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Comparison and relationship between indices for the characterization of the moisture resistance of asphalt–aggregate systems

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HIGHLIGHTS

- Surface free energy (SFE) test, binder bond strength (BBS) test and Hamburg wheel tracking device (HWTD) test were compared.
- HWTD test is a benchmark test while BBS test is a screening test in characterizing the moisture performance of modified asphalt.
- The receding procedure in the Wilhelmy Plate Method gives better results than the advancing procedure.
- High mobility of base binders influences the moisture sensitivity of asphalt mixture negatively.

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ABSTRACT

The complex and diversified asphalt modification makes it harder for the assessment of testing methods capable of characterizing the performance of different modified asphalt in the presence of water. In this study, three representative test methods addressing the moisture performance of asphalt were evaluated and compared: surface free energy (SFE) test, binder bond strength (BBS) test and Hamburg wheel tracking device (HWTD) test. Results indicate that the HWTD test can be a benchmark test while the BBS test is a screening test in characterizing the moisture performance of various modified asphalt. In addition, the surface energy component obtained from the receding procedure in the Wilhelmy Plate Method correlated better with the adhesion property of asphalt than those based on the advancing procedure did. The various indices obtained from the three tests were classified as suitable or unsuitable indices on the basis of the analysis of specific additives. Furthermore, based on the degree of their improvement in the moisture performance, additives were classified into three grades: (1) the first grade including linear styrene–butadiene–styrene (SBS), branched SBS and gilsonite; (2) the second grade including high-density polyethylene, and polyphosphoric acid; (3) the third grade including asphalt rubber and terminal blend asphalt. Finally, it was found that base binders with shorter-chain structures and lower aromatics contents showed better moisture resistance in the HWTD test. High mobility of base asphalt binder negatively influenced the corresponding mixture's moisture sensitivity.

1. Introduction

The common wisdom "water gets everywhere" certainly holds true for asphalt pavement. Moisture damage diminishes the performance and service life of hot-mix asphalt (HMA) pavements, consequently increasing maintenance and rehabilitation costs [1]. Stripping is one of the major indicators for identifying moisture damage in HMA and can be defined as the weakening of the adhesive bond between the aggregate and asphalt binder. It is usually used as the exchange name for moisture damage or moisture sensitivity [2]. In this paper, the term "moisture performance" was used to represent the asphalt–aggregate system's resistance to the moisture damage including the adhesion property of asphalt binder, the stripping potential between the binder and aggregates, and the performance of asphalt mixtures in the presence of water.

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Many test methods have been developed to characterize the moisture performance of asphalt materials and can be classified as tests that are performed on loose mixtures and tests that are performed on compacted samples. The former is used to determine the loss of the original asphalt coating from the aggregates, whereas the latter is used to measure the change of mechanical properties of the asphalt mixture in the presence of water. Some common test methods include boiling water test, static immersion test, Lottman test, AASHTO T 283, and loaded-wheel tests [3]. Recently, several new tests, such as moisture-induced sensitivity test, atomic force microscopy, and computational models, have been developed to simulate the moisture-induced damage in asphalt materials [4]. However, few of these tests have been widely accepted because the laboratory test results and the field performances are usually poorly correlated.

A major problem that has held back the development of the accurate evaluation method is the complex and diversified asphalt modification. In recent decades, in order to achieve pavements with long service-life and overcome the problems of conventional pure asphalt, modifiers and additives are used [5]. However, most evaluation methods have limitations when they are used to evaluate modified asphalt binders. The majority of new methods were not designed to be “blind” to the type of asphalt. Mixed or even contradictory results are frequently obtained when different methods are used to evaluate the moisture performance of modified asphalt [6]. This causes confusions among pavement engineers during the selection of modified asphalt materials with acceptable moisture performance.

