Asphalt damage reservation due to self-repair: A literature review

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Abstract. In this paper, a comprehensive state-of-the-art study regarding the mechanism and enhancement of self-repair in asphalt pavement is presented. The review starts with defining the self-repair phenomenon as a natural property in asphalt materials that is associated with other properties such as the viscoelastic response. The difference between self-repair and the viscoelastic response is also presented. In addition, the factors influencing the self-repair mechanism (positively and negatively) are investigated. However, some of these factors remain vague and need to be investigated further. Furthermore, two enhancing self-repair processes, which are extrinsic technologies such as induction heating and encapsulated rejuvenators, are presented as alternative preventive maintenance applied to asphalt pavement. In conclusion, the self-repair could be achieved in an economic way in countries with hot climates, such as Iraq where temperature plays a significant positive role in enhancing the asphalt repair if enough rest period is provided, without the need to other extrinsic technologies to be applied.

1. Introduction
The worldwide use of asphalt pavement and its requirement for maintenance have urged the road agencies to increase their budget. The increased budget to keep roads safe and serving efficiently without flaws could not be reached in most countries. In the USA for instance, the American Society for Civil Engineers estimated a budget deficit of 48% in 2010 with a possibility to reach 54% by 2040 [1]. This budget deficit would lead to postponed maintenance and rehabilitation actions, causing more expensive interventions. This issue has brought the idea of the construction of long-lasting pavements [2] as a solution.

The self-repair phenomenon, which is a natural property in bituminous materials that help heal damages by themselves without external intrusion. This phenomenon is inherent in asphalt materials that can be used as an alternative to asphalt maintenance. This can hugely decrease maintenance expenses, besides extending the service life of highways and eventually promote the environment by decreasing the emissions from slowed vehicles [3]. Self-repair is an intrinsic property that happens due to the diffused molecules between the crack sides. In this way, it prevents the discontinuity of the cracked material [4,5]. Some recent research papers studied this phenomenon mainly based on the mechanical reactions of asphalt pavements [6,7,8]. Mechanically evaluated tests are able to quantify the macroscopic recovery of the damage. However, it is believed that not all damage recoveries are attributed to self-repair because of the viscoelastic responses. Ayar et al [9] and Baaj et al. [10] found that viscoelastic responses could recover damages in asphalt pavement mechanically similar to that of self-repair during the rest period.

Therefore, it is crucial to present all these fundamental concepts and suggest relevant methods that can maximise the self-repair of asphalt material.
The influencing factors that cause self-repair must be studied and separated from those who lead to the mechanical recovery of asphalt during the unloading stage. In this review paper, a technical overview is presented to propose several studies concerning the asphalt self-repair ability and its possible application for clever and sustainable construction and maintenance.

2. Self-repair of asphalt

2.1. Definition

The mechanism of healing or repair in asphalt materials is still unclear because of the complex composition of asphalt with its micro-structure and potential interactions. However, for a general understanding, it can be considered as a natural reaction of asphalt material to repair cracks and eventually restore partially the original properties [11,12]. This process generally occurs in the microcracks because macrocracks cannot be wetted due to their size [13,14]. The wetting capacity, however, is affected by the type of asphalt and its properties. Figure 1 shows the schematic diagram of this mechanism.

![Figure 1. Schematic diagram of self-repair mechanism in asphalt [12].](image)

2.2. The viscoelastic response

Menozzi et al. [15] stated that the asphalt self-repair cannot recover damages that result from permanent deformation, such as plastic deformation (rutting) and high viscosity failures. Healing is usually indicated as a process that occurs due to the diffusion of molecules and wetting. This process could start any time of damage or cracking, not only during rest periods [12]. The viscoelastic response and self-repair of asphalt cracks are not technically related to the damage. They can be defined as a progressive molecular rearrangement that can reverse the mechanical properties of the asphalt material, which relies on the sol-gel process. This builds stronger asphaltene connections with time [16]. The presence of rest periods leads to a progressive shift from a gel to a sol structure while restoring the gel structure [17], as shown in Figure 2.
2.3. Self-repair considerations

Due to its effect on extending the pavement life by reversing the aging of asphalt, some parameters were proposed to include the self-repair property of asphalt material in the Shell Pavement Design Manual [18]. The relationship between these parameters and the rest period were further investigated by Lytton et al. [19]. They found that those parameters could vary from 1.09 to 2.7 for a 30s of unloading. However, researchers are still not accurate on which method that could correctly quantify and predict the healing parameters for different procedures of mechanical testing. However, Gaskin [20] indicated that the compression due to traffic loading in the surface course has significantly improved the healing capability. Figure 3 below shows different types of cracks that appear at different levels of asphalt pavements.

