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INVESTIGATION OF THE POTENTIAL USE OF CALCIUM ALGINATE CAPSULES FOR SELF-HEALING IN POROUS ASPHALT

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Abstract

Incorporating self-healing technology in asphalt pavement has been demonstrated to have great potential to prolong its service life. To this aim, the calcium alginate capsules encapsulating rejuvenator were manufactured and proved to have sufficient thermal stability and mechanical resistance to survive the asphalt production and compaction process. In this research, the healing effect of calcium alginate capsules were investigated in porous asphalt concrete. X-ray computed tomography (XCT) was used to visualize the distribution of capsules in porous asphalt concrete. A damaging and healing programme was carried out to evaluate the healing efficiency of these capsules. Semi-circular bending (SCB) tests was employed as a damaging process to investigate the fracture resistance of the porous asphalt concrete samples. The results showed that calcium alginate capsules were able to improve the healing capacity of porous asphalt concrete.

1. INTRODUCTION

Embedded rejuvenator encapsulation method provides an extrinsic solution for self-healing asphalt [1]. The concept is to add encapsulated healing agent(rejuvenator) in the asphalt mix, allowing the release of encapsulated healing agent on demand(upon cracking) and healing the crack by softening the aged binder allowing it flow which in turn closes the crack and repairs the damage [2]. To this aim, several encapsulation methods are developed, including epoxy capsules [3], Melamine-formaldehyde(MMF) modified capsules [4], calcium alginate capsules [2] and alginate fibres [5]. Among them, the calcium alginate capsules have the advantages of simple production process, low cost, environmental friendly and ability to encapsulate higher amounts of rejuvenator, which shows great potential for the application in self-healing asphalt [5, 6].

In a previous paper, Xu et al [2] successfully prepared calcium alginate capsules (Figure 1). The X-ray tomography image of the capsule indicates that the calcium alginate capsules have a special porous structure instead of a traditional core-shell structure, which small rejuvenator droplets are encapsulated by porous media within the shell. The capsules thermal stability and compressive resistance were tested through thermogravimetric analysis (TGA) and micro-compressive tests . Xu et al [2] showed that the calcium alginate capsules are able to survive the asphalt production and compaction process. Furthermore, the healing effect of these capsules were investigated with a three-point-bending testing and healing programme on asphalt mastic beams. The results indicated that the healing capacity of asphalt mastic beams with calcium alginate capsules are significantly higher than reference beams.

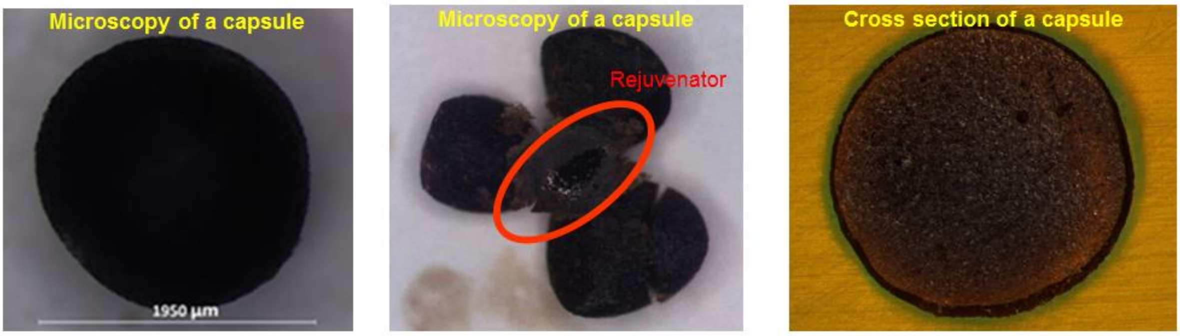

FIGURE 1 Calcium alginate capsules prepared by Xu et al [2]

The previous paper [2] generally explored the potential use of calcium alginate capsules in self-healing asphalt by investigating the capsule properties and the healing effect in mastic. However, the efficiency of the calcium alginate capsule encapsulating rejuvenator healing system in a full asphalt mix is unknown. Therefore, the objective of this study was to investigate how calcium alginate capsules encapsulating rejuvenator affect the healing capacity of porous asphalt concrete. To this aim, a porous asphalt mix with capsules was designed and compacted. A porous asphalt mixture without capsules was used as reference mixture. The distribution of the calcium alginate capsules was investigated by XCT. The healing capacity of the porous asphalt mix was evaluated by a testing and healing programme based on SCB tests.

