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Laboratory evaluation of self-healing properties of various modified asphalt

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HIGHLIGHTS

- The modifier significantly affects the healing potential of asphalt binder.
- Increasing modifier content will deteriorate the healing capability.
- Methylene plus methyl hydrogen to carbon (MMHC) ratio is unsuitable for characterizing the modified asphalt.
- Viscosity @135 °C can predict the healing property of the modified asphalt.

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ABSTRACT

The self-healing capability of asphalt materials has been known for many years. Related studies have focused mostly on the healing mechanism or self-healing behavior during load repetitions. Limited work has been accomplished to fully understand the healing performance of different modified asphalt. In this paper, the effects of various contents of different modifiers on the healing capability of binders were investigated by a simple self-healing test procedure to give suggestions to ensure better choice of asphalt materials with good healing properties. Results from the Binder Bond Strength (BBS) test indicate that the modifier significantly affected the healing potential of asphalt binder depending on both the type and content of modifier that was used. Interestingly, increased modifier content deteriorated the healing capability of the base binder regardless of the type of additive employed, thereby suggesting that soft binders are more desirable for healing. Furthermore, methylene plus methyl hydrogen to carbon (MMHC) ratio was verified to be useful for predicting the healing potential of base asphalt binder but was found to be unsuitable for characterizing the healing potential of modified asphalt. By contrast, rotational viscosity @135 °C can predict the healing property in the case of base and modified asphalt. Finally, the Four-Point Beam Fatigue (4PB) test further confirmed that the BBS test can help to determine the healing potential of asphalt binders in an efficient and simple manner.

1. Introduction

Since the 1960s, the healing potential in asphalt materials has been a focus of research in both laboratory and field [1]. Asphalt binder plays an important role in bonding the individual aggregate particles together and is the essential component that results in the self-healing of asphalt material. A comprehensive qualitative and quantitative understanding of healing properties of different asphalt materials will help with developing materials with tailored healing characteristics and an optimized material design to reach extended field performance of asphalt pavements.

It is known that the self healing capability is a quite complex phenomenon, different approaches have been developed to evaluate the healing capability of asphalt concrete, such as the most widely-used fatigue-healing-refatigue test [2–5], the discontinuous fatigue test with different rest period/load period ratio [6], and the intrinsic two-piece healing test [7]. Most of these tests are very complex and time consuming. When it comes to the binder, DSR based test is the most often-used test to measure the self-healing ability of asphalt binder [8,9]. At the molecular level, Kim et al. [10] proposed two parameters to quantify molecular characteristics related to self-healing: the methylene plus methyl hydro-

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gen to carbon ratio (MMHC) and the methylene to methyl group ratio (CH2=CH3). Bhasin et al. [11] used Molecular Dynamics (MD) simulation to confirm the viability of using MMHC to predict the healing potential of asphalt binder from the point of molecular self-diffusivity view. However, whether MMHC could also be applied to characterize the healing potential of modified asphalt has not been investigated.

Based on the findings of some researchers [12], the healing process in bituminous materials consists of a three step mechanism: (1) surface approach due to the consolidation of stresses and flow of bitumen, (2) wetting and (3) the complete recovery of mechanical properties due to diffusion and randomization. Among them, extent of flow depends on the combination of viscoelastic properties of the material and thermodynamic conditions of the process. Wetting is governed by surface energy, with a short-term contribution that is inversely proportional to non-polar component of surface energy and a long-term contribution that is directly proportional to its acid-base component. Finally, inter-diffusion and randomization stem from reptation-type interactions which are strongly affected by molecule structure [13]. Thus, asphalt binder types can considerably affect the healing potential of binder.

Polymer-modified asphalts (PMA) derive their technological and conceptual origin from the need for enhancing the performance and durability of asphaltic materials as well as their adhesion to mineral aggregates. With respect to modified binder, Bahia et al. [14] studied the healing performance of two unmodified asphalt, two asphalt modified with plastomers, two modified with elastomers and two modified by oxidation. It was shown that the modified binders show better healing performance than the base binders do. Besides, Lee [15] found that SBS positively affect the self-healing of asphalt.

