Construction and Building Materials 177 (2018) 388–394

Contents lists available at ScienceDirect

Construction and Building Materials

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

Evaluation of moisture and temperature effect on crack healing of asphalt mortar and mixtures using healing agents

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HIGHLIGHTS

- Influence of moisture and temperature on crack healing and rehealing was evaluated.
- Wet cracks of long term aged asphalt materials could be healed using healing agents.
- Moisture infiltration before drying of the healing agents is detrimental to healing.
- Increase in temperature increased crack healing in asphalt materials.
- Water ingress has a nominal effect on the multiple fracture-rehealing performance.

ARTICLE INFO

Article history:
Received 21 January 2018
Received in revised form 19 April 2018
Accepted 4 May 2018

Keywords:
Asphalt pavements
Crack healing
Healing agents
Moisture
Temperature

ABSTRACT

This study investigated the effect of temperature and moisture ingress on the crack healing ability of long term aged AC-13 asphalt mortar and mixtures. Base bitumen emulsion (BBE) and two maltene based cationic emulsions were applied on the cracks of fractured semi-circular samples of the asphalt mortar and mixtures to promote healing. Test results indicated that wet cracks of long term aged asphalt concrete could be healed using healing agents (HAs). Moisture infiltration before drying of the HAs was found to be detrimental to crack healing but initial moisture state of the crack was less influential to the ultimate healing for selected HAs. Increase in temperature increased the extent of crack healing in dry asphalt materials while moisture at 25 °C–45 °C had a minimal effect on crack healing. Water ingress had a nominal effect on the multiple fracture-rehealing performance. Generally, carefully selected HAs applied at higher pavement temperatures have the potential to heal and reheal wet cracks of asphalt pavements provided that sufficient time is allowed for the HAs to dry.

1. Introduction

Asphalt materials are the most popular pavement construction materials worldwide. Flexible pavements constructed using these materials are designed for a service life of about 16 years [1], but premature failure usually occur as a result of traffic loading and environmental factors. Asphalt pavement cracking is considered among the most popular distresses responsible for this failure. It arises due to the decreased relaxation capability of the asphalt binder as a result of aging, moisture damage, temperature variations and repeated traffic loading. Damage usually begin at the microstructure level with the formation of numerous delocalized micro-cracks which progressively interconnect to a network of cracks. Ideally these cracks not only independently impair the structural integrity of the pavement by causing it to act as an incoherent structural unit, but they also prelude to other damages. A related consequence of cracking is the permeation of rain water, capillarity of ground water, and absorption and adsorption of water vapor onto the crack surfaces [2]. This water is trapped by the non-porous seal coats below the surface, and fabrics or interlayers present within the structure [3].

Several studies have demonstrated that cracking of asphalt materials can be reversed autonomously or through stimuli mediated healing strategies. These studies reflect a general consensus among researchers that induction heating [4,5] and microcapsule impregnation [6–11] can successfully heal micro-cracks of asphalt concrete. Micro-capsules and steel wool fibres are added to the asphalt mixtures at the initial construction stage. However, when macro-cracks form or when these materials are not included during the construction stage, additional materials are needed to fill

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https://doi.org/10.1016/j.conbuildmat.2018.05.020
0950-0618/

and seal the cracks, and then promote healing. This could be achieved via seal and heal method using HAs [12–14]. Autogenous healing of bitumen is highly sensitive to aging and moisture conditioning [15]. Mehrara and Khodaii [16] observed that in addition to moisture and aging, temperature also play a key role in crack healing of asphalt materials. The normal force acting on the faces was also found to be critical for healing [17]. The interplay of these factors could be considered realistic for actual pavements.

Crack healing mechanism involves an instantaneous gain in the load transfer ability due to adhesion or cohesion followed by a subsequent long time healing due to molecular diffusion across the interface [18]. These healing mechanisms are influenced by external factors such as presence of adsorbed water on the crack faces and the temperature of the asphalt pavements. Water ingress could cause loss of adhesion and cohesion and thus reduce the healing capacity. Further, healing could be reduced when water interrupts the dipole balance in the mixtures by bonding with the highly polar groups of asphalt molecules or water soluble ions and salts linked to the polar sites of asphalt [19].

The effect of water ingress on asphalt mixtures has been studied extensively using both experimental and computational approaches [20–24]. It is known that moisture can cause damage in asphalt mixtures through detachment, displacement, spontaneous emulsification, pore pressure, pH instability and hydraulic scour [23]. Attempts to recover the properties of moisture damaged asphalt mixtures have also been reported [15,16,25]. Presence of moisture was reported to be detrimental to induction and microwave healing of fiber and/or steel slag reinforced mixtures despite the fact that moisture increased its heating rate [25]. Similarly moisture conditioning was observed to negatively impact both instantaneous and time dependent self-healing of asphalt binders [15]. In contrast, moisture saturated mixtures were reported to recover from fatigue damage when sufficient rest time was allowed [16,24].

