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Experimental assessment of the long-time crack healing in asphalt mixtures using healing agents

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HIGHLIGHTS

- Maltene based healing agents had a promising healing effect.
- Ultimate healing index depends on the healing agent, healing time and mixture aging.
- Healing in the initial stage had the highest contribution to the ultimate healing.
- Gain in peak strength preceded the recovery of fracture energy.
- Long-term healing was insensitive to the frequency of fracture-rehealing cycles.

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ABSTRACT

This study reports the long-term crack healing effect of five healing agents (HAs) applied on fractured semi-circular bending test samples of AC-13 asphalt mixtures. A multiple fracture-rehealing test was adopted to simulate the effect of crack opening and closing on treated asphalt pavements. Test results showed that healing was most rapid in the initial stage (0–4 days), it slowed down in the intermediate stage (4–60 days) and formed a plateau in the tertiary stage (60–120 days). Healing in the initial 4 days had the highest contribution to the ultimate healing. Maltene based HAs had a better healing effect than traditional asphalt emulsions. More than 80% of the peak strength and 70% of the fracture energy could be recovered after long-time healing. The ultimate healing was dependent on the type of the HA, healing time and aging of mixture but it was less sensitive to the frequency of the initial multiple fracture-rehealing cycles. Gain in peak strength preceded the recovery of fracture energy. The time needed to attain the optimum healing was dependent on the type of the HA and not the aging of the mixture. Generally, carefully selected HAs have the potential to heal cracks in asphalt pavements.

1. Introduction

Asphalt is an essential construction material for flexible pavements worldwide. Dense-graded asphalt pavements are usually designed to have a service life of about 15–20 years [1,2]. However, the service life is reduced when cracks occur as a result of traffic loading and environmental factors. Cracks weaken the structural performance of the pavement and also increase its vulnerability to moisture induced damage [3]. Cracking is more likely to happen at low temperatures especially after pavement aging. Both of these effects make asphalt brittle, reduce its relaxation capability and increase its sensitivity to fatigue damage. Nonetheless, top-down cracking can occur in hot climates with high average temperatures [4,5]. Asphalt is a self-healing material and thus repairs itself [6,7]. The extension of fatigue life and recovery of dissipated energy due to the self-healing potential of asphaltic materials have been reported [8]. Self-healing of asphalt is a complex physical process, which depends on the flow characteristics of asphalt binder on the crack surfaces [9,10]. When sufficient rest time is allowed, self-healing is activated at elevated temperatures. However, in real field conditions, low ambient temperatures and continuous traffic flow impedes self-healing.

Some innovative technologies have been proposed that would take advantage of the self-healing capacity of asphalt, by developing self-healing and long-lasting pavements. The main idea behind

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these technologies is to soften the binding system in between the solid particles in asphalt mixtures. Thus, the binding system then can flow across the micro-cracks and repair the damaged areas. Micro-cracks healing via induction heating [11–17], microwave heating [18–20] and embedding microcapsules containing rejuvenators in asphaltic materials [21–27] are the most studied technologies to activate or improve the healing potential of asphalt pavements. Moreover, in order to promote the macro-cracks healing of asphalt pavements, additional sealing materials are usually used to fill and seal the cracks. However, this technique often fails due to the weak adhesion between the fillers/sealants and the crack surfaces [28], and for this reason, the use of healing agents and spraying of them has been proposed [29–32]. Nonetheless, a recent study done by Franesqui et al. indicated that top-down macro-cracks could be healed by using the combining method of metallic additions and microwave heating [19].

The healing mechanism of asphalt materials using healing agents (HAs) is strongly related to diffusion and capillarity of the bituminous materials [10,29,33–36]. Both transport mechanisms are dependent on time, concentration gradient of the light components in the HAs and the degree of swelling of the asphaltenes in the binder [34]. Flow of the HAs is initially rapid, and later proceed at a slow pace in the terminal stages [36]. The short-term recovery of the mechanical properties of cracked or fatigued bituminous materials could be attributed to initial flow of the HAs. Nonetheless, recovery of the mechanical properties proceeds over a relatively long-period of time. Although the short-term recovery of mechanical properties is well documented, the evolution of the terminal healing due to the HAs has not been explored.

The main objective of this study was to evaluate the long-term crack healing performance of HAs in asphalt mixtures. Cracked semicircular AC-13 asphalt mixtures were healed with five HAs. The effect of crack opening and closing on freshly healed asphalt pavements was simulated using a multiple fracture-rehealing cycles and its impact on long-term healing was investigated. The effect of aging as well as the time required for the treated aged and unaged asphalt mixtures to attain the maximum healing index was also investigated. Finally, the rehealing ability of the treated mixtures after a preceding long-term healing was assessed.

