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Original Research

MICROCAPSULES AND INDUCTION HEATING: TWO METHODS FOR CLOSING CRACKS IN ASPHALT POROUS PAVEMENTS

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Abstract: Asphalt concrete is widely known to be a self-healing material, by repeated loading the micro-cracks have appearing and disappeared when both faces of a fissure touch. This process is applied until the crack is completely gone and the material regains its prior resistance. In this study, two strategies are presented to boost of healing rate and applied in porous asphalt, one of them is induction heating. This method is used by mixing 1.1% of steel wool fiber to speed up this phenome, with 20mm aggregate size for porous asphalt mixture and 21% air voids content. Another approach is self-healing by 0.5% encapsulated agents using. These capsulate are incorporated within the asphalt mixture, then the capsules break when subjected to repeating loading on the asphalt surface. It has been discovered that there is a moment in the lifespan of an asphalt road where the capsules or induction heating applied can successfully self-heal the existing crack damage.

Keywords: Porous pavements, Microcapsules, induction heating, Weibull distribution, Wöhler curve, probability for breaking, self-healing

1. Introduction

Asphalt concrete is the most common material used to construct roads. Aggregates, filler, and bitumen make up this composite material. Because bitumen's viscosity is temperature dependent, over a specific temperature range of 30°C to 70°C, it behaves as a Newtonian fluid[1], and as a non-Newtonian fluid below this temperature threshold. The causes underlying this

behavior, however, is still unknown, because it is a new approach needing

The primary component of the road infrastructure that needs maintenance is the pavement. As a result, methods for improving pavement sustainability have been developed, such as the use of sustainable materials [2].

Bitumen is also a built-in property material. When the temperature of a fractured asphalt pavement rises over the threshold of the temperature, because bitumen is a fluid, gravity, capillarity, and hydrostatic pressures cause it to move across the internal pore network of asphalt layers [3]. Bitumen is poured into cracks in the asphalt mixture till the stress and surface tension of the bitumen has filled the fissures equal to that of the asphalt mix [4].

Additionally, if asphalt roads do not subject to loading stresses that can widen cracks, they can self-heal [5]. However, total healing may take several days, which is unachievable in practice owing to continuous traffic flow [6]. Moreover, it has been previously reported that (1) bitumen viscosity (Self-healing is aided by bitumen with low viscosity) [7]; (2) bitumen chemical structure (the composition and healing properties of

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bitumen from various origins differ) [8]; and (3) the older of the highway (with time and exposure to the elements, asphalt roadways get tougher. [9], (4) the aggregates utilized (mixtures containing aggregates with a high affinity for bitumen have greater self-healing qualities [10].

There are currently various technologies available to speed up the recovery of asphalt mixes. Induction heating in asphalt [11] is one example, which involves combining ironic materials into the asphalt mix and subjecting it to a Kilohertz-frequency oscillating electrostatic energy [3]. Induction heating trials were also carried out to ensure that the procedure was correct [12]. This causes an electrical current to flow through the ferrous particles, the Joule theory raises their temperature, and the heat energy subsequently diffuses into the asphalt mix, boosting the bitumen temperature. When this process was used in the lab, cracked asphalt beams were able to restore up to 80% of their strength [13].

A second method for healing approaches in asphalt mixtures is the use of capsule rejuvenators, which are microspheres or capsules that contain approximately 70% oil [14], such as sunflower oil, and have been introduced as an addition. [15]. Oil is a strong bitumen soluble [16, 17]. The microcapsule can prevent the core from being damaged in high-temperature environments, according to the results of thermogravimetric analysis (TGA) and heating simulation tests The capsules are destroyed, split, and release their contents as a consequence of the repeated loading from vehicles

Adding an encapsulating curing agent to an asphalt mix to increase its ability to self-heal was considered an advanced maintenance approach because it reduced maintenance fees and gradually expanded the life span of the pavement surface [1, 18, 19]. Different types of rejuvenators were encapsulated healing substances. Sunflower oil is a type of leftover cooking oil. In addition, a number of encapsulation methods, like core-shell microcapsules, capsules with multiple cores, and fibers with compartments, have been developed to improve the efficacy of asphalt self-healing.

Sun et al.2018 [19] created MUF microcapsules that have a core-shell configuration. To boost the self-healing characteristics of the asphalt mixture, a light component oil was enclosed in microcapsules. The microcapsule doubled the asphalt mixture's fatigue life in a 4-point bending fatigue test developed a multi-core construction for calcium alginate capsules.

