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Aging of asphalt binders from weathered asphalt mixtures compared with a SHRP process

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HIGHLIGHTS

- Quantitatively evaluated the aging of asphalt binders by means of the nano-morphlogy, adhesion and modulus of elasticity.
- A weathering duration of 0 and 2400 h caused the same aging responses of RTFO and RTFO + PAV residuals, respectively.
- The roughness of morphology of asphalt binders was gradually reduced as aging increased.
- The roughness of adhesion and modulus of elasticity of asphalt binders were increased as aging increased.

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ABSTRACT

Aging of asphalt binders from weathered asphalt mixtures was quantitatively evaluated in both micro- and macro-level properties by Atom Force Microscope (AFM) and by Dynamical Shear Rheometer (DSR), respectively. The asphalt binders tested were recovered from asphalt mixtures weathered for different weathering times, in addition to those control asphalt binders aged by following a SHRP binder process. The results of this research are summarized as follows: 1) The aging of asphalt binders from both weathered mixtures and those aged by a SHRP process can be characterized quantitatively by AFM technologies; 2) "Bee structures" occurred in the morphology of these binders were not observed in the images of both adhesion and modulus of elasticity; 3) Agings of asphalt binders for a weathering duration of 0, 2400 h were roughly equivalent to those by RTFO, RTFO + PAV residuals, respectively.

1. Introduction

Asphalt pavement takes up a majority percentage of all the highway pavements in most of developed countries and much more than Portland cement concrete (PCC) pavement owing to its many advantages in technologies and initial cost saving [1,2]. However, its life span is usually much shorter than that of PCC pavement because the aging of the asphalt binders in the asphalt paving mixtures will normally cause pavement failures such as low-temperature cracking, moisture damage and fatigue cracking [3,4]. The aging of asphalt binders is resulted from the reaction of several climate factors including oxygen, ultra-violet, moisture and heat.

To prolong the service life of asphalt pavements, it is beneficial to increase the aging-resistance of asphalt binders after understanding the mechanism of the aging. Many efforts have been devoted to the study of asphalt aging. It has been found that aging of asphalt binders involves many complex physic-chemical reactions that result in harder and more brittle products [5,6]. The aging of asphalt binders are currently simulated or reappeared in a laboratory by Roll Thin Film Oven (RTFO) for short-term aging (that is occurred during the production of asphalt mixtures and paving) and aged by Roll Thin Film Oven and Pressure Aging Vessel (RTFO + PAV) for long-term aging (that is occurred during the service life of the asphalt pavement) [7]. In addition, aging of asphalt binders are also simulated or reappeared by aging asphalt mixtures directly in an oven. Both the agings of the short-term aging (STA) and the long-term aging (LTA) are reproduced in a lab by aging the mixtures in an oven at different temperatures and durations [8,9]. The chemical components and morphology of aged asphalt depend on the above aging processes, i.e., STA or LTA [10,11].

Aging of an asphalt binder in asphalt pavement exposed to the air is mainly the result of the combined reaction of weathering factors such as air, sunlight (ultraviolet), water and temperature [12].

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The current specifications of aging in a laboratory consider mostly the main factors of both heating and oxygen, but lacking of several other weathering factors that also cause, to some extent, the occurrence of aging. Research by Yu, et. al. indicated that the effect of rain water led to the loss of soluble substances in asphalt binders easily, which accelerated in part the aging of asphalt binders [13]. Wang found that as the aging time of ultraviolet light increased, the original colloidal structure of asphalt was progressively destroyed, and it gradually turned from sol to gel and colloid to solid [14,15].

In order to reproduce the aging of asphalt binders in asphalt mixtures in the lab more accurately, accelerated weathering machine (AWM) is used recently for asphalt mixtures aging, which can accommodate temperature, oxygen (air), moisture and ultraviolet (UV) [16]. The effects of the type of aggregates and the gradation of mixtures on the asphalt aging can be possibly considered in the weathering machine.

Aging degree of asphalt binders is normally evaluated in terms of their physical properties, chemical compositions and mechanical properties [17,18]. Most recently, advanced atomic force microscope (AFM) technology was explored to measure the changes in the micro-level properties i.e., nano-sized structure and mechanics on aged asphalt binders [19,20]. The AFM indexes used included morphology, adhesion and modulus of the asphalt binders [21,22]. Wynand JvdM Steyn characterized the surface morphology of asphalt binders samples (untreated and treated with TiO_2) by AFM and found that TiO_2-treated samples had a smoother surface than the untreated sample [23].