2. Materials and experimental program

2.1. Materials

Crushed basalt aggregates were used to prepare AC-13 asphalt mixtures. Table 1 shows the gradation of the aggregates as determined from JTG E20-2011 [37] and the properties of the basalt aggregates and limestone filler. SBS modified asphalt with a penetration value of 7.3 mm, viscosity of 0.645 Pa.s at 135 °C, ductility of 52.1 at 5 °C and softening point of 68 °C was used as the binder. The optimum asphalt content of the mixtures was determined as 4.7% based on the Marshall design method with specimens compacted with 75 blows per face. Base asphalt emulsion (BBE), SBR modified asphalt emulsion (SBRE) and three maltene based pavement maintenance cationic emulsions (HA-1, HA-2, and HA-3) were used as HAs. BBE and SBRE are standard emulsions commonly used for surface treatments (chip seals, micro-surfacing and flush coats) of asphalt pavements. HA-1, HA-2, and HA-3 are commercial pavement maintenance materials with high content of aromatics. Aromatics are reported to be important for the self-healing of asphalt [38–40]. The SARAs (saturates, aromatics, resins and asphaltenes) composition and the viscosity of the emulsions and residues of the HAs are shown in Table 2.

2.2. Sample preparation

Three types of asphalt mixtures: unaged (UA), short-term aged (STA) and long-term aged (LTA) were used in this study. The aging processes were conducted according to AASHTO R30 [41]. The mixtures were compacted using a Superpave gyratory compactor (Model-4140, USA). 100 mm diameter samples were cored from the gyratory samples. Semi-circular bending samples (SCB) of dimensions 25 mm thickness and 100 mm diameter were then fabricated according to AASHTO TP105 [42]. Before testing, the SCB samples were preconditioned at −10 °C for 4 h to create a brittle fracture and to avoid creep deformation [14,15,28]. Fractured samples were allowed to attain room temperature (25 °C). A soft brush was used to apply the HAs on the fractured surfaces at a rate ranging from 0.4 to 0.7 kg/m^2, to avoid excessive bleeding of the agents. Because HAs had different viscosities and residue contents, the effective HA content that remained on the treated surfaces varied from 0.25 to 0.35 kg/m^2. The difference in the effective HA content was considered to be small enough not to have any significant influence on crack healing. The samples were then carefully placed together and stored in a direction normal to the cracked surface, so that the weight of the upper half of the sample would squeeze out any excessive HA. Detailed information about the sample preparation could be found in [30].

2.3. Experimental program

Treated asphalt pavement are usually opened to traffic shortly after the application of the HAs. This exposes the pavements to dynamic loading which could cause opening and closing of the treated cracks. This effect interrupts the initial healing process especially in the initial 4 days of healing when the HAs are soft [30] and their load transfer and bearing capability is limited. As the agents dry, the opening and closing of the treated crack is expected to reduce. To simulate this effect and assess its impact on long-term healing of the asphalt mixtures, a multiple fracture-rehealing test was designed.

Fig. 1 describes the experimental program for this research. The test samples (UA, STA and LTA) were first divided in two groups. HAs were applied to one group and no HA was applied to the other (control). All samples were healed for either 1, 2, 4 or 8 days at 25 °C and then tested (cycle 1). The samples with HAs were carefully put together (without re-application of the HAs), allowed to heal for the same duration as in cycle 1 and then tested. The same fracture-reheal process (for either the 1, 2, 4 or 8 day samples) was repeated four times (4 cycles). Later each group (with and without HAs) was subdivided further into five sub-groups and then conditioned at room temperature (25 °C) for 15, 30, 60, 90 and 120 days of uninterrupted healing. To assess the rehealing performance of samples fractured after long-term healing, the samples tested after 90 days of healing were carefully placed together and re-tested after a further 30 days of healing. In this study, each data point is the average of the test results of three replicate samples.

Healing was evaluated based on the recovery of peak strength and fracture energy properties. Peak strength is the maximum loading force in the force–displacement curves while fracture energy is sum of the energy required to break the molecular forces and the energy dissipated due to the plastic or viscoelastic

Table 1
Gradation and properties of basalt aggregates and limestone filler.

Sieve size (mm)	Gradation Passing % Basalt aggregates	 Limestone filler	Properties Basalt aggregate	Value
16	100		Crushed stone value (%)	12
13.2	95.1		Los Angeles abrasion value (%)	7.8
9.5	76.5		Flakiness & elongation index (%)	8.5
4.75	53.2		Specific gravity (g/cm^3)	2.96
2.36	37.1		**Limestone filler**	
1.18	26.5		Density (g/cm^3)	2.83
0.6	19.2		Chemical composition	
0.3	13.5	100	CaO (%)	51.8
0.15	9.9	93.0	SiO$_2$ (%)	3.49
0.075	5.8	86.0	Al$_2$O$_3$ (%)	1.29