Asphalt mortar is richer in bitumen than mixtures and thus it is expected to have a higher healing effect compared to mixtures. When subjected to water and temperature changes, mortar and mixtures could show a difference in the healing performance. The goal of this work was to evaluate the effect of moisture ingress, temperature, and their combined effect on crack healing of asphalt mortar and mixtures using healing/rejuvenating agents. Base bitumen emulsion (BBE) and maltene based cationic emulsions were used to heal cracks of fractured semi-circular samples of AC-13 asphalt mortar and mixtures. Moisture conditioning was carried out to assess the effect of the initial moisture state of the crack on healing. In addition, crack healing was conducted at different temperatures in both dry and wet conditions in order to evaluate the effect of the ambient conditions on healing. Finally, the effect of temperature and moisture on multiple fracture-rehealing performance of the asphalt mortar and mixtures was evaluated. The healing level was quantified by a healing index (HI) defined as the ratio of the recovered peak strength after healing (F_h) to the initial peak strength (F_i) according to Eq. (1).

$$HI = \frac{F_h}{F_i} \times 100 \quad (1)$$

2. Materials and experimental procedures

2.1. Materials

SBS modified asphalt cement with a viscosity of 0.645 Pa·s at 135 °C, penetration value of 73 dmm, ductility of 52 cm at 5 °C and softening point of 68.0 °C was used as the binder. The optimum binder content of AC-13 asphalt mortar and mixtures was determined as 9.2% and 4.7% respectively using Marshall design criteria with specimens compacted with 75 blows per face. Crushed basalt aggregates with Los Angeles abrasion value, crushed stone value, flakiness and elongation index and specific gravity of 7.8%, 12.0%, 8.5% and 2.961 g/cm^3 respectively were selected to fabricate AC-13 asphalt mortar and mixtures. The gradation of the mortar and mixtures was determined according to JTG E20-2011 [26]. For mixture samples, the passing percentage at sieves of sizes 16, 13.2, 9.5, 4.75, 2.36, 1.18, 0.6, 0.3, 0.15 and 0.075 mm were 100%, 95.1%, 76.5%, 53.2%, 37.1%, 26.5%, 19.2%, 13.5%, 9.9% and 5.8% respectively. For mortar samples, the passing percentage at sieve sizes 4.75, 2.36, 1.18, 0.6, 0.3, 0.15 and 0.075 mm was 100%, 66.8%, 50.2%, 32.8%, 22.5%, 14.5% and 9.6%. Limestone powder with a density of 2.83 g/cm^3 and chemical composition of 51.8% CaO, 3.49% SiO_2 and 1.29% Al_2O_3 was used as the mineral filler.

Two maltene based pavement maintenance cationic emulsions with a high content of aromatics were selected for this study. They were labelled as HA-2 and HA-3. In addition, base asphalt emulsion (BBE) was also used as a HA. The SARAs (saturates, aromatics, resins and asphaltenes) composition of the residue of the HAs as determined by means of thin-layer chromatography, and the viscosity of their emulsions and residue at 25 and 60 °C respectively are summarized in Table 1. More detailed information on the HAs can be found in [14].

2.2. Sample preparation

Semi-circular bending test (SCB) specimens of long term aged (LTA) mixtures and their associated mortars were fabricated. Aging of the mixtures was done at according to AASHTO R30 [27] while mortar samples were prepared from loose mortar aged in a force draft oven at 100 °C for 96 h [28]. Tests done on the binder extracted from the aged mortar and mixtures showed that the aging of mortar was equivalent to that of mixtures. Marshall specimens of approximately 10 cm diameter and 63 mm height were prepared from the aged mortar and mixtures. From these specimens, notched SCB samples of 100 mm diameter with a notch 4 mm thick and 10 mm deep were prepared.

2.3. Application of the healing agents

When HAs are applied on the cracks, they seep through the open cracks, fully fill and seal the macro-cracks, and adhere strongly to the crack faces. To simulate this, a soft brush was used to apply the HAs on the cracked surfaces at a spreading rate ranging from 0.4 to 0.7 kg/m^2. This rate was found appropriate in order to avoid excessive bleeding of the agents. Fig. 1 shows the appearance of the crack faces before and after application of the HAs. During the healing process all samples were stored in a direction normal to the cracked surface so that the weight of the upper half could squeeze out any excessive HA.

2.4. Sample testing

Fig. 2 shows an overview of the experimental testing plan. Testing was conducted in three sections: tests on the healing performance of control samples, tests on the effect of initial moisture state of the crack on healing, and tests on the effect of temperature and moisture on the multiple fracture-rehealing performance of the asphalt mortar and mixtures. A universal testing machine (UTM-25) was used to conduct SCB tests on the samples at a temperature of −10 °C and a loading rate of 0.5 mm/min. Before testing, the samples were preconditioned at −10 °C for 4 h in a temperature chamber. Our previous study showed that this was necessary in order to avoid creep deformation and to create a brittle fracture on the samples. Detailed information about the test set up can be found in [14]. For each test, a minimum of three replicates were tested. A total of 230 samples were prepared and over 1150 tests were carried out in this study.

2.4.1. Testing on the healing performance of the control samples without HAs

In this test, no HA was applied on the control samples. One set of samples was healed in air while another set was healed under water. Both sets were healed at 25 °C for 1 or 4 days. After the designated healing time, an SCB test was done on the samples.

2.4.2. Tests on the effect of the initial moisture states of the crack on healing

Dry and wet moisture states of asphalt mixture cracks before and after application of HAs were simulated in this study. Three sets of samples with three replicates each were used in this test. In the first set (set 1), the completely broken samples were moisture conditioned, after which the HAs were applied on the crack faces. In the second set (set 2), HAs were applied on dry crack faces and then the samples were moisture conditioned. In the third set (set 3), the HAs were applied on the dry cracks with no moisture conditioning. Moisture conditioning was done by immersing the broken asphalt mixture samples in water at 25 °C for 3 h [20,29]. All the samples were then carefully placed together, allowed to heal in air at 25 °C for 1 day and then tested.

2.4.3. Test on temperature and water immersion effect on multiple fracture-rehealing

A treated pavement is usually opened to traffic shortly after the application of the HAs. This exposes the pavement to dynamic loading which then interrupts the healing process via continuous refracture and rehealing processes. During the