Research Progress on Self-Healing and Repairing Technology of Asphalt Mixture Crack

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Abstract. The latest research results at home and abroad have comprehensively analyzed the self-healing and repairing technology of asphalt mixture, and introduced the self-healing mechanism of asphalt and self-healing behavior of asphalt. Active and passive healing methods are mainly discussed. Both methods can effectively enhance the healing properties of asphalt materials and achieve the purpose of repairing cracks and looseness of asphalt concrete pavement. The development of self-healing asphalt concrete technology at home and abroad is expounded, and the application significance and application prospect of the technology are analyzed. The conclusion is that the environmental and social benefits of self-healing asphalt concrete technology are outstanding, and the promotion is of great significance and good development prospects.

1. Study on Self-Healing Mechanism of Asphalt Mixture

After the fatigue damage of the asphalt, micro cracks appear inside, and gradually develop and penetrate to form macroscopic cracks, which leads to the occurrence of diseases such as fatigue cracking of asphalt pavement [1].

In 1967, Bazin et al. [2] found that the asphalt has self-healing properties. After the fatigue damage, it introduces a period of intermittent time, and the internal micro-cracks gradually disappear, and the strength and rigidity also recover to some extent. The self-healing behavior of asphalt is an extremely complicated physical and chemical process. It is essentially the wetting, adsorption and diffusion behavior of asphalt molecules at the crack interface to reduce the surface energy. It is also a key factor to inhibit the crack propagation of asphalt pavement and extend the fatigue life of asphalt pavements [3].

In the early years, the researchers used traditional fatigue or mechanical tests to evaluate the self-healing properties of asphalt. A gap time was introduced in the test, and the self-healing properties of the asphalt were evaluated by the recovery degree of the mechanical properties of the asphalt after the gap time [4]. Although the traditional macroscopic test can evaluate the self-healing properties of asphalt, it is difficult to analyze its internal healing mechanism. Therefore, Lytton et al. established the relationship between the joint speed of asphalt crack interface and surface energy based on Schperry fracture mechanics, and believed that the reduction of surface energy of crack interface is the source of power for the self-healing of asphalt. The traditional surface energy theory regards asphalt as a continuous medium for research. However, in fact, the internal composition and structure of asphalt are very complicated. There are certain limitations in analyzing the self-healing mechanism of asphalt from a macroscopic point of view [5].

In recent years, researchers have come to realize that complex composition changes and structural changes in asphalt have an impact on the self-healing properties of asphalt. They have begun to study the microstructure of asphalt by means of advanced testing equipment, such as fluorescence microsco-
Atomic force microscopy has become a powerful tool for the study of asphalt microstructure due to its high resolution and low requirements for detection environment. In 1996, Loeber et al. [6] first observed the microstructure of asphalt based on atomic force microscopy (Atomic Force Microscope) and named the observed "group-like" phase as "bee-like structure". Subsequently, Pauli, Jager et al. [7,8] found the existence of "bee-like structures" in asphalt based on AFM technology, and Pauli, Jager (etc. [7,9] considered the initiation, propagation and healing of microcracks inside the asphalt. Internal phase changes are closely related.

Wool et al. believe that polymer healing involves five stages: (1) surface reorganization, (2) surface proximity, (3) surface wetting, (4) interfacial diffusion, and (5) molecular diffusion causing structural reorganization until balance. Wetting and diffusion are the key processes for the self-healing of asphalt properties. Wetting and diffusion are the key processes for the self-healing of asphalt properties. On this basis, Phillips proposed three stages of asphalt healing: (1) the combination of stress and asphalt flow leads to the closure of micro-cracks; (2) the surface energy drives the micro-crack closure caused by the adhesion of crack surfaces; (3) Recovery of mechanical properties caused by diffusion of the asphalt group structure.

Smith et al. considered that among the three stages proposed by Phillips, stage (1) was the fastest, but only the stiffness of the material was restored, and stage (2) and stage (3) proceeded very slowly, but the stiffness and strength of the material can be restored to the original level.

