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Effects of nano-silica and rock asphalt on rheological properties of modified bitumen

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HIGHLIGHTS

- Nano-silica and rock asphalt are proposed as composite modifier.
- The effect of rock asphalt on rheological properties is more significant compared with nano-silica.
- Compound modified asphalt has better performance than bitumen modified by nano-silica or rock asphalt respectively.
- The optimal content is identified: 6% QC rock asphalt and 1% nano-silica.

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ABSTRACT

In this research study, rheological properties of sixteen asphalts with different contents of nano-silica and Qingchuan rock asphalt were analyzed by univariate analysis and variance analysis. The experimental tests performed were rotational viscosity (RV) test, dynamic shear rheometer (DSR) test, bending beam rheometer (BBR) test and scanning electron microscope (SEM) test. RV test results showed that the two materials had significantly influence on rotary viscosity. The compound modified asphalt had a better ability to resist deformation at high temperature. The results of DSR test revealed that Qingchuan (QC) rock asphalt had a remarkable impact on the complex shear modulus G^* and phase angle δ, while the effects of nano-silica were relatively small, which mainly improved G^* and barely had any influence on δ. From the results of BBR test, the low temperature performance of the modified asphalt subjected to degradation as the additives contents increasing. Meanwhile, the effects of nano-silica were relatively small. To achieve similar high temperature characteristics, the compound modified asphalt had smaller declination in low temperature performance compared with QC rock asphalt modified bitumen. And it was not cost effective for only using nano-silica to improving the anti-rutting performance of asphalt. From the results of DSR and BBR test, the performance grades of different combinations were obtained. Moreover, based on rheological properties of different combinations and the dispersion status of nano-materials, the optimal content, which consisted of 6% QC rock asphalt and 1% nano-silica, was determined.

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1. Introduction

Asphalt had become the primary choice of highway, due to its advantages, such as smooth, comfort, short construction period and convenient maintenance. With the rapid development of transportation, overloading and traffic channelization is getting more and more serious. Thus increasingly high requirements had been put forward on high temperature stability and anti-rutting performance for asphalt, as ordinary asphalt could hardly meet the requirements [1]. Many methods could be taken to improve the high temperature performance of bitumen, of which adding nano-silica and rock asphalt were two solutions.

Nano-silica is a white amorphous powder with a special particle structure. At high temperature, it has excellent properties in strength, toughness and thermal stability. When added to asphalt, nano-silica could absorb certain amount of deformation work. Thus it has excellent enforcement on toughness and thermal stability, and can significantly improve the resistance to moisture-induced damage [2]. Studies of Chen et al. showed that

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the anti-rutting properties of asphalt modified by nao-silica were enhanced [3]. Sun et al. reported that stability of nano-silica modified asphalt improved significantly, while low-temperature performance was slightly dropped. But it could still meet the requirement of surface crack resistance at low temperature [4,5]. Rock asphalt is natural bitumen produced by the oil in mountains or rock fractures after a long period of precipitation hardening and geological changes, including Gilsonite, Buton, QC, UM from USA, Buton Island of the South Pacific Indonesia, China and Iran, respectively [6]. The research of Zhong revealed that the addition of rock asphalt had greatly improvement on the high-temperature stability and temperature sensitivity [7]. Li et al. incorporated three different types of rock asphalts including Buton, QC and UM. The tests conducted on modified and fine aggregate matrix. They found that all the rock asphalts could significantly enhance the anti-rutting performance at high temperature, and QC rock modified asphalt has the greatest improvement. However, none of them avoided the slight adverse effects on low temperature performance [8]. Jahanian et al. evaluated the performance of Hot Mix Asphalt containing bitumen modified with Gilsonite. The Marshall Stability, resilient modulus parameter as well as the rutting resistance was improved considerably [9].

Previous studies had reported the performance of pavement mixture modified by nano-silica and QC rock asphalt respectively [10,11]. In addition, many papers investigated the performance of asphalt modified by one of the materials with SBS, EVA or SBR [12–15]. However, there is limited information in the literature that describes the characteristics of nano-silica and QC rock asphalt compound modified bitumen. In the former studies, we had chosen four nano-materials to identify which is the best choice to match with QC rock asphalt [16]. Nano-silica was selected. The main objective of this study was to investigate rheological properties of sixteen asphalts modified with different contents of nano-silica and QC rock asphalt. The effects of nano-silica and QC rock asphalt on rheological properties were compared through univariate analysis and variance analysis. Then the suitable case for this literature was explained and the optimal dosage, 6%QC rock asphalt and 1% nano-silica, was determined.

2. Materials and sample preparation

2.1. Materials

In this study, AC-60/70 asphalt from Karamay was compound modified by QC rock asphalt and nano-silica. QC rock asphalt was provided by Sichuan Shuntian Mining Technology Research and Development Department. And Hangzhou WanJing New Materials Limited Company offered the nano-silica. Figs. 1 and 2 showed the specimens of nano-silica and QC rock asphalt. The properties of QC rock asphalt and nano-silica were noted in Tables 1 and 2.

2.2. Sample preparation

The sample production processes are as follow: Take a certain quality of matrix asphalt, and then heat it to 170 °C. According to the adulterate amount (Table 3), the nano-silica and QC rock asphalt are mixed with the base bitumen. And then the mechanical mixing lasts for 30 min at the speed of 5000 r/min after artificial stirring for 20 min. When there is a mirror surface vein, stop the stirring. With reference to the research findings of rock asphalt modified bitumen, the reasonable doping ration of QC rock asphalt is about 8% [17–19]. Given the combined effects of the materials and the price of nano-silica, the amounts of materials used in the test were listed in Table 3.

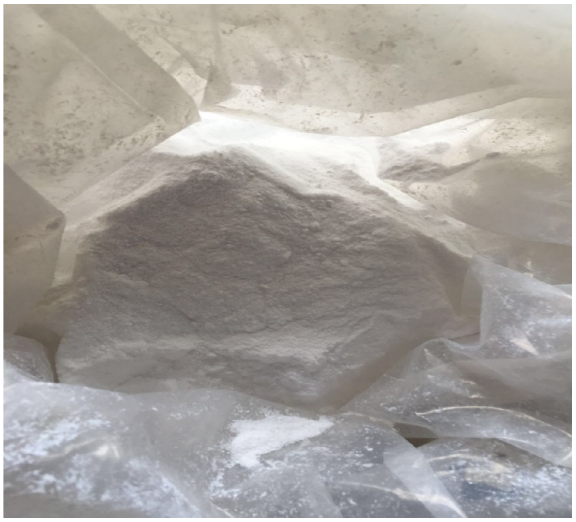

Fig. 1. Nano-silica.

Fig. 2. QC rock asphalt.

3. Experiments

3.1. Rotational viscosity test

RV test, also known as Brookfield viscosity meter rotation method, is used to determine the apparent viscosity of asphalt at specified temperature. This method was adopted by the Strategic Highway Research Program (SHRP). In this paper, the rotary viscosity characteristics were applied to evaluate the high temperature stability and workability of modified asphalt. As recommended by ASTM D4402, the rotary viscosity at 135 °C is no more than 3 Pa·s.

3.2. Dynamic shear rheometer test

DSR test was proposed by SHRP to evaluate the asphalt cement high-temperature stability. The principal parameters obtained from DSR were complex shear modulus (G^*) and phase angle (δ). G^* refers to the maximum shear stress divided by the maximum

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