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Recycling long-term-aged asphalts using bio-binder/plasticizer-based rejuvenator

Haoran Zhu [a,b], Gang Xu [c], Minghui Gong [c], Jun Yang [c,*]

[a] Jiangsu Transportation Institute, PR China
[b] National Engineering Laboratory for Advanced Road Materials, 4800 Caoan Street, Shanghai 201804, PR China
[c] School of Transportation, Southeast University, 2 Sipailou, Nanjing 210096, PR China

HIGHLIGHTS

- Bio-rejuvenator with a dosage of 10% is sufficient to restore the viscosity of the PAV-aged asphalt to its original level.
- The fatigue resistances of aged asphalts cannot be improved to the level of that of the virgin asphalt.
- The carbonyl and sulfoxide indexes of the PAV-aged asphalt can be reduced by adding the bio-rejuvenator.
- The asphaltene content of the PAV-aged asphalt can be reduced by adding the bio-rejuvenator.

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ABSTRACT

In this study, a bio-binder/plasticizer-based rejuvenator was used to restore the properties of a long-term-aged asphalt binder. The chemical properties of the rejuvenated-asphalt binder were then analyzed. Pen70 asphalt and an SBS-modified asphalt were used in this study as virgin asphalt binders. A pressure-aging-vessel test was conducted to simulate the long-term aging process of the asphalt samples. The aged asphalt binders were blended with a bio-rejuvenator at dosages of 5% and 10%. The results show that adding the bio-rejuvenator with a dosage of 10% helps in restoring the workability and rutting resistance of the long-term-aged asphalt to their original level. The fatigue resistance and low-temperature cracking resistance of the aged asphalt binder also improved. The bio-rejuvenation helped reduce the oxygenated-group peak-area intensities of the aged asphalt. The results of the component analysis show that the asphaltene content of the aged asphalt reduced by adding the bio-rejuvenator. The molecular-weight-distribution patterns were further examined. The results show that the bio-rejuvenator helps increase the medium-weight molecular content whereas the high-weight molecular content remains unchanged.

1. Introduction

Asphalt concrete is widely used in constructing pavements worldwide. As a petroleum-derived organic substance, asphalt ages during the construction process (known as short-term aging) and service process (known as long-term aging). The two types of aging processes deteriorate the properties of asphalt, thus making pavements more prone to crack and fatigue. To address the aging deterioration of asphalt pavements, a rejuvenator seal has been developed for preventive maintenance to extend the service life of pavements. Lin et al. found that rejuvenator seal materials (RSMs) helped in softening the aged asphalt binder. The RSM also helped enhance the raveling property; moreover, the skidding resistance of the asphalt mixture decreased [1]. Mitchell et al. employed an RSM to restore the properties of a highly aged parking-lot pavement. Tests were conducted to analyze the effects of the treatment on asphalt binders obtained from different layers of the pavement. The results showed that aged asphalts in the top 1 cm of the treated pavement were softened considerably [2].

As mentioned previously, the performance of asphalt pavements can be restored through preventive maintenance. Another method of improving the sustainability of asphalt pavements is to take advantage of reclaimed asphalt pavements (RAPs). The RAPs are milled and processed materials comprising old aggregate and aged asphalts. By mixing the RAP with virgin materials (aggregate/asphalt) and/or rejuvenator, the asphalt pavement can be

* Corresponding author.
E-mail addresses: dndxzhr@163.com (H. Zhu), xugang619@hotmail.com (G. Xu), gongminghui@seu.edu.cn (M. Gong), yangjun@seu.edu.cn (J. Yang).

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recycled, thereby saving several tons of asphalt [3–9]. Although incorporating the RAP into pavement construction is economical and pollution-free, excessive use of RAPs could lead to undesirable pavement performance. Generally, the rutting performance of the asphalt concrete can be enhanced by adding RAPs, though adversely affecting the fatigue and cracking properties of the mixture. Recycled-asphalt mixtures fail to meet the expectations because virgin asphalt cannot blend with RAP materials because of the variations in their physical and chemical properties [10]. Accordingly, some studies show that rejuvenators are essential in enhancing the blending between the virgin asphalt and the RAP materials. Oldham et al. showed that a bio-binder with a dosage of 10% could alleviate the negative impact of recycled asphalt shingles (RAS) on asphalt, which can be attributed to the adequate blending between the RAS binder and the virgin binder [10].

