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Asphalt modification using nano-materials and polymers composite considering high and low temperature performance

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HIGHLIGHTS

- Nano-materials and polymers are proposed as composite modifiers of asphalt.
- Enhanced asphalt performances at high-temperature and low-temperature are achieved.
- Screening of nano-materials and polymers is based on asphalt performance indicators.
- Orthogonal experiment design determines optimal composite modifiers.

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ABSTRACT

Nano-materials have a great potent ial as modifiers for enhancing performance of base asphalt binder. However, existing studies in the literature focus on the improvement of high-temperature performance of base asphalt binder, whereas the low-temperature performance of base asphalt binder is overlooked. Studies have shown that nano-materials will even weaken the low-temperature performance of base asphalt binder. To address this issue, nano-materials and polymers as composite modifiers are studied to improve base asphalt performance at both high temperature and low temperature. Nano-materials and polymers were screened and selected according to conventional performance indicator of asphalt binder, including softening point, ductility at 5 °C and viscosity at 60 °C. Optimal formulas of composite modifiers were determined using orthogonal experiment design and range analysis. SHRP tests including RTFOT, DSR and BBR tests were conducted to better evaluate the anti-aging, high-temperature performance and low temperature performance (i.e., crack resistance and water stability) of the proposed optimal composite modified asphalt binder against performances of 5%SBS modified asphalt binder and AH-70 base asphalt binder, showing an improved pavement performance.

1. Introduction

As construction materials for highway and airport, asphalt is used as a binder to form asphalt mixture. To improve the pavement performance of asphalt mixture, different types of materials including resins, rubbers, polymers, sulfur, metal complexes, fibres and chemical agents have been used to overcome the high-temperature performance, low-temperature crack resistance and aging resistance of base asphalt binder.

Because of morphological features on the nano-scale dimensions, nano-materials have some special properties, such as large specific surface area, high surface free energy and good ability for dispersion [12]. Nano-materials are of great scientific interest as they represent an effective bridge between bulk materials and atomic/molecular structures [2]. Mechanical, thermodynamic, electrical, magnetic, optical and chemical properties of nano-materials are subject to considerable changes when the material is examined at different scales: from a macro scale to a nano scale.

Performance of asphalt binder can be improved through physical and chemical action between nano-materials and asphalt materials. In recent years, nanotechnology has gradually been incorporated into the field of modified asphalt with various kinds of nano-materials being used to modify asphalt. Polacco et al. [10,11] and Zare-Shahabadi et al. [22] analyzed the effect of

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bentonite clay and synthesized organic bentonite on the rheological properties of the modified asphalt. Jahromi et al. [4] discussed the influence of nano-layered silicate on the rheological properties of modified asphalt. Goh et al. [3] analyzed the mechanical properties and water resistance of nano-clay and carbon-fibre modified asphalt binder and asphalt mixture. Sureshkumar et al. [19] analyzed the road performance of EVA/nano-layered composite asphalt binder. Khattak et al. [7] characterized the high temperature performance of carbon nano-fibre modified hot mix asphalt mixture. Yusoff et al. [21] revealed the effect of moisture susceptibility and aging conditions on nano-silica/polymer modified asphalt mixture. Karahancer et al. [5] evaluated the pavement performance of nano-modified asphalt mixture. Yao et al. [20] analyzed the moisture susceptibility of nano hydrated lime modified asphalt mixture. Shafabakhsh et al. [14,13] investigated the rutting and fatigue performance of nano-TiO_2/SiO_2 modified asphalt mixture. Moreover, nano-$CaCO_3$ particles [6], nano-ZnO particles [15,16] and nano-$CaCO_3$ compound [17,18] have also been investigated to modify performance of asphalt with various levels of success. These studies show that nano-materials can significantly improve the road performance of base asphalt, especially the high-temperature performance, which proves the advantage and the feasibility of the application of nano-materials in modified asphalt.

However, most of existing studies only focus on the improvement of high-temperature performance, moisture susceptibility and aging resistance of base asphalt using nano-materials, whereas the low-temperature performance of nano-materials modified asphalt is overlooked. Even some studies have shown that nano-materials weaken the low-temperature performance of base asphalt [15,16], which will lead an adverse effect to asphalt pavement in cold regions. To address this issue, nano-materials and polymers as composite modifiers are studied in this study to improve the overall performance of nano-modified asphalt at both high and low temperature.