Several studies have explored the healing property of modified asphalt materials. However, the effect of different modifiers on the healing behavior of asphalt materials remains unclear, and studies on this issue have yielded mixed results [2]. This paper performed investigations on the self-healing capability of different types of asphalt binder modified by different modifiers at various concentrations by BBS test. Then, the viability of using MMHC obtained by the FTIR spectroscopy and viscosity measured by rotational viscometer to characterize the healing capabilities of different asphalt binders was investigated from two aspects: base binders and modified binders. Finally, the BBS test results were further compared with the data from the mixture evaluation through the 4PB test to find their relationship.

2. Materials and testing methods

2.1. Materials

In this paper, a 60/80 pen grade base asphalt binder with PG 64–22 grade was obtained from Esso. To evaluate the effects of different modifiers on the healing capability of asphalt materials, linear styrene–butadiene–styrene (SBS), gilsonite, High Density Polyethylen (HDPE) and crumb rubber were selected to modify the same base binder in this study, i.e. binder A (PG 64–22). Table 1 summarizes the modified binders selected for evaluation; all of these modifiers were incorporated into neat binder by the weight of binder with the exception of the crumb rubber, which was introduced internally (for example, 5% introduced internally means the ratio of the weight of modifier to the weight of neat asphalt is 5:95 instead of 5:100).

In this paper, all of these modified asphalt represent the common types used in practice in China, and the content levels of modifier of this study are widely adopted in industrial production. In addition, the point of this study is to evaluate the impacts of different additives and modifiers on the healing of asphalt, thus the mount of additives maybe a little higher to show the difference between additives and modifiers.

The storage stability of some SBS-modified asphalt binder is usually poor at elevated temperatures due to the incompatibility between SBS and base asphalt. The addition of sulfur has been reported to improve the stability of polymer-modified asphalt [16]. Thus, in this study, all of SBS modified asphalt were added with 0.15% Sulfur except one control group. Besides, crumb rubber was used to prepare Terminal Blend (TB) rubberized asphalt binder which is a new type of homogeneous crumb rubber modified binder. In the present study, TB asphalt binder was supplied by a commercial asphalt producer and further modified with 3.0%SBS (10TB + 3.0% SBS).

In addition, all of the mixtures were designed by following Superpave specifications for an N_{des} of 100 gyrations. HMA mixtures were designed with typical gradation Sup-12.5 following the Superpave® volumetric mix design method. The design asphalt binder content was 5.0% for all of these asphalt binders. Besides, in order to make the results from different scales are comparable, all aggregates used in this study were basalt, which were produced by most ore fields with a better shape and strength than other aggregates.

2.2. Binder bonder strength test

In this paper, BBS test was performed based on AASHTO TP-91 [17], and testing parameters can be found elsewhere [18] (chapter 3, the asphalt film thickness was controlled at 0.2 mm and the loading rate was 0.7 MPa/s). The global set-up of the test method is shown in Fig. 1, involving asphalt sample preparation, failure–healing (F–H) cycles, and tensile testing.

As shown in Fig. 1, after sample cools at 25 °C for 1 h, stubs are marked to record their initial positions, and the initial Pull-off Tensile Strength ($POTS_I$) can be measured by BBS test. The stubs are immediately returned to their original positions without applied pressure to prepare the healing specimen. Then, this healing specimen is submerged in a 25 °C water bath for 24 h to restore its strength. The recovered bond strength can be measured after this healing period and recorded as $POTS_A$. After several (i) F-H cycles, different $POTS_{Ai}$ can be obtained. It should be noted that the recovered bond strength can be extremely low after several F–H cycles. Thus, additional F–H cycles are not needed for the specimen in this case. The Healing Index (HI) can be defined as Eq. (1):

Table 1
Descriptions of modified asphalt binders.

Asphalt type	Base binder	Modifier	Content level (%)
Base asphalt A	PG 64–22	–	–
SBS	PG 64–22 + 0.15% sulfur	SBS	1.5, 3.0, 4.5
	4.5% SBS	Sulfur	0, 0.10, 0.15, 0.20, 0.25, 0.30
Gilsonite	PG 64–22	Gilsonite	4.0, 8.0, 12.0, 20.0, 24.0
HDPE	PG 64–22	HDPE	2.0, 4.0, 6.0, 8.0
Crumb Rubber	PG 64–22	Rubber	5.0, 10.0, 15.0, 20.0