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High temperature performance of asphalt modified with Sasobit and Deurex

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HIGHLIGHTS

- Sasobit and Deurex showed an obvious increase for asphalt mixtures' workability.
- Sasobit and Deurex improve the elastic performance and the resistance to deformation.
- A great miscibility and compatibility existed among asphalt, Sasobit and Deurex.

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ABSTRACT

Warm Mix Asphalt (WMA) is a valued and effective technology to decrease asphalt binder's viscosity in order to save energy and to reduce the release of carbon dioxide (CO_2). Sasobit (an organic additive) is a widely used warm mix additive, which has been studied in several aspects by some researchers such as the increase of physical properties as well as the increase of rheological properties of asphalt binder. Deurex (natural sugar cane wax or free of paraffins), which is similar to the Sasobit, can be seen as a new warm mix additive. The study aims to assess the high temperature rheological properties and viscosity reduction of asphalt which is modified with the two additives: Sasobit and Deurex. During the study, Deurex was added into the base asphalt in same proportion as the Sasobit as 0%, 1%, 2% and 3%, so 16 different binders could be obtained. Above all, the study conducted the Rotational viscometer test (RV), which separately and together measured the two additives' effects for the viscosity of the binders. The conventional tests results reveal that adding Deurex to the Sasobit can improve the cracking properties of binders as compared to the Sasobit at low temperature. And the viscometer test results reveal that both Sasobit and Deurex can reduce the viscosity and the Sasobit can be more effective than Deurex when the content of additive is low. Furthermore, the decrease of asphalt binders' viscosities is more obvious at lower temperature. Then the study conducted the Dynamic shear rheometer (DSR) test including the Performance grade, frequency sweep and temperature sweep tests. G^*(complex shear modulus) and δ (phase angle) can be measured in the test, and the results reveal that the Sasobit and Deurex increase the value of G^* and decrease the value of δ. Therefore, the rutting factor $G^*/\sin\delta$ is improved. In other words, the high temperature properties of modified asphalt binders are increased, particularly the ability of resistance to deformation. The test also found that the 2%Deurex play a relatively big efficacy with Sasobit. Finally, the Fourier transform infrared spectroscopy (FTIR) test was used to analyze the modification mechanism of the modified binders. All in all, the Sasobit and Deurex modified asphalt do have a good performance in high temperature. And 2%Deurex with 2% or 3%Sasobit is recommend.

1. Introduction

On the highway, the asphalt pavement with its well-known good performance is favored by many countries. The road construction in the asphalt pavement is using the conventional hot mix asphalt (HMA) mixture, which has a good road performance, especially in terms of stability. However, one of the major sources of pollution associated with transportation infrastructure (road construction) is the manufacturing, mixing, compaction, paving and conservation of the mixtures [1]. Therefore, the negative impact of the use of HMA is the destruction of the environment,

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the large consumption of energy and the reduction of human survival circle, which has been to the point where it needs to be given enough attention. For the past few years, warm mix asphalt (WMA) mixture has been used widely, which is designed to save energy and reduce emissions produced from the construction process without degrading the usability, and it also reduces the total costs by lowering the production temperature during the mixing period [2,3].

Comparing with the HMA, the WMA can reduce the production temperatures during the mixing and compaction processes, which helps to obtain around 30 °C of the temperature drop [4]. Organic additives, water-based foaming processes (or water-containing) and chemical additives are the main types of the WMA additives to be used to reduce the temperature [5]. Besides, some studies have shown that the WMA mixtures can also offer a greater rheological properties and other conventional physical properties than the common HMA mixtures [6]. Thus, some WMA additives are also used as the modifying agents such as the Sasobit.

Sasobit, a product of Sasol-Wax from South Africa, is a sort of long-chain aliphatic hydrocarbon crystals in the Fischer-Tropsch (FT) process when the coal gasification produced, which includes 40 to 120 carbon atoms and is also known as FT solid paraffin [7]. The appearance of Sasobit is white granules or powder, insoluble in water, and exist as the form of solid long-chain saturated hydrocarbons at room temperature.

Sasol-Wax company stated that the melting temperature of Sasobit ranged between 99 °C and 116 °C and all can be dissolved in the asphalt mixtures when the temperature exceeds 116 °C, which plays an important role in increasing the asphalt mixtures' workability and so the mixture can be mixed and compacted during the low temperature. When the temperature is lower than the melting point, Sasobit will appear as a mesh lattice structure in the asphalt so that the stability and the deformation resistance of pavement are improved, and Sasobit reduces the construction temperature (>35 °C) with the appropriate amount of asphalt (i.e., 2–4%), compared with HMA [8,9]. Sasobit is also commonly used as a modifying agent apart from being a warm mixing agent, which has some similar properties with conventional modifier such as the styrene–butadiene–styrene (SBS). Banerjee et al. thought that HMA additives like Sasobit, Rediset produced in Sweden or Evotherm produced in Virginia are able to reduce the rate of binders' aging [10]. Zelelew et al. studied that the mixture made by the Sasobit has higher stiffness, higher dynamic modulus, higher rut parameters and higher fatigue crack parameters compared to other WMA additives [11]. In addition, Sasobit can also be mixed with other additives as to obtain more harmonious performance. Abdolhamid Behroozikhah et al. showed that ideal fatigue properties of the modified mixture can be caused by Sasobit with RAP and debris rubber, meanwhile better elastic modulus, loading capacity, and lower cumulative damage rates can be obtained compared with origin samples [12,13]. Xuelian Li et al. studied the effect of the Sasobit for the styrene–butadienestyrene (SBS) modified mixtures, showing that the optimum additive content of Sasobit is 3%, which can reduce 15 °C compared with origin samples [14].