2. RESEARCH METHODOLOGY

2.1 Porous asphalt concrete

The mix design of porous asphalt concrete based on the standard porous asphalt mix PA 0/11. The capsules were added in the porous asphalt mix by replacing 7% volume of the bitumen which followed the optimum percentage of capsules from previous research [2].

2.2 XCT

A Phoenix Nanotom CT scanner was employed in order to investigate the distribution of calcium alginate capsules in the porous asphalt mix. To fit the lateral dimension of the small porous asphalt cylinder, the resolution was set as 20 µm between each computed voxels.

2.3 SCB tests

The SCB tests were performed according to EN 12697-44:2010. The SCB samples had a diameter of 100±2 mm, thickness of 50±1 mm and radius of 50±1 mm. A notch was placed in the middle of each sample, with a notch length of 10±0.2 mm and width of 3±0.1 mm. The loading speed was set as 5 mm/min. In order to achieve a brittle fracture from the notch throughout the test specimen, the SCB tests were performed in a temperature controlled chamber at 0ºC.

2.4 Healing efficiency evaluation

In this research, evaluation of the healing efficiency was conducted with a testing and healing programme based on SCB tests. To evaluate the healing efficiency of a SCB specimen:

1. Firstly, the initial peak load of the specimen were measured by the first SCB test;

2. Then, the fractured specimen was spliced to close the fracture face and conditioned at 23 ºC for 20 h on a plain surface. In order to create a constant confinement to ensure the close of cracked surfaces, the specimens were carefully wrapped with tape during the healing process;
3. Subsequently, the second SCB test was performed to acquire the regained peak load of the specimen after healing. Afterwards, step 2 was repeated to perform another healing cycle following by the third SCB test.

Healing efficiency of the specimen was determined using healing index(HI), which was calculated with the peak load measured from three SCB tests (1).

$$\mathrm{HI} = \frac{C_x}{C_1} \tag{1}$$

Where:
HI=the healing index (%),
C1=original peak load of the sample;
Cx= fracture property after x cycles of healing.

3. RESULTS AND DISCUSSION

3.1 XCT

Figure 2 shows a slice of XCT scanning image of the porous asphalt sample. The XCT image clearly illustrate the porous structure and the material distribution of the porous asphalt mix. The calcium alginate capsules, which recognized as black round spots, are distributed in the porous structure together with asphalt mastic. The capsules within the structure preserve perfect round shape, which indicate that capsules are not damaged from the porous asphalt manufacture process.

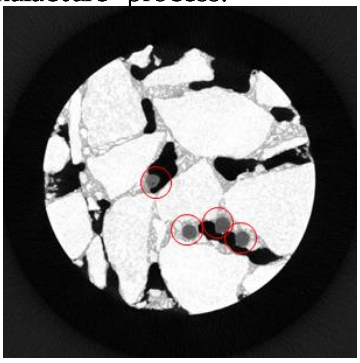

FIGURE 2 A slice of XCT image of porous asphalt concrete

3.2 SCB fracture face

The fracture surface of a SCB specimen with capsules is shown in Figure 3. As shown in Figure 3, broken capsules can be found on both sides of the fractured beams, which indicates that the capsules are able to break upon propagation of cracks. On the other hand, presences of these capsules demonstrate that the calcium alginate capsules have not been crushed by mixing or compaction in this research, which indicates a huge potential for the application in field construction.