In recent years, with the continuous improvement of computer technology, molecular simulation technology has begun to be applied to simulate the structure and properties of asphalt molecules. Domestic and foreign scholars have determined the structural models of asphalt (matrix asphalt and modified asphalt). The stable phase is obtained by the relaxation process [10]. The molecular dynamics (MD) theory is used to simulate the trajectory of the asphalt molecular structure under different ensemble conditions. The mean square displacement (MSD) and the mean slope of the mean square displacement (MSD) can be obtained. The diffusion coefficient $D$ has a relationship as shown in the formula (1).

$$D = \frac{\alpha}{6}$$  \hspace{1cm} (1)

Where: $\alpha$ is the limit slope of the mean square displacement (MSD), and the unit is $10^{-4}$ cm$^2$/s.

The advantage of the molecular diffusion model is that it can qualitatively evaluate the self-healing behavior of different types of asphalt (matrix asphalt and modified asphalt), but the rationality of asphalt molecular structure and model parameters needs further study.

The research on self-healing properties of asphalt materials is still in the theoretical stage. How to improve the self-healing efficiency of asphalt materials, so that the road surface subjected to fatigue damage during actual use can self-heal in time and effectively become a research topic of many scholars. Existing asphalt self-healing techniques can be divided into active and passive depending on whether an additional energy field is required.

2. Active

2.1. Microcapsule Technology

White et al [11] first proposed self-healing concept and core-shell structure in 2001. The self-healing process of microcapsules is shown in Figure 1. When the microcapsules are damaged by force, the internal release of healing agent fills the crack and reaches The purpose of healing.
Figure 1. Microcapsule self-healing process.

Garcia et al [12] first proposed the application of microcapsule technology to the self-healing of asphalt. The technical route is to use porous sand with regenerated agent as the core material, and cement and epoxy materials as the shell material. 1.60mm microcapsules, when the microcapsules are destroyed, the internal release of the regenerant fills the cracks and achieves the purpose of self-healing. The results show that the microcapsules have good high temperature resistance and tensile strength.

Su et al [13] selected methanol modified melamine (solid content 78%) as shell material, styrene-maleic anhydride copolymer (SMA) as dispersant, and Kuwait oil as regenerant, prepared by in-situ polymerization. The double-layer microcapsules were used to simulate the cracking of the asphalt binder under low temperature conditions, and the crack healing was observed by a fluorescence microscope. Since then, they have also studied microcapsules using geothermal oil as a regenerant, and developed a microcapsule material using methanol-melamine as the inner layer and 10% nano-calcium carbonate modified methanol-melamine as the outer layer.

Kyungho Chung et al [14] used xylene (DMP) or styrene-butadiene-styrene block copolymer (SBS) / xylene (DMP) as the core material, and urea/formaldehyde resin as the shell material. The microcapsules with a size of 20-600 μm showed that the self-healing effect of SBS/DMP was better than that of DMP as a microcapsule modified asphalt.

Pei Jianzhong of Chang’an University [15] proposed a design scheme of asphalt self-healing microcapsules using urea/formaldehyde resin as shell material and regenerant as core material, in which the regenerant consists of aromatic components containing a large amount of polar epoxy groups. Light oil composition.

Sun Daquan et al. [16] of Tongji University used optical microscopy, field emission environment scanning electron microscopy combined with DSR and other techniques to find microcapsules of regenerator/melamine resin based on complex modulus and loading times. When it is 40 to 90 μm, the self-healing effect is good.

The microcapsules mostly use regenerant as the core material. The advantage of this technology is that it utilizes the contact reaction, the healing efficiency is high, and the strength recovery effect of the pavement material after healing is good; the disadvantage is that the cost is high, there is no repeti-
tive healing function, and the production is mixed with the asphalt. And in the process of pavement construction, it is difficult to ensure the uniformity and integrity of its distribution.

2.2. Hollow Fiber Structure
Van der Zwaag [17] and Schlangen et al. [18] have proposed that a hollow fiber tube filled with a healing agent can be added to the asphalt mixture. The fiber breaks during the damage and the healing agent overflows to repair the crack, but the technology has not been seen in asphalt or Research reports on the application of asphalt mixtures.

2.3. Nanoparticle
When a crack is generated, the nanoparticle will accumulate at the crack under the action of the nanometer, thereby hindering the development of the crack. Therefore, Santagata et al. [19] found that carbon nanotubes form bridging in cracks, which can reduce the crack spacing and improve the self-healing properties of asphalt binders. However, for high viscosity asphalt binders, carbon nanotubes will delay the flow. The wetting process of the phase will reduce the self-healing properties of the asphalt binder.