Preventive maintenance and utilization of RAP/RAS are two promising methods in dealing with the aging issue in asphalt pavements. In both the methods, the rejuvenators play a vital role in alleviating the stiffness of the aged asphalt. In the aging process of asphalts, the viscosity of the asphalt increases because the volatile components evaporate and the binder undergoes oxidation. The ratio of the asphaltenes to the maltenes becomes higher as asphalt ages. Technically, rejuvenation is performed to reverse the aging process. By adding a rejuvenator, the ratio of the asphaltenes to the maltenes returns to the original value, thereby restoring the properties of the asphalt binder. Several studies have been conducted wherein rejuvenators were employed to recycle the aged asphalt. Bio-rejuvenators have gained increasing attention owing to their low cost and renewable nature. To enhance the rheological properties of vacuum tower bottoms, Podolsky et al. compared several experimental bio-derived rejuvenating additives with a commercially available modifier. The results show that commercially available additives help in reducing the stiffness of vacuum tower bottoms the most [11]. Oldham et al. used a bio-binder as a rejuvenator for wet RAS in pavement construction. The results show that the bio-binder helped in improving the properties of the RAS while also improving the blending between the RAS particles and the virgin binder [10]. In our previous study, we found that bio-oils have the potential to restore the properties of short-term aged asphalts [12]. Nevertheless, the property of a bio-rejuvenator is source dependent. There is no specification that specifically helps in selecting an appropriate bio-oil or bio-binder as a rejuvenator [13]. Hence, in this study, a bio-binder (different from the bio-oil used in our previous study) is used as the rejuvenator to recycle long-term aged asphalts. A plasticizer is added to the bio-binder to enhance the rejuvenating effects [14].The rejuvenation effects are evaluated via both physical and chemical methods. This study provides a better understanding of the effect of bio-binders or bio-oils as a rejuvenator on aged asphalts.

2. Objectives

The objective of this study is to analyze the rejuvenating effect of a bio-binder/plasticizer-based rejuvenator on long-term aged asphalts.

3. Materials and experiments

An aged base and styrene-butadienestyrene (SBS) modified asphalts were blended with a rejuvenator at two dosages. The virgin, aged, and rejuvenated asphalt samples were tested using a rotational viscometer (RV), dynamic-shear rheometer (DSR), bending-beam rheometer (BBR), Fourier-transform infrared spectroscopy (FTIR), SARA analysis, and gel permeation chromatography (GPC). The RV results were used to evaluate the workability of the virgin, aged, and rejuvenated asphalts. The DSR was used to obtain the rutting parameter at high temperatures and fatigue parameter at intermediate temperatures. The low-temperature properties of the asphalt samples are characterized by conducting BBR tests. The functional-group information of the samples is obtained by analyzing the results obtained from the FTIR. The changes in the SARA fraction are studied by comparing the colloid indices of different asphalt samples. The relationship between the molecular-weight distribution and the rheological property of the asphalt is investigated by conducting a GPC test.

3.1. Materials

3.1.1. Asphalt

Two commonly used asphalts, a Pen70 asphalt and an SBS-modified asphalt were used in this study. Table 1 lists their properties. The aging was achieved using the thin-film oven test (TFOT). Table 1 lists the basic properties of the asphalts used in this study.

3.1.2. Bio-binder and plasticizer

The bio-binder used in this study is the by-product in cotton-oil production. Table 2 lists the basic properties of the bio-binder.

A literature survey shows that a plasticizer can be used to enhance the rejuvenating ability of the bio-binder in recovering the low-temperature performance of the asphalt [14]. Dibutyl phthalate (DBP) is selected as the plasticizer owing to its wide range of applications. In the present study, the dosage of DBP in the bio-rejuvenator is set as 7.5 wt%. The combination of the bio-binder and plasticizer is referred to as the bio-rejuvenator in this study.

3.2. Experiments

3.2.1. Aging procedure

The aged asphalt was obtained by conducting TFOT (5 h, 163 °C), followed by a pressure-aging-vessel (PAV) test. The aging temperature in the PAV test was 90 °C. The pressure was set as 2.1 MPa. The duration of the test was 20 h.

3.2.2. Bio-rejuvenated asphalts

The aged asphalts and bio-rejuvenators were blended using a high-shear mixer at 5000 rpm for 15 min. The blending temperatures were set as 130 °C and 160 °C for the Pen70 and SBS-modified asphalts, respectively, with the help of an oil bath. The dosages selected in this study were 5% and 10% (by total weight of aged asphalt), respectively.

3.2.3. Rotational viscometer

The viscosities of the virgin, aged, and rejuvenated asphalt binders were measured using a Brookfield viscometer at temperatures between 115 °C and 145 °C. The activation energy of each sample was obtained via the Arrhenius relationship. The relative compaction effort required for these samples can be ranked by comparing the activation-energy data.

The Arrhenius equation used to describe the relationship between the viscosity and temperature is as follows.

$$\eta = Ae^{\frac{E_f}{RT}} \tag{1}$$

Here η represents the viscosity of the asphalt sample (Pa·s); A is a constant; T is the temperature (K); E_f is the activation energy; and R is the universal gas constant (8.314 J mol^{-1} K^{-1}) [15].

3.2.4. Dynamic-shear rheometer

The DSR test was conducted to investigate the rheological properties of the virgin, aged, and rejuvenated asphalt binders at