Self-Healing Bitumen Using Biomimetic Capillaries Hollow Fibers: Fabrication, Microstructure and Properties

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ABSTRACT

Bituminous pavement has a self-healing capability to restore its stiffness and strength by closing the microcracks, which occur when the pavement is subjected to traffic loads. However, this self-healing capability will be ruined with the aging of bituminous material. To date, several approaches have been carried out to improve the self-healing capacity of the asphalt. These technologies deal for instance with polymer blends, nano-particles, induction heating and rejuvenation from outside or from inside by adding rejuvenator in microcapsules or fibers. The aim of this work was to fabricate biomimetic capillaries hollow fibers containing rejuvenator for self-healing asphalt. Microstructures of these hollow fibers were investigated. Moreover, bitumen samples were formed mixing with different weight contents of hollow fibers. Tests were carried out to observe the morphology, integrity, distribution, thermal stability, interface bonding and triggered rupture of microcapsules in bitumen. Fluorescence microscope morphologies showed that microcapsules survived in bitumen resisting high temperature and strong agitation without premature damage. In bitumen samples, hollow fibers still kept a stable state after the extreme temperature change. At the same time, it was found that the hollow fibers improved the mechanical properties of bitumen samples. Interface debonding phenomenon did not appear. Microscopic observation results reflected that hollow fibers could be pierced by microcracks in the asphalt binder and the encapsulated rejuvenator could flow out under the force of capillary action.

1. INTRODUCTION

Asphalt is widely used pavement material. Because of the effect of natural environment, loading and other factors, asphalt becomes brittle and microcracks will generate in the asphalt pavement [1]. It is well known that bitumen has a self-healing naturality. Its capability of self-healing is associated with temperature, healing time and aging degree of itself. The aging problem of bitumen will damage the asphalt original properties. Comparing with the deterioration process, this healing capacity of bitumen is not enough to repair the damage like surface raveling and reflective cracking which are caused by aging. Therefore, several methods have been used to improve the self-healing capability of bituminous materials, including rejuvenation, polymer blend, heating induction, and nanoparticles. It has been found that microcapsules containing rejuvenator is one of the most effective methods [2]. Encapsulation rejuvenator mixed in bitumen is an alternative method not only to promote repair capacity but also overcome the disadvantages of oily rejuvenator. When microcracks encounter capsules in the propagation and open them, the rejuvenating agents fill the cracks with the help of capillarity; at the same time the released rejuvenator reconstitutes the asphalt binder's chemical composition caused by aging. In order to obtain higher compact shells, we have fabricated self-healing microcapsules with a methanol modified melamine-formaldehyde resin as shell material which was synthesized through a two-step polymerization [3, 4]. The formation of shells would be a two-step coacervation due to the interfacial equilibrium. The rigidity and toughness of shells was promoted by using MMF resin. Although this method has been proved to be an ideal way to enhance the self-healing capability of asphalt, it still has several disadvantages. The microencapsulated rejuvenator may not enough for a larger microcrack of asphalt. The fabrication of microcapsules may not easy to control.

The possibility of mimicking desirable properties from nature accelerates material improvement and generates commercial interests. Figure 1 illustrates of self-healing bitumen using biomimetic capillaries hollow fibers For human body, ruptures of biomimetic capillaries can self-heal because of the blood. Inspired by bionics, hollow fibers containing healing agents have been reported as a material to heal a crack in materials [5]. However, the fibers were not fabricated by one step spinning process. The diameter, length and content of agent can not be controlled easily. These hollow fibers had low mechanical properties and degradation, which are not suit for self-healing of asphalt. In this study, we fabricated self-healing hollow fibers containing rejuvenator using spinning technology. The fiber material is poly (vinylidene fluoride) (PVDF). Figure 2 (a, b) show the one step spinning process of hollow fibers containing rejuvenator. Figure 2 (c, d) show the hollow fibers without and with rejuvenator. The fibers has a thermal degradation is higher than 390 ^{o}C and its ultimate tensile strength is 59 Mpa.

