Construction and Building Materials 174 (2018) 401–409

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Investigation of the flow and self-healing properties of UV aged asphalt binders

Lei Zhang [a], Quantao Liu [a,*], Shaopeng Wu [a], Yinqiu Rao [a], Yihan Sun [a,b], Jun Xie [a], Pan Pan [c]

[a] Wuhan University of Technology, State Key Laboratory of Silicate Materials for Architectures, Luoshi Road 122, Wuhan 430070, China
[b] Zhejiang Provincial Institute of Communications Planning, Design & Research, Hangzhou 310015, China
[c] School of Resource and Civil Engineering, Wuhan Institute of Technology, Xiongchu Road 693, Wuhan 430073, China

HIGHLIGHTS

- The softening point reaches its limit when asphalt is aged to a certain extent.
- No healing threshold temperature can be found once reaching the ageing limit.
- The flow activation energy increases with the deepening of asphalt ageing.
- Healing threshold temperature has a good linear relation with flow activation energy.

ARTICLE INFO

Article history:
Received 8 January 2018
Received in revised form 3 April 2018
Accepted 12 April 2018

Keywords:
Asphalt
Ageing
Flow performance
Self-healing
Threshold temperature

ABSTRACT

In this paper, the flow behaviors and self-healing properties of two asphalt binders with different ageing degrees were investigated. Fourier transform infrared spectroscopy (FTIR) test was first used to characterize the ageing degrees of the binders. Then, frequency sweep test was conducted to calculate the flow behavior indices of asphalt binders with different ageing degrees to determine their self-healing threshold temperatures and fatigue life recovery test was performed to investigate their real self-healing rates. The capillary flow test was finally carried out to simulate the flow ability of asphalt binders with different ageing degrees within cracks in asphalt. It was found in FTIR that the carbonyl index increased with the ageing degree of the binders and tended to level off once the binders approached their ageing limits. With the deepening of ageing, the self-healing threshold temperature and the flow activation energy of asphalt binders increased and their healing performance was getting worse. Once the asphalt binders were aged to a certain extent, no self-healing threshold temperature can be found and the fatigue-healing rate was very low. A strong correlation between self-healing threshold temperature, flow activation energy and self-healing ratio can be found.

1. Introduction

Asphalt concrete is prone to ageing during the mixing, compaction and service processes. Ageing is an important factor affecting the performance of asphalt pavement and it tends to result in temperature cracking and fatigue cracking that represent the major cause of failure for asphalt pavements under low temperatures and traffic loading conditions [1,2]. To repair the cracking and prevent the water on pavement surface from infiltrating into the base of the pavement, a few preventive maintenance measures including sealants, fog seal, slurry seal and chip seal have to be applied on the pavement [3,4]. However, these preventive maintenance measures can only maintain the pavement performance for 2–4 years and the maintenance activities resulted in severe traffic jams and consumed a great amount of sealing materials [3]. As environment protection (e.g. reduction of harmful emissions) and resources conservation (e.g. recycling techniques) have been the aims of pavement-engineering strategies, asphalt pavement is badly in need of advanced maintenance technologies.

It is well known that asphalt is a self-healing material and it can automatically repair the mechanical or thermodynamic damage [5–8]. The self-healing of asphalt has always been a hot research topic since the self-healing phenomenon of asphalt was firstly reported [9]. These researches involved in explaining the mechanisms of self-healing of asphalt, defining the self-healing rate of asphalt and exploring the self-healing techniques to promote healing [4,7,10–13]. Liu et al. and Dai et al. proves that enhanced

* Corresponding author.
E-mail address: liuqt@whut.edu.cn (Q. Liu).

https://doi.org/10.1016/j.conbuildmat.2018.04.109
0950-0618/

self-healing technologies can efficiently heal the cracks in asphalt concrete and double the service life of asphalt pavement [14–16]. Thus, taking advantage of the self-healing ability of asphalt concrete to heal the micro cracking is an environmentally sustainable strategy to extend pavement service life, reduce the maintenance costs and greenhouse gas emissions [17].

A consensus has been built up is that the capillary flow and diffusion are the main mechanisms of self-healing of asphalt binder [18]. The self-healing performance of asphalt binder was highly associated with the temperature and it can repair itself quickly at higher temperatures. Garcia found that there exists a threshold temperature for asphalt self-healing [18]. When this critical temperature is reached, the flow behavior index of asphalt binder reaches 0.9 and the binder becomes a near-Newtonian fluid which can flow into the cracks and heal them rapidly with capillary force [11,19]. Tang et al. investigated the self-healing properties of different asphalt binders and found that the threshold healing temperature of asphalt is dependent on the type, softening point and viscosity of asphalt binder [13].

During the service, asphalt binder becomes harder and harder due to ageing and the softening point and viscosity of the binder are increased. As a result, the capillary flow speed of the binder can be seriously decreased, probably resulting in a lower self-healing ratio. The threshold healing temperature of asphalt can be influenced as well. However, none has explored this topic and it is still unclear how the threshold healing temperature of asphalt changes with ageing. It is of great importance to investigate the self-healing performance of asphalt binders with different ageing degrees and find out their specific threshold healing temperatures for applying external induced self-healing technologies (e.g. induction heating, microwave heating and so on) on asphalt pavement [6,20].

This paper aims to investigate the threshold temperatures, flow behaviors and self-healing ratios of asphalt binders with different ageing degrees. The relationship between the self-healing performance and the flow performance of asphalt binders will be explored as well.

