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Research on properties of bio-asphalt binders based on time and frequency sweep test

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HIGHLIGHTS

- Bio-asphalts prepared with different dosages of bio-oil extracted from sawdust were studied.
- The influence of short-term aging condition on the rheological properties of bio-asphalt was analyzed.
- The rutting factor master curves of bio-asphalt based binders were developed.
- Incorporations of bio-oil into the SBS modified asphalt has greatly increased the rutting factor.

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ABSTRACT

Bio-asphalt is a binding agent that is made of bio-oil and petroleum asphalt, or bio-oil modified with incorporations of some other additives under certain conditions. This study was carried out to evaluate the properties of bio-asphalt binder-based in terms of the value of complex shear modulus (G^*) and the phase angle (δ) tested by dynamic shear rheometer (DSR). Four bio-oil dosages of 5, 10, 15, and 20% based on the weight of asphalt (S100) were used to alter the SBS-modified binder. Whereby, the SBS content is approximately 1% of the weight of the virgin asphalt. The complex shear modulus and frequencies of virgin and short-term aged binders were tested. The master curves of rutting factor ($G^*/\sin\delta$) of different bio-asphalt were then generated to survey its rheological properties in a broad range of frequencies and temperatures. Based on the results, it was found that the addition of bio-oil extracted from sawdust has significantly increased the complex shear modulus of asphalt binder at the same frequency conditions after going through rolling thin film oven (RTFO), which is desirable for rutting prevention of asphalt mixtures. The rheological properties of bio-binders are more susceptible to the RTFO aging condition compared to the reference binder. The master curve of rutting factor of bio-binder indicated that the rutting factor of bio-asphalt increased with the increase of frequency before and after RTFO. Additionally, incorporations of bio-oil into the SBS modified asphalt, has greatly increased the rutting factor ($G^*/\sin\delta$) after RTFO, regardless of the loading frequency. However, the degree of enhancement was dominated by the percentage of bio-oil and aging condition.

1. Introduction

With the rapid development of road and highway networks, alongside with the pavement maintenance and rehabilitation, the demand towards asphalt materials has been continuously increased since it was first introduced. At the same time, the source of crude oil that typically used to produce petroleum asphalt is also dwindling. Thus, it creates attention among researchers and engineers to seek into potential alternative to overcome the shortage of the asphalt binder or any uncertainties that could be facing by the asphalt industry [1]. Among a variety of renewable energies, biomass energy has large reserves and the characteristics of wide distribution [2–5]. It could be used to extract bio-oil through further processing. Bio-asphalt is a binder made of bio-oil and petroleum asphalt under certain conditions or bio-oil modified with some other additives. Bio-asphalt is renewable and environmentally conscious so it has become the new direction of research.

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In recent years, a number of researches have been done on materials regarding bio-oil among experts. Onochie et al. studied the high-temperature viscosity and rheological behavior of composite modified bio-asphalt prepared with nano-clay and nano-silica [6]. Several studies were carried out to assess the short-term aging properties of bio-bitumen prepared from pig manure as raw material [7–9]. Other studies tested the high temperature performance of bio-asphalt binder prepared from oak sawdust, cedar wood chips and other raw materials [10,11]. Tang et al. incorporated 3%, 6%, and 9% bio-oil to modify the base binder, and the high temperature level of bio-binder was tested before and after RTFO aging protocol [12]. Huang et al. evaluated rheological properties of asphalt binders containing waste engine oil and investigated the fatigue properties of reclaimed asphalt pavement (RAP) blending with virgin binder and waste oil [13,14]. Meanwhile, Wang et al. studied the complex shear modulus, phase angle, rutting factor, and viscosity of bio-asphalt, and evaluated comprehensive performance of bioasphalt mixtures [15,16]. He et al. conducted a series of test to evaluate the performance of modified bio-asphalt in terms of penetration, softening point, ductility, and other conventional properties [17]. Despite the significant research efforts on bio-asphalt had been made in recent years, most of the existing literatures focus on the basic performance of the bio-asphalt, the influence of each factor at a broad range of temperatures and loading frequencies are not properly studied. Motivated by the current research status, this paper aims at investigating the rheological properties of bio-asphalt based on time and frequency sweep test using the dynamic shear rheometer (DSR). The effect of bio-oil content and aging on the shear modulus (G^*), phase angle (δ), and rutting factor ($G^*/\sin\delta$) of the bio-binders were investigated. The master curve of the rutting factor ($G^*/\sin\delta$) of bio-binders was constructed to investigate the influence of bio-binders over a broad range of temperatures and loading rates. This study can lay a foundation for the further study of high temperature performance evaluation of bio-asphalt.