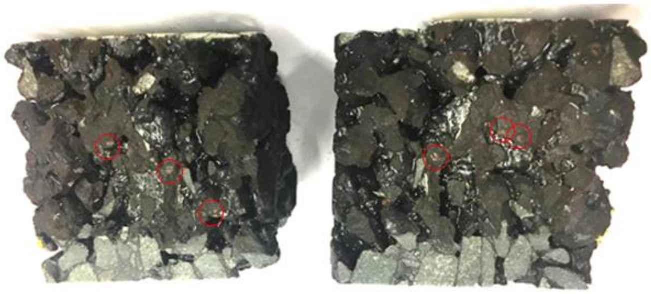

FIGURE 3 Fracture surface of a SCB specimen with 7% capsules

3.3 Healing efficiency

In this research, the healing efficiency was evaluated by the peak load healing ratio during rest periods. The healing results are presented in Figure 4. The results show that the SCB specimens with capsules are able to restore 19.3% of the initial peak force, which is 6% higher than the specimens without capsules. In the third time SCB tests, SCB specimens with capsules can still achieve a healing ratio of 14.3%. Without capsules, the healing effect is only 9.9%. Figure 4 also illustrates that even with calcium alginate capsules, the healing effect on such a serious fracture is very limited. Although the application of calcium alginate capsules largely improved the healing capacity, the limitation of these capsules as well as other rejuvenation methods lies on the damage level. The calcium alginate capsules are more capable of micro-crack healing, aimed to close crack at early stage thus preventing serious defect in asphalt pavement. In this way, the calcium alginate capsules possess a healing potential in the application in construction field.

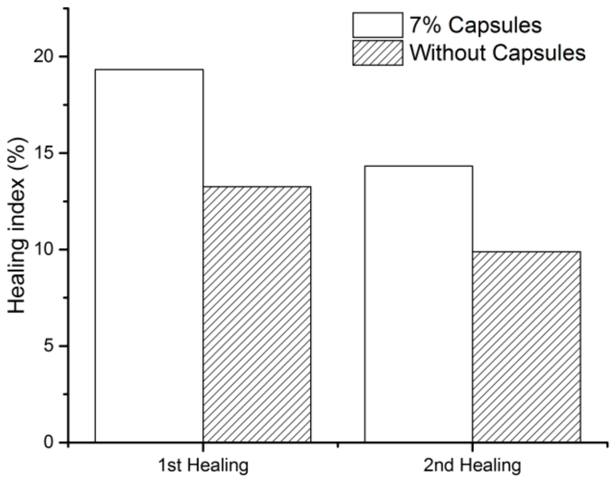

FIGURE 4 Healing index of SCB specimens

4. CONCLUSIONS

This study explores the potential use of calcium alginate in porous asphalt and following conclusions are drawn:

- XCT is an effective method to analyze the structure and material distribution in porous asphalt mix. In XCT images, the presence of capsules in the porous asphalt mix demonstrate that calcium alginate capsules are able to survive asphalt manufacture process;
- After SCB tests, the presence of capsules on the fracture surfaces indicates that calcium alginate capsules are able to fracture upon the initiation and propagation of cracks. By this means, the encapsulated rejuvenator are able to release and heal the damage site;
- In the SCB testing and healing programme, samples with capsules are able to achieve a healing index that is 6% higher than the reference samples, which means addition of calcium alginate capsules improves the healing capacity of asphalt. However, samples with capsules could only achieve a maximum healing index of 19% in the healing cycles, which indicates that if the damage beyond the healing capacity, the calcium alginate capsules are not able to recover all the loosing properties especially interlocking effect between aggregates.

5. RECOMMONDATIONS

This research explores the potential use of calcium alginate capsules in porous asphalt concrete, the authors will continue the research on fatigue healing effect from these capsules. Compares to the induction healing method, calcium alginate capsules show limit healing effect on fracture damage. Thus, the future research will be conducted on the development of a combined healing system which calcium alginate capsules are incorporated in induction healing to achieve an optimum healing which combines both effective crack healing and aged binder rejuvenation.

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