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Evaluation of asphalt binder containing castor oil-based bioasphalt using conventional tests

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HIGHLIGHTS

- The bioasphalt has a softening effect on the modified asphalt binder.
- The softening effect causes increased penetration and decreased softening point.
- The bioasphalt has more impurities, inducing decreased ductility of the binder.
- The bioasphalt has a temperature susceptibility improving effect on the binder.
- The improving effect results in increased PI and plasticity temperature range.

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ABSTRACT

The asphalt binder containing up to 30% castor oil-based bioasphalt was evaluated for suitability of paving applications using conventional tests at the laboratory. The test results and data analyses show that the addition of the bioasphalt into regular petroleum asphalt may result in varying effects on different properties of the asphalt binder. The penetration increases considerably with increasing bioasphalt content at a given temperature, indicating a softening effect of the bioasphalt. The standard penetration increases by about 2 (0.1 mm) per percent bioasphalt on average. The softening point decreases slightly with increasing bioasphalt content. However, the 15 °C ductility decreases significantly with increasing bioasphalt content from greater than 100 cm to about 44 cm when the content changes from 15% to 30%. The flash point and density are nothing unusual; while the solubility decreases notably with increasing bioasphalt content from 99.6% to 92.1% when the content changes from 0% to 30%. The mass change, the retained penetration, and the ductility after RTFO test vary moderately with increasing bioasphalt content, indicating acceptable aging resistance of the bioasphalt. The penetration index increases remarkably with increasing bioasphalt content, indicting a temperature susceptibility improving effect of the bioasphalt. Both the equivalent softening point and the equivalent breaking point decrease, while the plasticity temperature range increases slightly with increasing bioasphalt content. The losing in high temperature rutting resistance is surpassed by the gaining in low temperature cracking resistance due to the temperature susceptibility improving effect of the bioasphalt.

1. Introduction

Asphalt is widely used as a binder in producing hot mix asphalt (HMA) with mineral aggregate for paving applications. Regular asphalt binder is usually a residue obtained in processing petroleum. Stringent environmental regulations, dwindling petroleum resources, and modifications to the refining process to increase the fuel quantity while minimizing asphalt residue have increased the cost of asphalt binder. As a result, non-petroleum alternatives have become more popular since the beginning of this century, leading to the introduction of bioasphalt that is more environmentally friendly and is made from renewable resources. These sources include animal waste, kitchen waste, sewerage effluent, various plant products, other organic substances, and so on. Partial or full replacement of petroleum asphalt by bioasphalt in paving industry will substantially reduce the cost, save the resource, and protect the environment [1–3].

The earliest known use of bioasphalt occurred in 2002 in Ohio, US, where a homeowner combined waste vegetable oil with dry aggregate to create a low-cost and less polluting paving material for a 200-foot driveway. Asphalt binder made with vegetable oil

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was patented by Colas SA in 2004. Shell Oil Company paved two public roads in Norway in 2007 with vegetable-oil-based asphalt binder [4]. A number of studies on the bioasphalt for paving applications have been conducted over the last decade. In these studies, the process of converting swine manure into bio-oil, which served as a starting material for bioasphalt, was explored; while the characterization of asphalt binder modified with bioasphalt from swine manure was presented [5–8]. The properties of asphalt binder and asphalt mixture modified or rejuvenated with bioasphalt from waste cooking oil were investigated [9–12]. The performances of asphalt binder and asphalt mixture modified with bioasphalt from bio-oil were examined [13–16]. The effect of aging on properties of asphalt binder modified with bioasphalt and the effect of bioasphalt on properties of reclaimed asphalt pavement (RAP) and recycled asphalt shingle (RAS) were quantified [17–20]. Studies to date indicate that bioasphalt is a promising alternative to petroleum asphalt. However, further studies are required for practical application of bioasphalt in paving industry due to the diversity in source and process. Particularly, no study related to castor oil-based bioasphalt has been found in the literature.