The other additive named Deurex, which is produced by a German company, is called Deurex AG. The chemical description of the additive is natural sugar cane wax or free of paraffins, which can be used as ecological modification of bitumen for road construction and a type of production of bio-bitumen [15]. Similar to the Sasobit, Deurex is also a type of long-chain aliphatic hydrocarbon crystals, so it has similar great properties such as better processing and compaction, higher deformation resistance, higher resistance against stripping, better utilization, optimal long-term performance, reduced maintenance costs and etc [16–19]. There are also some other interesting additives by studying other works published lately on this subject, such as crumb rubber, silane, nanoclay and emulsion, which have certain improvements according to their studies [20–22].

In the study, high temperature performance of asphalt modified with Sasobit and Deurex were measured. The two additives are in the same proportion (i.e., 0%, 1%, 2%, %3) so that 16 different groups are obtained. Rotational viscometer test, dynamic shear rheometer test including performance grade, frequency sweep and temperature sweep tests, as well as fourier transform infrared spectroscopy test were conducted.

2. Methods and materials

2.1. Sample experimental preparation

In the test, the melted base asphalt was poured into the bucket and stayed warm in the oil bath at a temperature of 150 ± 5 °C. Then, it was added with appropriate amount of Sasobit and Deurex. By using shearing machine with the speed of 4000 rpm, Deurex was added first and followed by Sasobit after 15 min, which means that the sample spent a total of 30 min in the machine so that distribution of warm mix asphalt could be obtained. Deurex was added into the base asphalt in same proportion as the Sasobit such as 0%,1%, 2% and 3%. During the test, 16 different binders was obtained.

In order to measure the high temperature rheological properties of the modified asphalt, the study conducted the Rotational viscosimeter (RV) test, the Dynamic shear rheometer (DSR) test as well as the Fourier transform infrared spectroscopy (FTIR), which are used to evaluate the binders' properties. The flowchart of the experiment is showed in Fig. 1.

2.2. Conventional tests

The conventional tests including the penetration (25 °C), softening point and ductility (15 °C) were conducted according to ASTM D5, ASTM D36 and ASTM D113 respectively.

2.3. Rotational viscometer test (RV)

The fluidity of asphalt in high temperature has always been a hot spot for road workers. The viscosity has been widely used as the indicator for the high temperature performance and flow property of asphalt [23]. Moreover, during the practical application, the asphalt binder should be offered a proper temperature to mix and compact.

According to AASHTO T316, the test mainly assessed the viscosity reduction of the Sasobit and Deurex modified asphalt binders by using Brookfield viscometer DVⅡ. In the test, temperature was divided into five parts ranging from 105 °C to 165 °C and using the No.27 spindle.

2.4. Dynamic shear rheometer test (DSR)

As we know, the driving load acting on the road have a repeated number of loading cycles rather than stationary. Under the influence of vibration load, the rheological properties of asphalt can produce great difference. Hence, the rheological properties of asphalt was measured by the Dynamic shear rheometer (DSR). Performance grade, frequency sweep and temperature sweep tests were conducted during the test, which all used two 25 mm diameter oscillatory plates with a 1 mm gap. The performance grade test was conducted with a frequency of 10 rad/s (i.e.,1.59HZ) and a strain of 12% at four different temperatures (i.e., 58 °C, 64 °C, 70 °C, and 76 °C). Frequency sweep test adopted frequencies from 100 to 0.1 HZ with an interval of 10 at 58 °C. The temperature sweep test was conducted with a frequency of 10 rad/s at temperatures ranging from 20 °C to 80 °C. From all of the three tests, the linear viscoelastic parameters such as G^*(complex shear modulus) and δ(phase angle) was obtained. Meanwhile, the rutting factor $G^*/\sin\delta$ was calculated. The G^* represents the binders' ability of resistance to deformation and the δ reflects the binders' viscoelastic ratio. Consists of G^* and δ, the rutting factor $G^*/\sin\delta$ is adopted as the index representing the asphalt binders' property (i.e., resistance to permanent deformation). So, the $G^*/\sin\delta$ is important as a rutting factor.

2.5. Fourier transform infrared spectroscopy (FTIR)

The FTIR can offer abundant of data including quick and accurate information such as substitution mode of aromatics, oxygenation and the average distribution length of aliphatic chains and so on [24]. This is achieved by exposing the materials to infrared light with a range of frequencies (about 4000 cm^{-1} to 400 cm^{-1}) and receive the corresponding responses (absorption peaks) for different chemical bonds or functional groups. Therefore, the chemical structures and substance can be identified through FTIR test. In this study, the FTIR also plays a role in analyzing the consistency of asphalt modification compounds as well as the great miscibility and compatibility by comparing the peaks before and after incorporation of addi-