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# Using bio-based rejuvenator derived from waste wood to recycle old asphalt

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## HIGHLIGHTS

- Possibility of using bio-oil derived from waste wood as a rejuvenator was explored.
- Bio-rejuvenator increases viscous components and alleviates stiffness of aged asphalt.
- Rheological properties of aged asphalt can be restored by the bio-oil significantly.
- Bio-oil with a concentration of 15% is recommended to rejuvenate the aged asphalt.

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## ABSTRACT

The objective of this study is to investigate the possibility of using bio-oil derived from waste wood as a rejuvenator to recycle aged asphalt binders. In this study, petroleum asphalt of PG58-28 was selected as the base binder. The bio-oil rejuvenators with concentrations of 10%, 15% and 20% by weight were added into the Pressure Aging Vessel (PAV) aged base binder to prepare the bio-rejuvenated asphalts. Through the chemical compounds analysis of the bio-oil using the Gas Chromatograph Mass Spectrometer (GC–MS) test, it can be found that the bio-oil derived from waste wood contains a high content of light compounds, including phenol, naphthalene, diethyl phthalate and so on. The rheological properties of bio-rejuvenated asphalts were evaluated and compared with the virgin and aged asphalts by Rotational Viscometer (RV), Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) tests. The bio-rejuvenator can increase the viscous components and alleviate the stiffness of the aged asphalt binder. The high content of light compounds in the bio-oil balanced the chemical compounds of the aged asphalt. As a result, the rutting resistance and fatigue resistance of the aged asphalt binder were restored by the bio-oil significantly. The low temperature crack resistance of aged asphalt binder can be restored to approximately to that of the PG 58-28 by the bio-rejuvenator with the concentration of 15% and 20%. The bio-oil concentration had less impact on the rheological properties of bio-rejuvenated asphalts when the bio-oil concentration was higher than 15%. Therefore, the bio-oil with a concentration of 15% was recommended to rejuvenate the aged asphalt binder to be reused in the construction of pavement.



## 1. Introduction

The consumption of asphalt in road construction and maintenance has led to the substantial increase in the price of petroleum asphalt binders in the past [1–4]. In addition, there has been a trend to pursue environmentally friendly pavement [2,5–8]. Rather than just relying on traditional routes of using petroleum asphalt binders, alternatives binders are being investigated.

Reclaimed asphalt pavement (RAP) material is an effective way to reduce the consumption of fresh petroleum asphalt binders [9]. Aging of asphalt binders during construction and service life is an important problem in pavement engineering [10–12]. The main aging mechanism of asphalt binders is oxidation and loss of volatiles, which leads to those asphalt binders having increased viscosity and being stiffer than fresh asphalt binders [13,14]. Many kinds of rejuvenators have been used to solve these issues by making the

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RAP asphalt binder effectively useful for blending with virgin materials, reducing the RAP asphalt binder stiffness and providing the required road performance for more service periods [9,15–19].

Among a variety of renewable energies, bio-oil has been getting more attention due to its advantages, such as a wide range of sources, large yields and low prices [2,20,21]. Bio-oil is mainly produced by fast pyrolysis technologies. After pyrolysis processing, three main components are generated, including bio-chars, gases, and liquids. The liquid is regarded as the bio-oil [22–24]. Bio-oils have an increasing application to modify or partially replace asphalt binders [2,25,26]. Previous research shows that bio-oils can soften asphalt binders and contribute to the improvement of their low-temperature performance [21,27,28]. Moreover, some researchers have investigated the potential of returning reclaimed asphalt binder to its original state. Various kinds of bio-oil can be used as rejuvenators, such as waste vegetable oil, organic oil, distilled tall oil and so on. The rejuvenation effects are different depending on the kinds of sources. In particular, the waste vegetable oil with a concentration of 12 wt% reduced the performance grade of aged asphalt from PG 94-12 to PG 72-33 through rejuvenation. And the cracking resistance of asphalt was improved by the waste vegetable oil rejuvenator [17]. The bio-oil rejuvenator derived from biodiesel residue can be applied to recycle the aged asphalt by compensating the loss of light components and the low temperature crack resistance and workability of aged asphalt were improved by the addition of 1.75–2 wt% bio-oil [29]. The waste cooking oil with a concentration of 3–4 wt% can rejuvenate the physical and rheological properties of asphalt with a penetration grade of 40/50 approximate to those of asphalt with a penetration grade of 80/100 [30].