Sunflower oil was incorporated in the capsules as a therapeutic agent. The pills were found to have the ability to speed up the healing of cracks in the asphalt in a CT scan. When Tabakovic et al used wet spinning technology to create a calcium alginate compartmented fiber encapsulating rejuvenator, the fibers increased the strength of asphalt mastic by more than 30%.

Sun et al. [19] developed a calcium alginate fiber with a novel compartment structure. The therapeutic agent sunflower oil was enclosed in the compartments as a droplet. The ability of highly secured fibers to improve asphalt's self-healing properties has been demonstrated. The effect mechanism of compartmented fibers was disclosed by microscopically monitoring the self-healing process of cracks in asphalt having compartmented fibers using a fluorescence microscope test. As shown in Fig. 1, the compartmented fibers' healing mechanism is that a compartment was ruptured by a crack, and then healing agent was injected into the crack by capillary action. The healing agent soaked into the asphalt. After that, the healing agent quickly dispersed throughout the asphalt. As a result, the viscosity of asphalt was reduced.

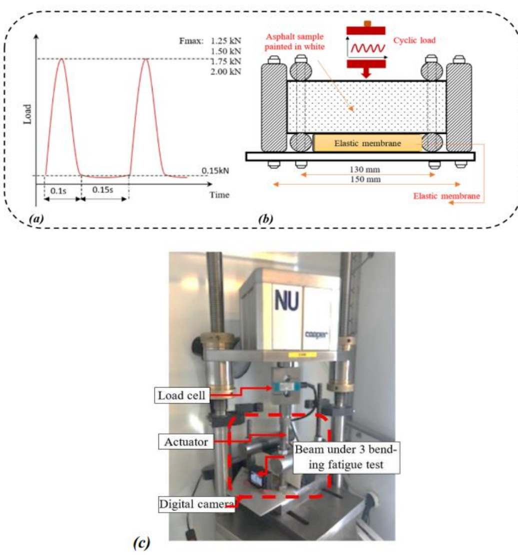
Furthermore, the authors were unable to locate any document in the literature that compared asphalt healing via induction and encapsulate agent technology in porous asphalt mixtures. This article presents two relatively new ideas: Asphalt concrete induction heating and microcapsules containing sunflower oil, both are intended to boost 0the self-healing rates of asphalt concrete and, as a result, the road's longevity. Although this research is not yet complete at the time of writing, the authors wish to present both ideas in order to provide a high-level overview of these technological innovations.

2. MATERIALS AND METHODOLOGY

2.1 Materials explanation

The achievement of the study objectives was accomplished in this method the Fig.2 shows the process. The study's mixture comprised a porous asphalt concrete (PAC-20) with coarse aggregate, limestone as a fine aggregate, and steel wool fiber particles as seen in Fig.1 to allow for the induction process and Microcapsules 0.5. Table 1 and Table 2 show the properties and gradation of mixture which met the requirements of Standard BS EN 13043:2013.

In addition, sunflower oil was used in this paper. The membrane consists calcium –alginate, however capsule was prepared from sodium alginate and sunflower oil as a basic materials (asphalt rejuvenator) [20]. The aggregates utilized (mixtures containing aggregates with a high affinity for bitumen have greater self-healing qualities [21].



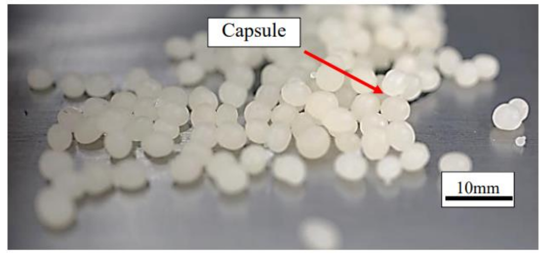


Figure. 1. (a) Dynamic load illustration. (b) Establishment of a fatigue test, (c) setup test (Universial machaine used) (d) Capsules additive

Table (1): Design properties of asphalt mixture PA 20 base 40/60

Aggregate Gradation	Passing %
31.5mm	100
20 mm	99.1
16 mm	95.5
14 mm	88.1
10 mm	53.4
8 mm	36.3
6.3 mm	23.1
4 mm	17.8
2.8 mm	16.6
2 mm	14
1 mm	10.2
0.5 mm	7.9
0.25 mm	6.3
0.125 mm	5.1
0.063 mm	4.1
Properties	Value
Binder content (%M)	(%M) 3.5
Air voids	(%) 21

The capsules have made using the method described by [20] . This suggests, Ionic gelatins, sodium alginate, and calcium alginate were used to make the capsules. It prepared 25 g sodium alginate was utilized in 75 g sunflower oil. In general, the encapsulation process consisted of the following steps: 1. Pouring an oil/water mixture into a 1000 ml of calcium chloride solution. 2. After trying to prepare a calcium chloride solve by dissolving twelve gr of calcium chloride in a falling nozzles with a 3 mm hole size; and 3 starting to dry the capsules at 40 degrees Celsius for 24 hours. The capsules implemented according to Norambuena-Contreras et al., 2018 [18].

