibility of using wasted vegetable oil as rejuvenator for aged asphalt. The aged asphalt was obtained by rolling thin film oven (RTFO) and pressurized aging vessel (PAV). Different percentages of W-oil (5%, 10%, 15% and 20%) were added into aged asphalt to prepare rejuvenated asphalt. The rheological properties of virgin, aged, and rejuvenated asphalt were characterized, including viscosity, complex shear modulus, and fatigue life. Chemical analysis was conducted to study the functional group and molecular size distribution of W-oil and different asphalt types. The detailed experimental plan is summarized in Fig. 1.

3. Materials and testing methods

3.1. Materials

3.1.1. Asphalt binder

The virgin asphalt used in this study was PEN50, which was extensively utilized in China. The aged asphalt was obtained by laboratory-accelerated aging. Firstly, the rotary thin film oven (RTFO) was used to simulate the short-term aging of asphalt during mixing, which was conducted at 163 °C for 85 min with the air flow rate of 4000 ml/min (ASTM D2872). The pressure aging vessel (PAV) (ASTM D6521) was employed to simulate asphalt long-term aging during pavement service life, which was conducted at 100 °C and 2.1 MPa and 20 h, respectively. The basic properties of virgin and PAV-aged asphalt were shown in Table 1.

3.1.2. W-oil

Waste vegetable oil (W-oil) was obtained from a company locating in Hubei province in China. The production process of W-oil was shown in Fig. 2. In the process of producing fatty acid, 20% waste vegetable oil was produced as byproduct. Traditionally, W-oil was burned as the rubbish, which would bring pungent smell and greenhouse gases. Therefore, a better way is needed to treat W-oil. The physical properties and elemental composition of W-oil was shown in Table 2.

3.1.3. Rejuvenated asphalt with W-oil

In preparing the rejuvenated asphalt binder, the aged asphalt and W-oil were heated to 135 °C and then stirred at the speed of 3000 rpm for 15 min. The content of W-oil varied at 5%, 10%, 15%, and 20% of the aged asphalt binder by mass.

3.2. Testing methods

3.2.1. Rotary Viscometer test

The viscosity is basic rheological property of asphalt, which reflected the frictional resistance of asphalt molecules during flowing deformation. In order to better clarify the relationship between the dosage of W-oil and the viscosity of aged asphalt, the viscosity at different temperatures were measured using Rotary Viscometer (RV). The rotational viscosity test was introduced to determine mixing and compaction temperatures in accordance with ASTM D4402. In this study, the samples of the rejuvenated asphalt binder were measured under five temperatures (120 °C, 135 °C, 150 °C, 165 °C, and 180 °C). The Brookfield viscometer (Model DV-III) and thermosel temperature control system were used in the test.

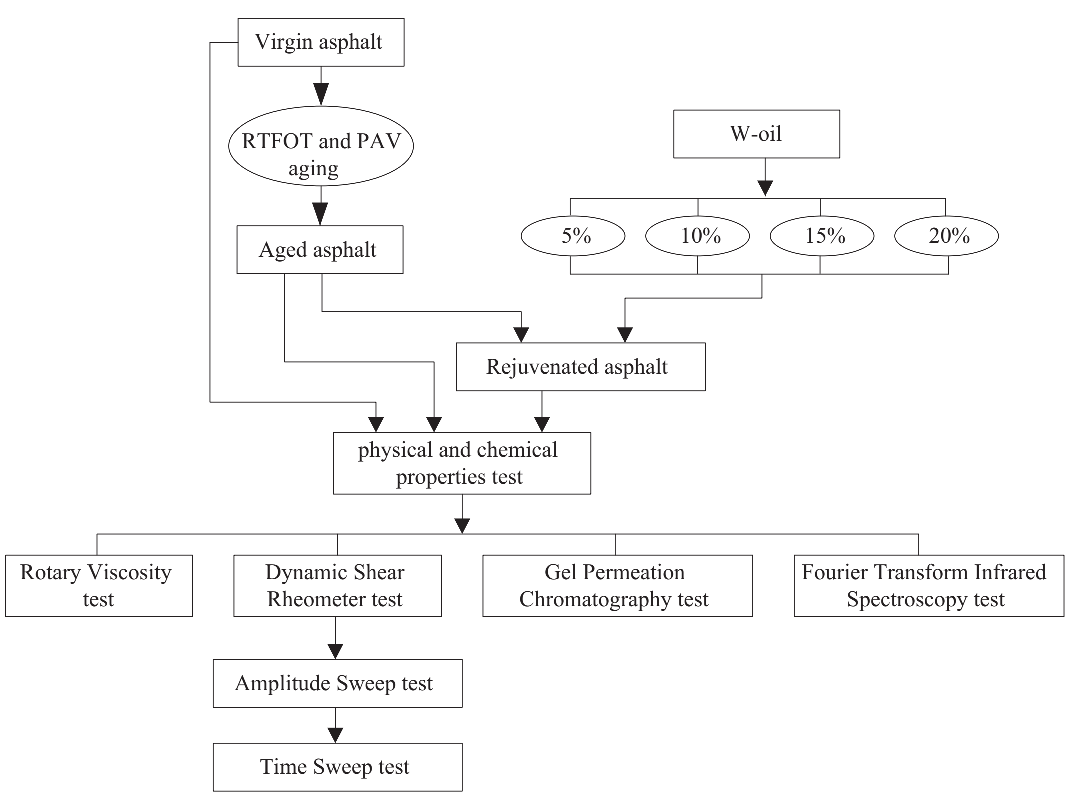

Fig. 1. Framework of experiment tests.