2. Materials and experiments

2.1. Materials

Two asphalt binders were used in this research. The Penetration grade asphalt 70 (named as Pen 70 asphalt for short) has a penetration of 69 (0.1 mm) at 25 °C and a softening point of 44.1 °C. The Penetration grade asphalt 90 (Pen 90) has a penetration of 80 (0.1 mm) at 25 °C and a softening point of 40.2 °C.

2.2. Asphalt ageing process

50 g of the Pen 70 and Pen 90 asphalt binders were placed in the ageing iron pan (Φ150 ± 0.5 mm) and then were aged by a thin film oven test (TFOT) at 163 °C for 5 h according to ASTM D1754. After TFOT ageing, the binders were placed in a UV chamber for 1 day, 7 days, 14 days, 21 days, 28 days or 60 days to simulate the UV ageing on pavement. The UV density in this ageing procedure was 20 w/m^2 and the ageing temperature was 50 °C [21]. The thickness of asphalt binder film in UV ageing was around 1 mm. After the ageing test, the ageing extents, rheological properties, flow behaviors and self-healing performance of the aged binders were investigated.

2.3. Physical properties test

According to ASTM D5, ASTM D36T and ASTM D4402, the penetration (25 °C, 0.1 mm), softening point (°C) and Brookfield viscosity (135 °C, Pa·s) of asphalt binders were tested to characterize their ageing extents.

2.4. FTIR analysis

FTIR spectroscopy analysis was used in this paper to explore the change of functional groups of asphalt after ageing to semi-quantitatively characterize the ageing degree of asphalt binder. Before the test, asphalt binder was dissolved in carbon disulfide to prepare the solution (5% by weight). The solution was then dropped onto a KBr wafer and dried to form a layer of asphalt film on the surface of the KBr wafer. The scanning range of the sample was set from 500 cm^{-1} to 4000 cm^{-1} with a resolution of 4 cm^{-1}. FTIR spectrometer (Nexus, ThermoNicolet Corp., America) was used to record the spectra of asphalt binders with different ageing degrees. After the test, the FTIR spectrums of the asphalt binders were analyzed by OMNIC software.

2.5. Frequency sweep test

Dynamic shear rheometer (DSR) (MCR101, Anton Paar, Austria) was applied to carry out the frequency sweep test. The asphalt samples with different ageing degrees were placed between two parallel testing plates (one is fixed base and the other is rotatable plate with precision motor) with a diameter of 25 mm and a gap of 1 mm. Frequency-sweep test (increasing from 0.01 Hz to 10 Hz) was conducted for each sample in eleven different temperatures (increasing from 20 °C to 70 °C with an interval of 5 °C). According to the exponential relationship between complex viscosity (η) and scan frequency (w) which were recorded automatically in the test, the flow index of the binder at each testing temperature can be obtained. The threshold self-healing temperatures of asphalt binders with different degrees can be obtained according to the flow index curves of the asphalt binders.

2.6. Fatigue life recovery test

Fatigue life recovery test was conducted to investigate the real self-healing performance of asphalt binders with different ageing degrees. This test consisted of three steps: (1) DSR fatigue test was applied to asphalt binder until the complex modulus of the sample dropped to 50% of its initial value (10 °C, 10 Hz, 1% strain); (2) The fatigued sample was heated to a certain temperature (60 °C for Pen 90 and 55 °C for Pen 70) and held there for 20 min to allow the binder to heal itself; (3) The temperature was cooled to 10 °C and the healed asphalt binder was subjected to another fatigue test until the complex modulus decreased to the same level as the first fatigue test. The fatigue life extension ratio (the second fatigue life divided by the first fatigue life) was used as an index to characterize the self-healing properties of asphalt binders with different ageing degrees.

2.7. Capillary flow test

In order to characterize the flow performance of asphalt binder with different ageing degrees, the capillary flow test was carried out where capillary tubes were used to simulate different cracks within asphalt mastic. Three capillaries with different diameters (0.20 mm, 0.60 mm and 1.0 mm) were affixed to a 100 mm × 40 mm quartz glass plate with an epoxy resin and placed vertically in a Petri dish (shown in Fig. 1). Asphalt binder (weight 17 g) was poured into a glass dish (diameter 60 mm), and the asphalt binder was heated to the desired temperature in advance using a temperature controlled electric furnace. In this study, the flow height of asphalt binder in diameter 0.2 mm capillary was studied, because self-healing is mainly designed to heal micro cracks in the actual pavement and the capillary phenomenon in such a tube is easier to observe. A digital camera was used to photograph the entire experimental process until the height was no longer increased and the photos were used to calculate the final flow height of the binder.

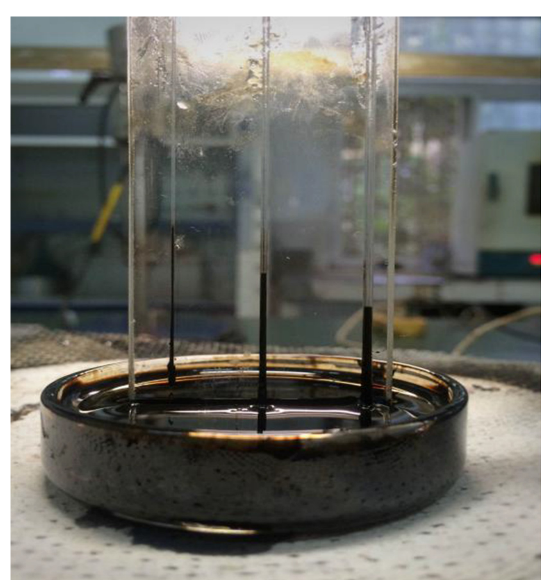

Fig. 1. Apparatus of the capillary test.