3. Factors affecting self-repair

3.1. Internal forces

Such as:

- Characteristics of bitumen, many studies have found that a soft bitumen with lower penetration can flow easily into the cracks due to capillary flow, which leads to wetting the crack surfaces [15].
Chemical composition, molecular mobility and microstructure of bitumen have considerable influence of self-repair capability of asphalt pavement [21,22].

The surface free energy, can be considered as the surface tension of both sides of the crack, where molecules on surfaces have more energy than molecules in the core of material. This energy has a noticeable effect on the damage recovery in asphalt pavement. It may cause a negative effect on the short-term self-repair and positive effect on the long term [19].

The self-repair effect on the filler/mastic system is higher than that of asphalt system. Al-Mansoori et al [6,8] have found that mastic asphalt system is more vulnerable to temperature effect on healing.

3.2. External forces
External factors can take part in the healing mechanism of asphalt material, such as:

- Rest period, as many studies have found that rest period can positively enhance the development of self-repair in asphalt materials [23].
- Temperature could be another essential influencer in triggering healing process. It is widely reported that healing happens rapidly with an increase of 35% at high enough temperatures [8,24]. Figure 4 below shows the effect of temperature alone in healing cracks.

![Figure 4. Natural self-repair of asphalt pavement activated by higher temperature [13].](image)

- Traffic loading, it is observed that applying different loading magnitudes with different frequencies on asphalt samples can lead to different healing responses since they help achieve full contact of broken surfaces [23].
- Aging reports are different, some found that aging has a negative effect on the healing of asphalt [22] as the asphalt becomes harder and not easy to flow again and fill the cracks. Others reported that that laboratory aged bitumen could exhibit higher damage recovery compared with the unaged bitumen due to the difference in viscosities [25].

4. Self-repair enhancement technologies

4.1. Induction heating
Temperature and rest period are significant factors in the healing capability of asphalt materials. To increase the temperature locally on damaged asphalt, induction heating is used, which can efficiently enhance the self-repair capability [13]. However, this method is not ideal as it requires big machines to
heat the asphalt and could not be applicable in the field. Besides the fact that higher temperatures may cause asphalt aging. Hot climate countries could have this natural temperature effect on asphalt repair without external intrusion as shown in Figure 5.

![Figure 5. Different healing levels in asphalt samples with and without external intrusion at different temperatures [6].](image)

As it appears from Figure 5, after 40°C, asphalt pavement tends to recover its strength and repair the damage without the need for external rejuvenators. This is crucial for countries such as Iraq to take this advantage.

4.2. Embedded rejuvenators
These rejuvenators are usually encapsulated and mixed with the asphalt to improve the self-repair level of asphalt materials. These rejuvenators were proved to be able to enhance the self-repair of asphalt pavement [6,7,8]. When microcracks appear, these embedded rejuvenators come out of their capsules, which will be broken by the fracture energy at the tip of the crack. Then, the rejuvenator, which should have a lower viscosity than the bitumen, is released and flows into the microcracks due to the capillary action and diffuse into the bitumen as shown in Figure 6.

![Figure 6. Schematic representation of crack healing in asphalt mixture with the presence of encapsulated rejuvenators [8].](image)

So far, those embedded rejuvenators applied to the asphalt materials believed to be used for only one passive release and a single repair, which means they can be used once and for the first cracks only. A picture of a capsule in an asphalt sample is shown in Figure 7.
5. Conclusions
An enhancement process to trigger the self-repair property in asphalt is essential and has a profound help to highway agencies and the country’s budget. Based on the state-of-the-art study presented in this paper. The following conclusions can be drawn:

- Self-repair of asphalt materials is a natural response to recover the original properties of the material that were damaged. This response is driven by spontaneous wetting and diffusion of molecules from both sides of the cracked asphalt.
- The self-repair process starts when the microcracks (hairline cracks) appear and continues so long as there still possible contact between the crack surfaces.
- Self-repair in asphalt is not straightforward at ambient temperature unless enhanced with enough energy, such as induction heating or added materials (encapsulated rejuvenators).
- The viscoelastic response could also cause mechanical recovery to the damaged asphalt pavement during the rest period. This is crucial if worked together with self-repair process to speed up the recovery.
- Longer rest periods, usually more than 72 hours, and high enough temperature, 40°C or more have a positive influence on the self-repair property of the asphalt materials.
- Both induction heating and embedded rejuvenators can significantly enhance the self-repair process of asphalt materials. However, based on literature, they could be unnecessary in a hot climate, in which asphalt could undergo high enough temperature to repair if enough rest period is provided.

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