Overall, the properties of bio-rejuvenators are source dependent. There have been limited studies on restoring RAP binder by using a bio-oil rejuvenator generated from waste wood. Moreover, the use of bio-oil as a rejuvenator to recycle the aged asphalt can achieve the reuse of waste biomass sources and waste construction materials, which benefits the green environment and sustainable development. Motivated by these, this study used the bio-based rejuvenator generated from waste wood to recycle old asphalt and evaluated the properties of bio-rejuvenated asphalt binders.

## 2. Research objectives

The specific objectives of this study are as follows:

1) To explore the possibility of using bio-oil derived from waste wood as a rejuvenator to recycle old asphalt binders.
2) To investigate the rheological properties of bio-rejuvenated asphalt binders.
3) To analyze the effect of bio-rejuvenator concentration on the rheological properties of bio-rejuvenated asphalt binders.

## 3. Materials and preparation

### 3.1. The base asphalt binder and bio-rejuvenator

The performance grading asphalt PG 58-28 was used as the virgin asphalt binder in this study. The bio-oil was selected as the bio-rejuvenator, which has a good compatibility with petroleum asphalt binder [27]. The bio-oil was obtained through the decomposition of waste wood based on fast pyrolysis technology. The heating temperature of the fast pyrolysis was 500–650 °C, the heating rate was 104–105 °C/s and the residence time was less than 2 s. This bio-oil is black-brown and has certain plasticity at room temperature.

### 3.2. Preparation of the aged asphalt

To simulate the RAP binder, the asphalt binder PG 58-28 was processed by conducting the Rolling Thin Film Oven (RTFO) test [31] and the Pressure Aging Vessel (PAV) test [32]. The RTFO test was used to simulate the short-term aging during construction. The PAV test was used to simulate the long-term aging to estimate the physical or chemical properties of asphalt binders after 5– 10 years of in-service aging in the field.

**Table 1**
Sample range matrix.

| Binder types | Asphalt binders |
|---|---|
| Virgin asphalt | Virgin asphalt PG 58-28 |
| Aged asphalt | PAV aged asphalt PG 58-28 |
| BR-10% | (PAV aged asphalt PG 58-28) + 10% bio-oil |
| BR-15% | (PAV aged asphalt PG 58-28) + 15% bio-oil |
| BR-20% | (PAV aged asphalt PG 58-28) + 20% bio-oil |

### 3.3. Preparation of the bio-rejuvenated asphalts

In order to have a better compatibility, the aged asphalt and bio-rejuvenator were blended by using a high-speed shear mixer for 15 min under the rotation speed of 5000 r/min. The blending temperature was set at a low temperature of 135 °C to prevent the bio-oil from being aged [33–35]. The concentrations of bio-rejuvenator used in this study were 10%, 15% and 20% of the total binder by weight, these bio-rejuvenated asphalts were referred as BR-10%, BR-15% and BR-20%, respectively. A total of five types of asphalt binders were used in this study, as shown in Table 1.

## 4. Experiments

### 4.1. Gas Chromatograph Mass Spectrometer (GC–MS) test

The Gas Chromatograph Mass Spectrometer (GC–MS) analysis was performed using an American Hewlett-Packard equipment. The chemical compounds of the bio-oil were identified based on the gas chromatography and mass spectrometry successively. For the conditions of gas chromatography analysis, the initial temperature of the sample was 40 °C and was maintained for 2 min. Then the temperature was increased to 290 °C with a heating rate of 4 °C/min and was kept for 20 min. The helium was selected as the carrier gas and its flow rate was 1.2 mL/min. For the mass spectrometry conditions, the temperature of the ion source was 260 °C and the temperature of the transmission line was 280 °C. The electron beam energy was 70 eV.

### 4.2. Rotational Viscometer (RV) test

Viscosity measurements were conducted on asphalts to investigate their resistance to flow and furthermore their workability. The experiment was conducted by Brookfield Rotational Viscometer following AASHTO Designation: T 316-13 [36]. The test temperatures were 110 °C, 135 °C, 150 °C and 165 °C, and the shear rate was 20 r/min.

### 4.3. Dynamic Shear Rheometer (DSR) test

The DSR test was used to investigate the mechanical responses of asphalt binders at varying temperatures and under varying frequency conditions. The virgin asphalt, aged asphalt and bio-rejuvenated asphalts were tested by the DSR device. The test temperature ranges were 46–70 °C and 18–42 °C, both with an increment of 6 °C. The AASHTO T315 [37] test procedure was followed for the DSR test.

### 4.4. Bending Beam Rheometer (BBR) test

The BBR test was to investigate the low-temperature stiffness and relaxation properties of asphalt binders to predict thermal cracking potential. The AASHTO T313 [38] test procedure was followed for the BBR test. The PAV aged asphalt samples of the virgin,