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Modification mechanism of high modulus asphalt binders and mixtures performance evaluation

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HIGHLIGHTS

- The particle size of the high modulus modifiers increased with time.
- The relative viscosity of the modified asphalt increased with time.
- The high modulus modifiers improved the high temperature performance, moisture–heat synthesis property of mixtures.

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ABSTRACT

To observe the micro-morphology of high modulus asphalt binders (HMABs), a scanning electron microscope (SEM) and a fluorescence microscope were employed. To evaluate the performance characteristics of mixtures using these binders, laboratory mixture tests were conducted. The binder morphology showed that the particle size of high modulus modifiers, PR PLAST S® (PRS) and PR PLAST Module® (PRM), and the relative viscosity of modified asphalt increased with time; PRS modifier droplets tended to form a network. The test results of the mixtures indicated that compared with the original asphalt mixture and the styrene–butadiene–styrene (SBS) mixture, the HMABs significantly improved the high temperature performance, water stability, moisture–heat synthesis property, and dynamic modulus of mixtures. The investigation results of test sections showed that the average rut depth and surface deflection observed in the test sections using the high modulus asphalt concretes (HMACs) were much smaller than those in the test sections using the SBS mixture after one year of service. Based on the colloidal system equilibrium and the lowest energy principle, the modification mechanism of the HMABs modified by PRS and PRM was analyzed in this paper by using the effects of swelling and interface layer. The effects of the HMABs on the performance of HMACs were evaluated. The test results of the mixtures confirmed the correctness of the analysis associated with the modification mechanism.

1. Introduction

French engineers developed high modulus asphalt concrete (HMAC) to reduce the thickness of the base course in the early 1980s [1]. HMACs were also used in the base layer of long life asphalt pavement in America [2]. Considering the good performance of HMACs, HMACs were used widely in the construction of the binder and wearing course to improve rutting resistance and limit the maximum thickness of the asphalt layer for heavy traffic sections in several European countries as well as in South Africa and China [3–5]. The development of high modulus asphalt binders (HMABs) should be the key element in the production of HMAC.

HMABs can be obtained by three methods: hard grade asphalt, rock asphalt modification, and polyolefin modification [6]. Compared with the traditional asphalt binder, hard grade asphalt binder and HMAB modified by rock asphalt decrease the temperature sensitivity and self-healing ability. In addition, the HMABs modified by polyolefin have better performances with regard to thermal cracking and fatigue than hard-grade binders and rock asphalt modified binders [7]. Therefore, in order to increase the rutting resistance of pavement in extremely high traffic conditions, it is preferable to use polyolefin modified asphalt to produce HMACs used in wearing courses or binder courses.

In recent years, rutting has become the main form of damage to highways in China [8]. Due to high temperatures, rainfall, and overloading, early damage to asphalt pavement is relatively serious in southern China [5,9]. Various studies have been undertaken to

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assess the properties of HMABs produced by different methods [1]. It has been recognized that rutting resistance of HMAC produced by hard grade asphalt was higher than that of the styrene–butadiene–styrene (SBS) modified asphalt mixtures [1]. In a more recent study, Hyun Jong Lee [10] mixed a high boiling petroleum product and styrene–butadiene–styrene (SBS) polymer and hard grade asphalt to produce HMAB and HMAC. His study showed that the stiffness modulus of HMAC increased significantly and the fatigue resistance and water damage resistance performance was also enhanced, while the low temperature performance was not affected. Full scale accelerated pavement test results in his study showed that the permanent deformation of a HMAC pavement was smaller even though the thickness of a HMAC pavement was less than that of a traditional asphalt mixture pavement. However, the modification mechanism of HMAB has not been analyzed clearly and the effects of HMABs on the performance of HMACs have not been thoroughly evaluated.

The main objectives of this study are to analyze the modification mechanism of HMAB modified by polyolefin and to investigate the effects of HMABs on the performance of HMACs. In order to achieve those objectives, some microscopic test instruments were adopted to analyze the modification mechanism of HMABs. Laboratory tests were conducted on mixtures to evaluate the effects of HMABs on performance characteristics of HMACs. In addition to the laboratory tests, test pavement sections were built and monitored to evaluate the performance of HMAC pavements.

2. Materials and methods

2.1. Materials

2.1.1. Asphalt binder and modifiers

An original asphalt, a SBS modifier, and two high modulus modifiers, PR PLAST S® (PRS), and PR PLAST Module® (PRM) were included in this study. The original asphalt with penetration grade 70 is produced by Xiamen Huate in China. PRM and PRS are polyolefin modifiers produced by PR Industrie in France. The original asphalt is used as base asphalt to produce binders with the modifiers mentioned above. Some important technical indicators of original asphalt are shown in Table 1.