The aim of the research was mainly to evaluate the aging of recovered asphalt binders from weathered asphalt mixtures in an AWM as compared with that aged by following a SHRP process, specifically, with the following objectives:

1) To characterize quantitatively, by AFM technology, the recovered asphalt binders from weathered asphalt mixtures to see the effects of weathering time on the aging in micro-level properties, i.e. nano-sized structure and mechanics.
2) To relate the properties of weathered asphalt binders in an AWM with those of the binders aged by a SHRP process, i.e., RTFO and RTFO + PAV, in terms of both AFM and DSR testing results.

2. Materials and methods

2.1. Materials

Asphalt mixture type of SMA-13 was used for weathering in the AWM in the study. The mixtures were produced with a SBS modified asphalt binder and basalt mineral aggregates. The SBS modified asphalt binder was produced with a base asphalt binder of penetration grade Pen70, from Shell company, mixed with 4.3% of SBS in the weight of base asphalt in Sanchuang Pavement Construction Co. Ltd (Suzhou, Jiangsu Province, and China). The properties of the SBS modified asphalt binder were measured and showed in Table 1. The properties of the basalt aggregates are shown in Table 2.

Mineral filler used in this project is limestone, which was also supplied by Sanchuang Pavement Construction Co. Ltd. The properties of the mineral filler are listed in Table 3 and are in compliance with the specifications of JTG E42-2005.

In addition, wood fiber, produced by Jiangsu perfect Global Project Material Co., Ltd, was added at 0.3% of the total weight of SMA-13 asphalt mixture.

Mixture design of SMA-13 was made by Marshall test, according to the specifications of JTG E20-2011, and the optimum asphalt content (OAC) was determined to be 6.1%. Shown in Fig. 1 is the gradation of the aggregates of the SMA-13 mixtures.

Table 1
Properties of the SBS modified asphalt binders (JTG E20-2011).

Properties		Testing results	Specifications
Original	Penetration, 25 °C, 5 s, 100 g (0.1 mm)	52.2	40–60
	Ductility, 5 cm/min (cm) (5°C)	38.6	≥20
	Soft point (R& B) (°C)	78.5	≥65
	Dynamic viscosity (Pa.s) (135 °C)	2.3	≤3
RTFO residuals	Quality loss (%)	0.08	≤±0.8
	Ductility, 5 cm/min (cm) (5°C)	31.5	≥15
	Penetration ratio, 25 °C, 5 s, 100 g (%)	81.6	≥65

2.2. Methods

2.2.1. Aging of asphalt mixtures by AWM

AWM used in the study is showed in Fig. 2. A control panel was used to adjust the parameters of temperature, oxygen (air pressure), moisture density and ultraviolet strength (UV) to simulate the aging of the asphalt mixtures occurred in the fields. The setting of the parameters used for the study was as follows [24]:

(1) A cycle of 1 h includes 51 min of UV opened plus 9 min UV closed, and the UV lamp was selected according to 6.1.3.3 of ASTM G154 (ASTM 2012) [25]. The water sprays only during the 9 min of every hour when the UV is closed.
(2) Chamber temperature is controlled at 60 °C, this parameter is set according to D4799 and D4798 in the ASTM2011 [26], and the constant temperature is controlled by temperature sensors, ventilators, and heating equipment.
(3) The distance between the UV lamp and the asphalt sample is 60 cm. and the average intensity of ultraviolet light researched to the samples was set to $360 w/m^2$.
(4) The speed of water sprinkling is at a rate of 25 mm/h.
(5) Extract and recovery of asphalt binders from the weathered SMA-13 were followed the process of Abson method of JTGE20-2011 [27].

2.2.2. AFM test

AFM has been a kind of advanced research equipment used as a tool for micro-level properties of materials for decades [28,29], is used in the study of asphalt binders [30,31]. Combined with chemical analysis, it will be more intuitive to explore asphalt microstructures [32,33].

The AFM used in the research was made by Bruker (Dimension Icon) as shown in Fig. 3. All the testes were carried out in Research Laboratory of Nano-Materials, Suzhou University, China. In the process of scanning, change of the micro surface height will make the change of the micro force between the tip and the sample surface (either attraction or repulsion force). The cantilever will obey Hooke's law in the formula (1). Through the perception of the cantilever beam, it can transfer signal to measure the image.

$$F = K \times \Delta Z \quad (1)$$

K is the elastic constant of the micro cantilever. $\triangle Z$ is the change of the micro surface height.

In this project, AFM scanned an aged asphalt binder sample of 20 μm×20 μm square, as showed in Fig. 4. In order to obtain reliable results of the roughness as an evaluating index of the asphalt samples, four sub-square areas were selected on the sample to analyze different measurements. The scanning area was 4 μm×4