The objective of this study is to evaluate asphalt binder containing castor oil-based bioasphalt for suitability in paving applications using conventional tests at the laboratory. A petroleum asphalt commonly applied in paving practice is used as the base asphalt. The bioasphalt, which is used as partial replacement or a modifier to the petroleum base asphalt, is a byproduct obtained in producing castor oil. With the base asphalt as a special case, the content of bioasphalt in the modified asphalt binder varies from 0% to 30% by total mass of the modified asphalt binder. The tests include conventional penetration test, softening point (ring and ball) test, ductility test, as well as general tests, such as flash point test, solubility test, density test, and rolling thin film oven (RTFO) test (RTFOT), as required in JTG F40-2004 "Technical Specifications for Construction of Highway Asphalt Pavements" [21]. The evaluation is then accomplished by analyzing various data, including material properties obtained directly from the tests and derived indirectly from the test results.

2. Materials

Materials used in the study include the base asphalt, the bioasphalt, and asphalt binder containing bioasphalt. The base asphalt and the bioasphalt are constituent materials for preparing the asphalt binder containing bioasphalt.

2.1. Constituent materials

The base asphalt is a petroleum asphalt. The asphalt meets all the requirements for Penetration 50 Grade A petroleum asphalt with Penetration of 40–60 (0.1 mm) as specified in JTG F40-2004 [21].

The bioasphalt is a dark brown cementitious material obtained in producing castor oil, which is semisolid at room temperature with density of 0.993 g/cm^3. Castor oil is a vegetable oil obtained by pressing the seeds of castor oil plant (Ricinus communis). Castor oil and its derivatives are used in the manufacturing of soaps, lubricants, hydraulic and brake fluids, paints, dyes, coatings, inks, cold resistant plastics, waxes and polishes, nylon, pharmaceuticals, and perfumes. As other types of vegetable oil-based bioasphalt, castor oil-based bioasphalt is the product of the oil residue after acidification, oxidation, purification, and saponification [13–20]. The purpose of acidification is to convert the active ingredients of oil foot into fatty acid for separation and purification. The purpose of oxidation is to reduce the impurity and increase the yield of fatty acid. The purpose of purification is to further remove the impurity by stratifying the intermediate product. The purpose of saponification is to obtain desired properties of the bioasphalt by utilizing the salt-forming reaction of fatty acid.

2.2. Modified asphalt binder

Castor oil-based bioasphalt is used in a sense as a modifier to the base asphalt in the study. With the base asphalt as a special case, the content of bioasphalt in the modified asphalt binder varies from 0% to 30% with increments of 5%, i.e., 0% 5%, 10%, 15%, 20%, 25%, and 30%, by total mass of the modified asphalt binder. In preparing the modified asphalt binder, the base asphalt and bioasphalt were heated to 120 °C, and the blend of the base asphalt and bioasphalt was then stirred at speed of 1500 rpm for 20 min using a mechanical stirrer. Fig. 1 shows the stirrer used for preparing the modified asphalt binder.

3. Laboratory testing

Laboratory tests were carried out on the modified asphalt binder with various bioasphalt contents. These tests include conventional penetration test, softening point (ring and ball) test, and ductility test, as well as general flash point test, solubility test, density test, and rolling thin film oven (RTFO) test.

3.1. Test procedures

The penetration test was carried out in accordance with the procedure in JTG E20-2011 T0604-2011 [22], which was equivalent to ASTM D5/D5M-13 "Standard Test Method for Penetration of Bituminous Materials" [23]. The penetration test was done with standard load of 100 g and time of 5 s at three temperatures. In addition to standard 25 °C, the test was also done at 5 °C and 15 °C for calculating derived properties of the asphalt binder. The penetration test is used to measure the consistency of asphalt, so that the materials can be classified into standard grades. Greater penetration indicates reduced consistency.

Fig. 1. Stirrer used for preparing modified asphalt binder.