The percentages of PRM and PRS were 10%, respectively. Binder modified with 4% SBS, which was produced by Xiamen Huate in China, was included for reference. PRM modified asphalt binder and PRS modified asphalt binder for microscopic tests were prepared by a high speed shearing device. The shearing lasted 15 min. The shearing rate was 4000 rpm and the temperature was 175 °C. The blends became homogenous. Mixing was then continued at 160 °C with low-speed shearing for different periods of time (30 min and 60 min), respectively.

2.1.2. Mixtures

Because the rut deformation is mainly concentrated in binder courses [3–5], a typical dense gradation (AC-20) with a nominal maximum aggregate size of 20 mm was used to study gradation, as shown in Table 2. The original asphalt, the SBS modified asphalt binder, the PRM binder and the PRS binder were used to produce asphalt mixture specimens.

Table 1
Technical indicators of asphalt.

Test properties	Unit	Test results
Penetration (15 °C, 100 g, 5 s)	0.01 mm	68.6
Ductility (15 °C, 5 cm/min)	cm	>100
Ductility (10 °C, 5 cm/min)	cm	35.7
Softening point	°C	47.5
Penetration index	–	0.05
Wax content	%	0.9
Viscosity (135 °C)	Pa · s	398

Table 2
Gradation of AC-20 asphalt mixture.

Sieve size (mm)	26.5	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
AC-20 Passing percentage (%)	100	91.7	79.9	67.1	50.8	35.6	24.2	17.4	12.6	9.4	7.7	5.8

Using the asphalt binders and the aggregate gradation described above, the original asphalt mixture, the SBS mixture, and two HMACs (PRM mixture and PRS mixture) were prepared for the laboratory testing.

The optimum asphalt contents were determined according to the Marshall mixture design method of Chinese F40 JTG 2004. The air void percentage of the mixtures at optimum asphalt content was 4%. The optimum asphalt contents of the mixtures are indicated in Table 3.

The materials used in the laboratory tests were the same as the materials used in the test sections.

2.2. Test methods

2.2.1. Scanning electron microscope test

The addition of a modifier will change the composition and internal structure of the asphalt binder. The morphology of the modified binders asphalt was captured by a scanning electron microscope (SEM). A vacuum coating method was used to surface of the modified samples. The SEM micrographs were obtained under a Hitachi S-4800 scanning electron microscope at magnification levels of 2000×.

2.2.2. Fluorescence microscopy test

A fluorescence microscopy was used to investigate the state of dispersion of the PRM and PRS polymers within the base asphalt. Fluorescence microscopy allowed the visualization of the biphasic morphology. The polymer-rich phase that swelled because of the oily aromatic part of the asphalt appeared to be light toned while the asphaltene-rich phase was dark [11,12].

Binder samples were examined at room temperature under an XSP-63XA fluorescence microscopy at magnification levels of 400×.

2.2.3. Wheel tracking tests at 60 °C and 75 °C

The effects of the modifiers on the asphalt mixture were evaluated using mixture tests.

The maximum air temperature was 42.5 °C and the pavement temperature was up to 75 °C in Guangxi, China, where the test sections were located. Therefore, wheel tracking tests at 60 °C and 75 °C were performed to evaluate the high temperature performance of the mixtures. The dimensions of the slab specimens were 300 mm × 300 mm × 50 mm in length, width, and height, respectively. A solid-rubber wheel traveling at a speed of 42 cycles/min and at a pressure of 0.7 MPa was used to correlate with rutting. Rut depths were measured per 20 s. The wheel tracking tests were conducted at 60 °C and 75 °C under dry conditions to evaluate the permanent deformation characteristics of the asphalt mixtures.

2.2.4. Freeze–thaw splitting test and immersion Marshall test

Water stability is one of the most important asphalt mixture performances. Freeze–thaw splitting test and immersion Marshall test were conducted to research the water stability of the mixture according to the requirements of current Chinese specifications. The freeze–thaw splitting test followed the procedure of Chinese T 0716-2011, in which specimens were subjected to continuous freezing at 18 °C for 16 h and thawing at 60 °C for 24 h, after which the indirect tensile strength was obtained.

The Immersion Marshall test followed the procedure of Chinese T 0709 2011, in which specimens were immersed in a water bath at 60 °C for 48 h. The Marshall stability was obtained after 48 h of water immersion.

The freeze–thaw splitting strength ratio and the immersion residual Marshall stability (MS′) were calculated to evaluate the water stability of the mixtures. The freeze–thaw splitting strength ratio is defined as the indirect tensile strength ratio (TSR) of freeze–thaw and dry specimens. The immersion residual Marshall stability (MS′) is defined as the Marshall stability ratio of wet and dry specimens.

2.2.5. Immersion wheel tracking tests

In high temperature and rainy areas, the rainy season is often in the summer. It is necessary to study the influence of water-heat synthesis on the performance of asphalt mixtures. A single index, rut depth or TSR, cannot fully evaluate moisture–heat synthesis property of mixture. Therefore, the immersion wheel tracking

Table 3
Optimum asphalt contents of mixtures.

Mixtures	Original	SBS	PRM	PRS
Optimum asphalt content (%)	4.0	4.1	4.1	4.1