Table (2): properties of mixture

Materials			
Porous Asphalt mix		**Properties**	**Density kg/ m³**
Aggregate	20mm		2596
Bitumen	4.5%*	40/60 pen	1028
Steel wool fiber	1.1% Of mixture	Dimeter 16μm to 72μm Length length was from 0.15 mm to 5mm	7.180
Capsule	0.5% of Mixture		1.116 [18].
Air voids	21%		
sunflower oil		Smoke and flash point , 315C, 277C respectively [20]	0.92

* Qiu, 2012 [8]

2.2 Preparation of the test specimen and configuration test

Fatigue tests were performed on samples using a 3-point bending setup to ensure a forming of vertical cracks at the middle point. The samples as well as between bottom components are protected by an elastic coating.

The beam samples for repeated loads were 150 X 60 X 50 mm3 and were cut from 306 X 306 X 50 mm3 slabs using a rotary cutting blades designed for concrete and rocky materials.

The materials were post for two hours at 160 degrees Celsius and compacted with a rolling compaction prior mixing. Finally, throughout repeated loading testing, One of the lateral sides had a uniform pattern. labeled with a white labeling sprig, which aided in the outside detection of cracks

The appropriate load waves lasted 0.1 second and rested for 0.15 second, yielding a frequency of 4 hertz (Fig. 1). To guarantee constant connection among for 25ºC. For sample and pneumatic cylinder for loading, a least load of 0.15 kN has always been sustained. To find the impact of the loading on recovery efficiency, 4 different max loads (1250N, 1500N, 1750N, and 2000N were used.

3. Self-healing asphalt measurement

The specimens were tested till they passed a number of three -point bending cycling loads that matched to a percentage of N0.5, indicating the asphalt mixture's pretty effective. The test samples have then allowed to relaxation for twelve hours at 20 degrees Celsius. Lastly, the test samples were run till they broke to find out service life , then the whole number of rotations was calculated (Ntotal). Using the equation below (Equation 1), the healing ratio (HR), or index of self-healing of the asphalt mix test samples, was calculated .

3.1 Self healing test by Induction heating

The effectiveness of self-healing was assessed using [22]. The specimens were fatigue tested at 20°C in a modified three-point bending fatigue arrangement, resulting in the formation of vertical fissures in the middle, Fig. 1 (b).

Self-Healing of asphalt specimens were achieved utilized 90 seconds of magnetic field on steel wool fibre-including samples and letting them to rest for a minimum of 2 hours. This technique generated electric the Joules effect heated the conducting fibers via micro-currents., and hence heated the bitumen by convection Gómez-Meijide et al., 2016 [23], as shown in Fig.2.

As a result, the bitumen's viscosity decreased but its volume increased as a result of thermal expansion, allowing it to drain via interior fractures and cavities [23]. The tempreature of asphalt mixture was restored to the surrounding ambient after heating, then the the sample continued to full fracturd .As a result, the samples have been increased the fatigue life. The magnetic fields were generated via a 150 x 150 mm^2 square coil connected to a 6000W inductor with a capacity output of 2800W and a bandwidth of 348 000Hz.

The spacing between wire and the specimens have been agreed to 20mm, the samples have been implanted in dust to avert durable deformations whilst also heating. A color infrared camera with a resolution of 320 X 240 pixels monitored continuously the heating temperature.

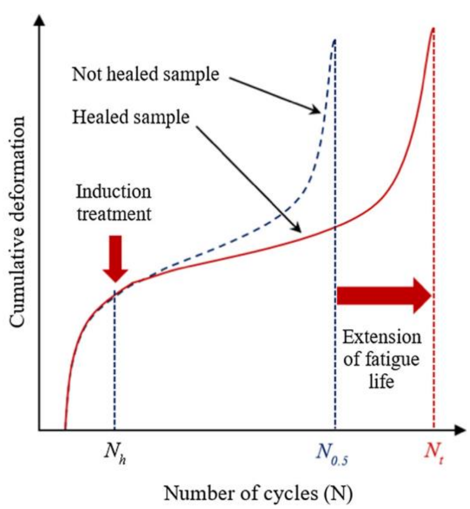


Figure 2. Graph depicting how induction heating can be used to extend fatigue life [24].