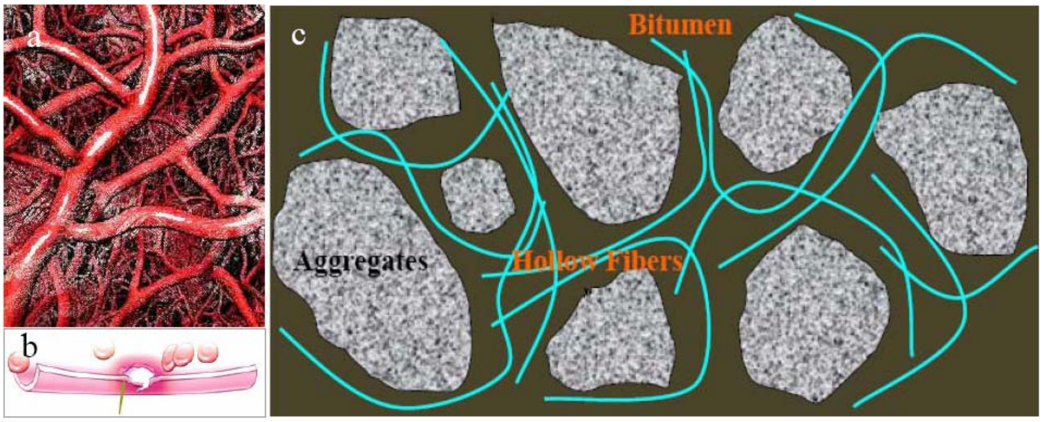

Figure 1 Illustration of self-healing bitumen using biomimetic capillaries hollow fibers, (a) biomimetic capillaries, (b) a rupture of a biomimetic capillary, and (c) the self-healing asphalt using hollow fibers containing rejuvenator.

2. EXPERIMENTAL METHOD

The hollow fibers were prepared using PVDF by a spinning technology. PVDF in pelletized form was dissolved in γ-BL solvent to prepare a 40 wt% solution. A clear and homogeneous dopesolution was achieved at 140^{o}C. For the spinning after degasification, the dope solution was transported to a spinning nozzle by a gear pump. Fig.2(a, b) show the process of spinning technology of hollow fibers containing rejuvenator. Fig.2(c, d) are hollow fibers without rejuvenator and with rejuvenator.

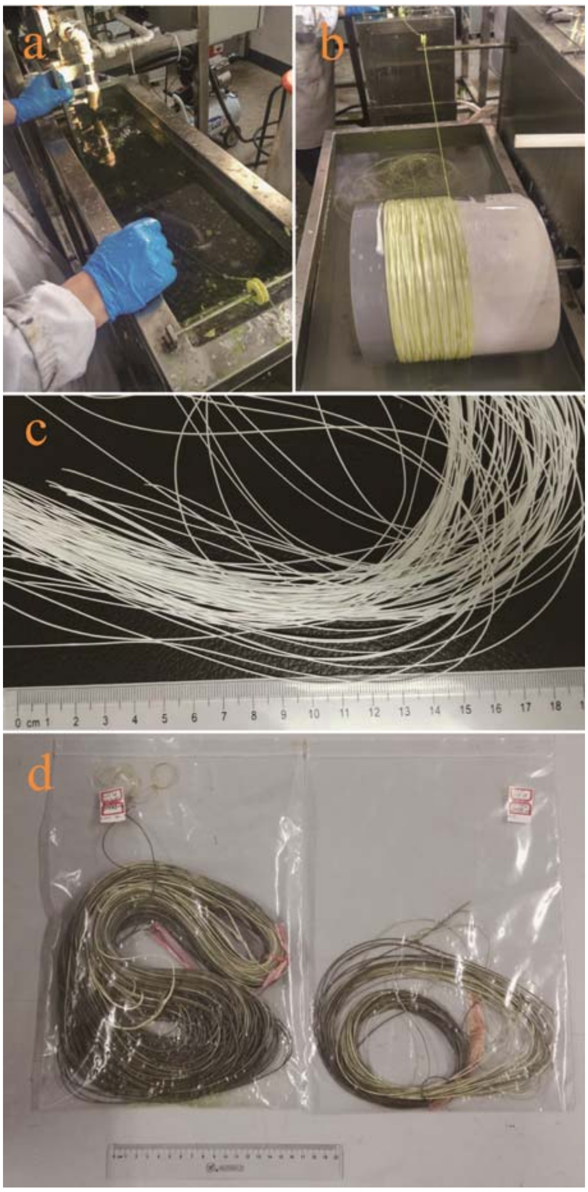

Figure 2 Spinning technology of hollow fibers containing rejuvenator, (a, b) the one step spinning process of hollow fibers containing rejuvenator, (c) hollow fibers without rejuvenator, and (d) hollow fibers with rejuvenator.