The remainder of the paper is as follows. Nano-materials and polymers modifiers are selected in Section 2. The optimal formula of nano-materials and polymer composite modified asphalt is determined through orthogonal tests in Section 3. Physical properties of the proposed modified asphalt binder are tested in Section 4. Road performance of asphalt mixture using the proposed modified asphalt binder is analyzed in Section 5. The economic analysis and the engineering application are plotted in Sections 6 and 7, respectively. Conclusions are drawn in Section 8. Fig. 1 provides a graphical abstract of the procedures used in this study.

2. Screening and preparation

2.1. Preparation procedure

Due to the large specific surface area and the high surface energy, nano-materials have a great inclination to agglomerate to form secondary particles. When nano-materials are poorly dispersed in base asphalt binder, the modified effent of the nano-composites will be similar to that of the micrometer-sized composites. Hence, it is necessary to disperse nano-materials uniformly to overcome the agglomeration problem. The preparation of nano-materials and polymers modified asphalt binder is as follows. Firstly, nanomaterials were added into 500 g of base asphalt binder. After 5 min manual mixing and 15 min high-speed shearing (5000 r/min) at 120 °C, polymers are mixed. Through 5000 r/min of high-speed shearing at 170 °C for no fewer than 30 min, test specimens of composite nano-materials and polymer modified asphalt binder are prepared.

2.2. Screening of nano-materials and polymers

The effectiveness of nano-materials and polymers as asphalt modifier depends on chemical composition and physical properties of the composite. It is necessary to screen out specific type of nano-materials and polymers that exhibits superb engineering performance when modifying asphalt binder. Therefore, six types of nano-materials and four types of polymers are firstly used to modify base asphalt binder, among which the most suitable ones were selected according to a series of conventional tests for asphalt binder. The particle size and specific surface area of the selected nano-materials are shown in Table 1. The technical parameters of the selected polymers are shown in Table 2.

Traditional performance indices for evaluating asphalt binders are penetration at 25 °C, softening point, ductility at 5 °C and Brookfield viscosity at 60 °C. The softening point and Brookfield viscosity at 60 °C denote the high temperature performance of asphalt binder, whereas the penetration at 25 °C indicates the hardness of asphalt binder. Ductility at 5 °C is related to low temperature performance of asphalt binder. All these tests were conducted following Chinese Technical Specification "*Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering* (*JTJ 052-2000*)". Test results are shown in Table 3.

This study focuses on the modified asphalt binder with improved both high and low temperature performance. As shown in Table 3, SBR modified asphalt binder has the highest ductility,

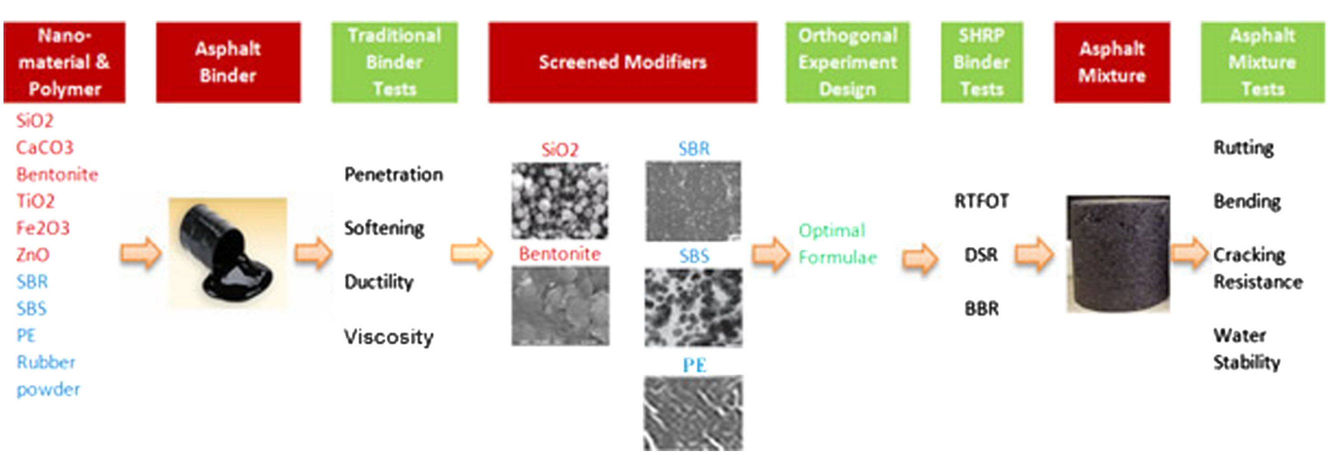

Fig. 1. Graphical abstract of the procedures used in this study.