2. Objective and scope

The objective of this study is to evaluate the rheological performance of bio-asphalt binder by the values of the complex shear modulus (G^*) and the phase angle (δ) based on time and frequency sweep test using the dynamic shear rheometer (DSR). The bio-asphalt binder was made with conventional asphalt and the bio-oil extracted from biomass. The bio-asphalt binder was subjected to the rolling thin film oven (RTFO) to study the influence of short-term aging condition on its rheological performances. The effect of bio-oil content and aging on the G^*, δ and $G^*/\sin\delta$ of the bio-binders were also investigated. The master curve of rutting factor $G^*/\sin\delta$ was constructed to investigate the influence of bio-binders.

The bio-binders were produced in the laboratory using a bio-oil source at four bio-oil percentages (5%, 10%, 15%, and 20% based on the weight of asphalt binder) with the control and SBS-modified binders, respectively. A dynamic shear rheometer was employed to test the rheological properties of the bio-asphalt binder at different temperatures. The detailed experimental procedures are illustrated in Fig. 1.

3. Materials and test program

3.1. Asphalt binders

A 50 penetration grade virgin asphalt binder (denoted by 50#) that was obtained from a construction site in Maoming, China was used in this study. The asphalt binder was graded in accordance with the standard test methods. The basic properties of the 50# base binder are shown in Table 1.

3.2. Bio-oil

In this study, the bio-oil was supplied by Toroyal New Energy Company located at Shandong province of China. It was extracted through the decomposition of biomass, via a pyrolysis method and has good compatibility with the base asphalt. Bio-oil used in this study was extracted from sawdust, which is dark brown in color and exhibits plasticity state at room temperature, as shown in Fig. 2.

Elemental compositions and characteristics of bio-oil are shown in Table 2.

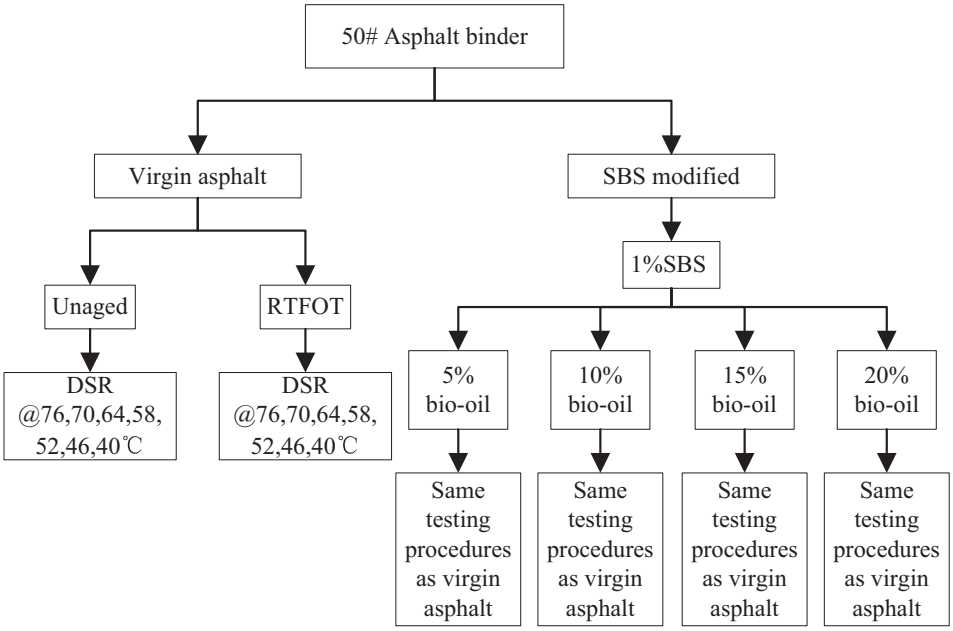

Fig. 1. Experimental design of assessments on the bio-asphalt binders.

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