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Review

Productions and applications of bio-asphalts – A review

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HIGHLIGHTS

- Bio-oils used in bio-asphalt mostly come from plant oil and pyrolysis oil.
- Additional waste wood-based bio-oil can improve fatigue life of asphalt mixture.
- The water stability of bio-asphalt meets the requirements of specification.
- The long-term performance of bio-asphalt still needs to be verified.
- Resin and asphaltene contents in biomass heavy oil are higher than petroleum asphalt.

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ABSTRACT

Bio-binder can be partially substituted for petroleum bituminous binder in highway engineering, providing with economic, social and environmental benefits. Biomass commonly used as a renewable energy source is a typically raw material for producing bio-binder, including soybean oil, palm oil, vegetable oil, microalgae, engine oil residue, grape residues, swine waste, and so forth. In this review, the production methods of different bio-oils and bio-binders from various biomasses were introduced firstly. And then, the physical and chemical characteristics of biomass heavy oils were summarized. Meanwhile, the rheological properties and fatigue performances of bio-binders were compared and analyzed. Moreover, conventional engineering characteristics of bio-asphalt mixtures as well as their practical applications were provided and discussed. Current review concluded that the most efficient method to obtain bio-oil from biomass is pyrolysis technology at optimized reaction conditions. The moisture content of bio-oil is found to have significant influences on the performances of bio-asphalt. Overall, various types of bio-binders have their own positive and negative properties. Most of bio-binders can improve the low temperature performance, but unfortunately depress the high temperature performance of bio-modified binders. Future research is recommended to focus on the interaction mechanism of biomass heavy oil and matrix asphalt on microscale. The development of innovative technologies to use more bio-asphalt without prejudice to the performances of asphalt mixtures is also an interesting topic.

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1. Introduction

Flexible pavement has gained popularity due to its excellent ridding comfortability, and accounted for 95% of the whole world's highways currently [1]. Thus, with the increasing demand of maintenance on existing pavements and construction of new asphalt pavements, a great consumption of bituminous binder material will be inevitable. As a kind of by-product of petroleum, gross cost of production of asphalt is close to the preservation of petroleum [2]. When petroleum runs out, we cannot gain the asphalt. Therefore, it is necessary to seek the succedaneum of petroleum asphalt.

There are two ways to decrease the use of petroleum asphalt. One is to use organic substances such as coffee grounds, nanoclay, polymer, rubber powder to partially replace petroleum asphalt through physical or chemical modification, the other one is to use bio-oil which has the similar pavement performance with petroleum asphalt [3–7]. Many works have been done based on the first thought, while this paper summarizes the relevant information of bio-asphalt.

The raw material of bio-oil is essentially biomass, which is a renewable energy source and mainly used to produce biomass fuel. At present, biomass that could be used to produce bio-oil comes from a variety of sources, including the municipal waste, woody chops, animal excrements and crop straw. Furthermore, the production cost of bio-asphalt is less than the petroleum asphalt (the former is 1500–2000 RMB per ton, the latter is 5000 RMB per ton) [8,9]. Additionally, the use of bio-asphalt has a positive impact on the environment as well. On the one hand, the reutilization of municipal waste and animal excrements avoids potential water and air pollution. On the other hand, the addition of bio-asphalt can decrease the viscosity of asphalt binder, thus reducing mixing temperature and leading to less energy consumption and greenhouse gas emissions [10]. Overall, bio-asphalt has better economic, social and environmental benefits in contrast with petroleum asphalt.

Many researchers had done extensive work on the production technology and property characterization of various bio-binders and the pavement performance of asphalt mixtures containing bio-binder. For example, Fini used Fourier Transform Infrared Spectroscopy (FTIR) to analyze the modification mechanism of swine manure based bio-asphalt and found that it was a chemical modification process [11]. Peralta added rubber powder into the bio-oil made from corn and analyzed the chemical component of the blend by means of FTIR. It was reported that the rubber powder could swell well in bio-oil [12]. Mills-Beale researched the aging resistance of swine manure based bio-asphalt. Raouf researched the temperature susceptibility, rheological behavior of oak-based bio-asphalt and conducted that bio-asphalt was more susceptible to temperature than base asphalt [13]. Wen conducted SHRP tests to evaluate the pavement performance of waste cooking oil based bio-asphalt and found that the capacity of rutting resistance decreased with the increasing proportion of bio-oil [14]. Mohammad researched the rutting resistance at high temperature, cracking resistance at low temperature, moisture susceptibility and fatigue resistance of pine wood chops based bio-asphalt by conducting Hamburg Wheel Tracking test, Modified Lottman test, Semi-Circular Bend test and Thermal Stress Restrained Specimen test respectively. It was found that the biomass heavy oil could improve the cracking resistance and moisture susceptibility to some extent [15].

The objective of this review is to discuss the production and application of bio-asphalt and moreover compare and analyze the properties of different bio-asphalts. The main body of this paper is composed of five sections: 1) the production methods of different bio-oils and bio-binders from various biomasses are introduced; 2) the physical and chemical characteristics of biomass heavy oils are summarized; 3) the rheological properties and fatigue performances of bio-binders are compared and analyzed; 4) conventional performances of bio-asphalt mixtures are provided and discussed; and 5) several practical applications are presented.

2. Summary of production methods for several Bio-asphalts

Generally, bio-asphalt technology is aiming to convert the biomass into the materials with similar characteristics of petroleum asphalt through a series of transformation [16,17]. Bio-asphalt can be classified to three categories according to the content in blended binders which are shown in Table 1 [15]. Raouf reported that bio-asphalt could not be used as a direct alternative binder in the pavement because there were water and volatile materials in bio-asphalt which had a negative impact on the performance of asphalt mixture [18].

Table 1
Classifications of bio-asphalts.

Category of Application	Content in the binder	Current State
Modifier	<10%	The application mode is rather mature
Extender	25%–75%	The application mode is common
Alternative binder	100%	The application mode cannot be achieved due to the limitation of performance of bio-asphalt