Therefore, the assessment of testing methods that accurately evaluate the moisture performance of different modified asphalt is urgently needed. In this study, three representative test methods addressing the moisture performance of asphalt at different levels were evaluated and compared:

(1) On Level 1 was the fundamental surface interaction test: the surface free energy (SFE) test. Currently, the theory of SFE has been widely used to assess the bonding and debonding potential of the asphalt-aggregate system [7].
(2) On Level 2 was the qualitative test evaluating the stripping potential of asphalt film from the aggregate substrate: binder bond strength (BBS) test [8].
(3) On level 3 was the test conducted on compacted asphalt mixtures: the Hamburg wheel tracking device (HWTD) test has the dynamic loading and may better simulates the actual field condition than other tests [9].

2. Objectives and scope of the present work

This research is motivated by the understanding that the accurate evaluation of efficient measurement methods for the moisture performance of modified asphalt materials will bridge the gap between the current state of knowledge and the current state of practice. This will, in turn, improve the efficiency of selecting asphalt materials with preferable moisture resistance. The objectives of this study are threefold:

(1) to classify the various indices obtained from three representative tests into two categories based on the specific analysis of specific additives: suitable indices and unsuitable indices;
(2) to grade various additives according to the degree of their improvement in the moisture resistance of asphalt–aggregate systems. However, the detailed reasons that account for their influence were not included in this paper due to the length limitation; and
(3) to gain a better understanding how chemical functional groups of base binders affect the moisture performance-related HWTD test results of asphalt mixtures.

3. Materials

In this paper, a 60/80 pen grade base binder meeting PG 64-22 grade was provided by an asphalt company. Different contents of linear SBS, branched SBS, sulfur, Gilsonite, HDPE, crumb rubber, and PPA were selected to modify the same base asphalt, i.e., PG 64-22. Modifiers were added by the weight of the base binder and detailed modification formulas are presented in Table 1.

Preparation of SBS modified binders was divided into three stages. Firstly, SBS was added to the base binder and sheared for 30 min at 180 °C with a high shear disperser. Secondly, the compound was stirred for 60 min using a mechanical blender at 800 rpm. Thirdly, different amount of elemental sulfur was added to the blend and stirred for another 90 min. In this study, 0.15 wt% of the elemental sulfur was used as a cross-linking agent to improve the thermal stability and mechanical properties of SBS modified binders (linear and branched) [10]. The dosage rate of the sulfur was selected as 0.15% because this percentage of typically provides the SBS modified asphalt with the desirable storage stability [11], while too much sulfur will increase the viscosity and the risk of gelation. The Gilsonite or HDPE modified asphalt binder was prepared in the laboratory by blending the Gilsonite or HDPE modifier and the base binder at 180 °C for 90 min. The PPA modified asphalt binder was prepared in the laboratory by mixing the PPA modifier and base binder at 180 °C for 45 min. Concerning the Asphalt Rubber (AR), crumb rubber was added to base binder and kept blending for 60 min at 190 °C. Terminal blend (TB) rubberized asphalt is a new type of crumb rubber modified asphalt. In the TB process, fine-mesh-ground tire rubber is blended with asphalt at a refinery or terminal to generate a homogeneous binder that is delivered to the hot mix plant to produce the final mix. In the present study, TB asphalt was supplied by a commercial asphalt producer.

The HMA mixtures were designed with typical gradation Sup-12.5 following the Superpave® volumetric mix design method. The designed asphalt binder content was 5.0% for all of these asphalt mixtures except the asphalt rubber (AR), which was 6.5%. In addition, all aggregates used in this study were basalt, and the filler was limestone. The gradation of AR mixture was the Asphalt Rubber Asphalt Concrete-13 (ARAC-13) recommended by the Arizona Department of Transportation Standard specifications for road and bridge construction [12], the specific gradation can be found in Ref. [13].

4. Testing methods

4.1. Fourier transform infrared spectroscopy

In this study, the infrared spectra values were collected using a FT-IR spectrometer equipped with a reflection diamond ATR accessory. The calculations were set on the peak areas rather than the peak absorbance in this study because that the band area varied little within the replicates of each sample [14]. The peak areas used in this paper were recorded automatically by Matlab code to minimize the manual error. Automatically base line correction and band normalization were employed in the OMNIC software after infrared spectrums were collected. Three replicates were performed for each sample, and the average FTIR results were reported in this study.