The self-healing of nanoparticle-enhanced asphalt binder is completely dependent on its own nano-effect, and has little dependence on the external environment. The application prospect is broad, but the cost is high and the technology is strong.

2.4. Ionomer
An ionomer refers to a high molecular polymer containing a small amount of ionic groups in a molecular chain, which is also called an ionomer or an ionomer. Due to the interaction between ions, the ionomer can heal, so the incorporation of the ionomer as an additive into the asphalt material enhances the self-healing ability of the asphalt material. Chen et al [20] used ethylene-methyl acrylate copolymer as a modifier to study the self-healing properties of asphalt binder. The results show that the ionomer can improve the self-healing properties of asphalt binder.

3. Passive
The key to this technology is to add to the asphalt binder materials that can generate heat under the action of external fields (electric, magnetic, acoustic, light, etc.) or contain reversible chemical bonding reactions (such as Diels-Alder reaction) when the environment changes.

3.1. Hot Trigger
Garcia [21], Qiu Jian [22], Liu Quantao [23], Wang [24], Norabuena-Contreras [25], etc., by adding electromagnetic fields and microwave fields to the asphalt mixed with carbon fiber or steel fiber. The mixture was heated and analyzed. The water stability and mechanical properties of the asphalt mixture before and after heating were analyzed. The results show that this method can effectively improve the self-healing rate of asphalt mixture.

Etienne Jeoffroy et al. [26] used the characteristics of ferromagnetics to incorporate γ-Fe2O3 nanoparticles with a grain size of 50 nm into the asphalt. After adding an alternating magnetic field, the crack healing on the asphalt surface was observed. The results showed that the asphalt healing rate was improved. The difficulty of this technology is how to ensure the uniformity of the distribution of heat sources (conductive phase or magnetic body) in the asphalt. In addition, the loading time and loading time of the applied energy field are not solved.

3.2. Light Trigger
Li et al. [27] reacted an oxetane-encapsulated chitosan macromonomer dispersed in dimethyl sulfoxide with polyethylene glycol and hexamethylene diisocyanate under nitrogen to obtain light. A catalyzed polyurethane network structure (OXE-CHI-PUR) repair film embedded with oxetane chitosan. When
the asphalt is damaged, the four bonds with weaker force in OXE-CHI-PUR are broken, and the chemical bond is reconstructed under the action of ultraviolet rays, thereby achieving the healing effect.

Wang et al [28] used graphite flakes and exfoliated graphite nanosheets (xGNP) modified asphalt to analyze the crack displacement in the image after sunlight exposure. The results show that the graphite modified asphalt has better self-healing ability than the matrix asphalt.

The shortcoming of the photoinitiation technique is that ultraviolet irradiation is required, and at the same time, the crack repair effect on the surface of the asphalt is not good.

4. Conclusion and the Next Research Direction

Comprehensive research at home and abroad, the focus of researchers has gradually changed from understanding the self-healing of asphalt to the use of asphalt self-healing for pavement design and repair services. At present, the main problems of self-healing and repair of asphalt concrete pavement and further research directions as follows.

(1) Asphalt itself does have self-healing ability. The factors affecting the self-healing of asphalt are more complicated. The current research mainly focuses on the effect of healing time and temperature on self-healing. The effects of polymer modifiers on asphalt self-healing reflect different conclusions, mainly due to their own complexity and the different evaluation methods used by the researchers.

(2) The increase of temperature can significantly improve the rate of self-healing of asphalt. The self-healing technology of induction heating asphalt concrete can heal quickly and can be repeated, which can repair the cracks and loose diseases. It is a promising technology. However, it is still necessary to study the mechanical properties of the composite, the rate of temperature change, and the timing of induction heating.

(3) Regenerant assisted healing is represented by microcapsule technology, which has the advantages of high healing efficiency and high speed, but its high cost and high technical requirements can only serve as a one-time healing effect. The choice, the mechanics of the capsule, the high temperature properties, and the effect of the capsule on the asphalt concrete are more studied.

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