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Nanoscale study on water damage for different warm mix asphalt binders

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Abstract

In order to analyze the water damage to different warm mix asphalt binders from the micro scale, five kinds of asphalt binders, 70#A base asphalt, sasobit warm mix asphalt, energy champion 120 °C (EC120) warm mix asphalt, aspha-min warm mix asphalt, sulfur-extended asphalt modifier (SEAM) warm mix asphalt, under different conditions (dry/wet, original/aging) are prepared for laboratory tests. The atomic force microscope (AFM) is used to observe the surface properties and measure the adhesion force between the asphalt and the mineral aggregate. The obtained results show that under the dry condition aspha-min warm mix asphalt and SEAM warm mix asphalt show stronger adhesive ability with the mineral aggregate compared with other asphalt binders, but also have relatively large dispersion and fluctuation in the tested results; under the wet condition, aspha-min warm mix asphalt and SEAM warm mix asphalt show stronger water damage resistance ability. The EC120 warm mix asphalt and aspha-min warm mix asphalt are less sensitive to moist, and their corresponding adhesion force is less susceptible to the change of external moisture conditions, leading to a better ability to resist water erosion. The aging process significantly lowers the moisture erosion resistance ability, which further impairs the water damage resistance ability. The base asphalt is more sensitive to moisture and more vulnerable to water damage, no matter whether it is under original or aging conditions. The aging aspha-min warm mix asphalt has the least loss of adhesion force, the smallest dispersion of the tested adhesion force, the strongest water damage resistance ability, no matter it is dry or wet.

Keywords: Road engineering; Warm mix asphalt; Moisture damage; Atomic force microscope; Microcosmic

1. Introduction

The material and structural characteristic of asphalt concrete pavement make it more susceptible to the moisture condition. The decrease in the adhesion force causes water damage at the asphalt–aggregate interface. Although the domestic and overseas researches on water damage to asphalt pavement has lasted nearly 70 years, this problem has not yet been effectively addressed. Two key problems of water damage in asphalt pavement have not been solved thoroughly: How to exactly measure the asphalt mixture performance loss caused by moisture variation? How to effectively reduce the water damage to asphalt pavement?

Numerous studies [1–6] have shown that the water damage of asphalt binders (mixtures) occurs at the molecular scale, or even at the nanometer scale. This is because of the fact that the root cause of water damage to asphalt binders is related to the loss of the adhesion force and the cohesion force. The loss of the adhesion force refers to the decline of the adhesive ability at the asphalt–aggregate interface as a result of the water and water pressure acting on the asphalt mixture; the loss of the cohesion force is due to the softening or the impairment of cohesion capability

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inside the asphalt binder subjected to the moisture and seepage force. Both the adhesion force loss and the cohesion force loss happen at the nanometer scale. Therefore, to quantify the adhesion force or the cohesion force at the nanometer scale is of highly positive practical significance to the research and prevention of water damage to the asphalt pavement.

The microscopic researches on water damage to the asphalt binders at home and aboard mainly focus on base asphalt and SB/SBS modified asphalt. However, there are few reports about the investigation of warm mix asphalt at the nanometer scale. With the application of the high-definition 3D image resolution of the atomic force microscope (AFM) and a precise force–displacement measurement system, the adhesion force between the asphalt–aggregate molecules is analyzed for different asphalt binders under dry/wet, original/aging states at the laboratory, followed by the evaluation of the water damage resistance for each warm mix asphalt binder under different conditions. The research results can provide theoretical basis for the discovery of the mechanism of water damage and the reduction of water damage. It should be noted that parallel tests are conducted in this article using modified asphalt SBS as comparative material, and the results showed no visible difference. In consequence, this article only presented the effects of base asphalt and warm mix modifies on water damage of asphalt binder.

2. Review of previous studies

Research on water damage of asphalt binder & mixture dates back to the 1930s, from asphalt to mineral aggregate, from test methodology to pavement structure [7]. To date, numerous test methods have been developed and used to predict moisture-induced damage in asphalt concrete [8–10]. In the past two decades, there have been significant improvements in moisture damage test methods and our understanding of the microscale to macroscale behavior of asphalt concrete. There exists evidence that moisture-induced damage in asphalt concrete is influenced by factors such as asphalt grade, viscosity, modifiers, phenol group concentrations, aggregate surface chemistry, minerals, roughness, porosity, clay coatings, mix air voids, asphalt content, permeability, and binder thickness. Yet, a combination of asphalt and aggregate that would be compatible enough to produce moisture damage-free asphalt concrete is not available [11]. There is an urgent need for the development and assessment of testing methods capable of examining the effect of moisture on asphalt concrete.

Moisture damage within the binder and/or at asphalt–aggregate interfaces has been studied by several researchers [2,6,8]. Recently, the surface free energy of asphalt and aggregate has been empirically related to the moisture-induced damage of asphalt concrete [2,5]. The surface free energy of asphalt and aggregate is indirectly measured using the Wilhelmy plate, sorption device, and Youn–Dupré equation. However, the Wilhelmy plate method cannot differentiate between the functional groups. For example, the surface free method fails to differentiate between actions of carboxylic acid (bad) and carbonyls (good), or carboxylic acid (bad) and nitrogen compound (good) under wet conditions. Also, the Wilhelmy plate technique cannot clearly distinguish between untreated asphalt and asphalt treated with amine antistrip. By the same token, the universal sorption device requires vacuum degas preconditioning, which is very different from the mixing plant conditions. More recently, Rafiqul et al. [12] tested the adhesion forces between base asphalt as well as SB & SBS modified asphalts and different functional probes. The results showed that modifiers SB and SBS can improve the water damage-proof ability of base asphalt and a 3% SB & SBS dosage can obtain the best effect. In addition, critical parameters for AFM testing on modified asphalt were also confirmed basically.

3. Materials and test methods

3.1. Raw materials

The raw materials used in the tests include: (1) The base asphalt: 70#A pavement petroleum asphalt. (2) The warm mix modifier sasobit: with low melting point and organic viscosity-reducing character. The admixture dosage is 3.0 percent of the mass of the asphalt binder, which can lower the mixed and compacted temperature by 20 °C–30 °C. (3) The warm mix additive energy champion 120 °C (EC120): a kind of linear aliphatic hydrocarbons. The admixture dosage is 3.0 percent of the mass of the asphalt binder, lowering the mixed and compacted temperature by 20 °C–30 °C. (4) The warm mix additive aspha-min: the artificial synthetic white powder zeolite. The admixture dosage is 0.3 percent of the mass of the asphalt binder, lowering the mixed and compacted temperature by 10 °C–25 °C. (5) The warm mix additive sulfur-extended asphalt modifier (SEAM): the sulfur. The admixture dosage is 30 percent of the mass of the asphalt binder, lowering the mixed and compacted temperature by 20 °C–35 °C. Each appearance of warm mix additives is shown in Fig. 1, and the main technical parameters of the asphalt binders are listed in Table 1.

3.2. The preparation of samples

In order to ensure the AFM to reliably observe the nanometer-scale surface properties of asphalt binders, the one-blending method is used to prepare the warm mix asphalt samples which are theoretically finely dispersed and uniformly distributed. In order to make the binder surface smooth, the particle size of asphalt mortar should be as small as possible, an advanced colloid mill machine (2000 mesh) is taken to grind the warm mix asphalt fully mixing the warm agents with the asphalt, at the revolving speed 4500 rpm and grinding time 4 h. The detailed preparation technology is sketched in Fig. 2. Moreover, size of material will not change the character of itself and the