3. RESULTS

The hollow fibers were cut into fixed length automatically and both ends were sealed with thermosetting glue. These fibers were mixed in bitumen forming composites samples. Figure 3(a) shows a ruptured bitumen sample. Fibers are distributed homogeneously in bitumen. In the fracture surface, all fibers were broken by the breaking power (Figure 3b). Outflow phenomenon of rejuvenator is observed, which is used the capillarity instantaneous blowing out the liquid, largely promotes the handling ability (Figure 3c).

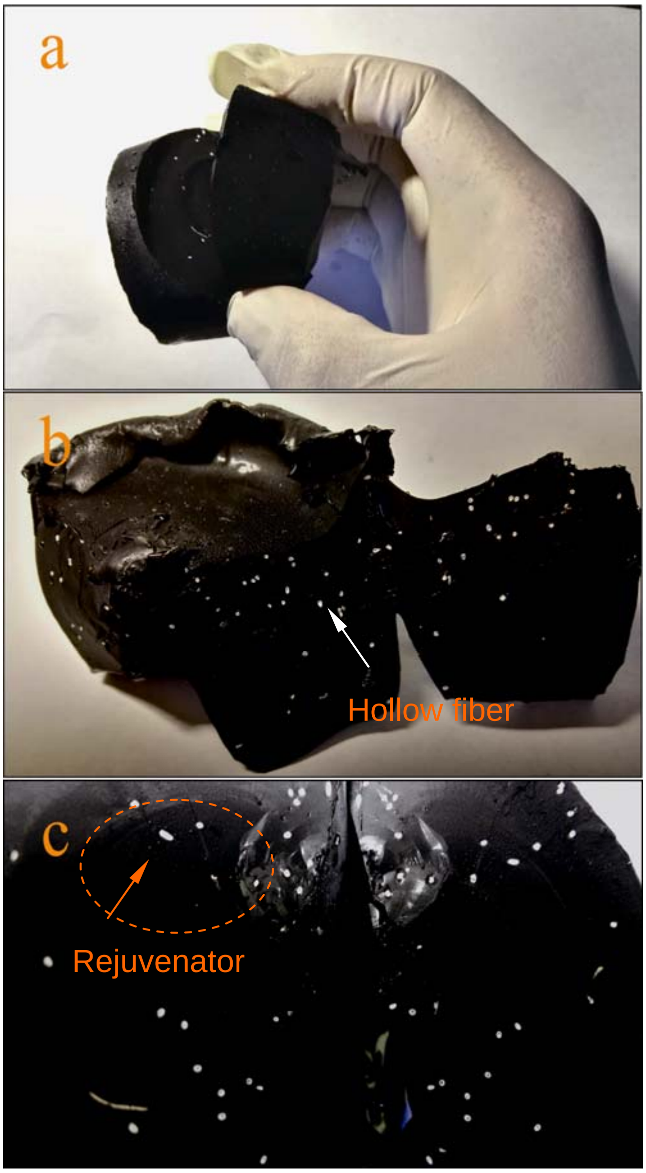

Figure 3 Photographs of bitumen/hollow fibers composites, (a) a rapture of a bitumen sample, (b) hollow fibers break, and (c) rejuvenator flow out from hollow fibers.

4. CONCLUSIONS

Self-healing hollow fibers containing rejuvenator for bitumen were successfully fabricated by a spinning method using PVDF as fiber material. The fibers survived in hot bitumen without break with a good thermal stability. The fibers were reputed by the crack in bitumen and rejuvenator flowed outside of fibers. All these results indicate that the hollow fiber containing rejuvenator is a promising material for enhancing the self-healing capability of aged bitumen. Future works will be carried out to optimize the microstructure of fiber/bitumen composites and investigate the micromechanical of self-healing behaviors.

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