3.2. Self- healing by Microcapsules

Capsules release a certain amount of oil. capsules is to lessen the amount of this released oil from self-healing evaluations and confine it to the oil produced after compression loads are applied to destroy the capsules. In accordance with the approach described in Al-Mansoori et al., 2017 [25], the quantity of oil discharged by that the capsule into the sample was quantified. Al-Mansoori et al. discovered a procedure built on the assumption that oils have a unique maximum absorption at 1745 cm-1 that bitumen does not. Sunflower oil was blended with bitumen in the following mass percentages: 2.0, 3.0, 5.0, 6.7, 8.0, 9.0, and 10. to have a reference to figure out how much oil there is released by the capsules, as shown in Fig. 10 (b) of reference by Al-Mansoori et al [26]. Furthermore, asphalt mortar specimens were needed to determine the amount of oil produced by the capsules. To accomplish so, a hot blade was used to scrape mastic samples from the surface of aggregates. The normalized area under the curve for mastic samples was matched to values produced by combining bitumen and safflower. Mastic was collected from freshly compaction mixtures at various phases of the cyclic loading process, as well as after the relaxing interval that was employed to allow the cracks to self-heal.

4- Results and discussion

4.1 Durability of asphalt mixture

- **By Induction heating after repeated loading**

The number of cycles is distributed using the Weibull distribution prevented by the test samples under a variety of load levels is shown in Figure 3 (a). Without relaxation periods, these graphs reflect the cycles that were avoided. As previously stated, these graphs were used to derive N0.5, which seems to be the duration when the probability of break is 0.5. N0.5.

The relationship between $N_{0.5}$ and the maximum repeated loads is shown in Fig.3(b). This is known as the Wöhler curve. Load level increases resulted in exponential reductions in fatigue life. Different loads were utilized such as 1250 N, 1500 N, 1750 N, and 2000 N, whereas 39240, 20840, 8020, and 2560 were represented the N0.5 for 150 X 60 X 50 mm^3 specimens respectively. Additionally, when 50 N and 70N were applied to 150 X 40 X40 mm3 specimens, the $N_{0.5}$ values were 5503 and 602, respectively.

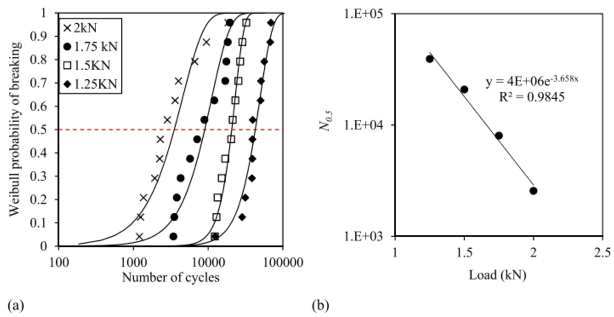


Figure 3. (a) Probability of breaking the test samples along the range of cyclic loads investigated, and (b) Wöhler curve for 0.5 probability

- **Asphalt mix durability after frequent load with capsules**

As an example, Fig.4 depicts the cumulative probability of breaking PA without capsules when were loaded at 1250N, 1500N, 1750N, and 2000N. The number of cycles that the asphalt could withstand was as expected, reduced as the load applied increased.

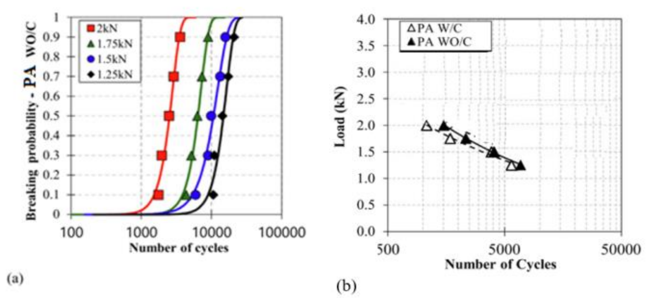


Figure 4. (a) The number of cycles for PA without capsules (WO) in different loading . And (b) Wöhler curves for porous asphalt (PA), with and without capsules (W/C and WO/C)

The major finally makes from Fig. 4(a) and Fig.4(b) is that the capsules decreased the number of cycles prevented by the Porous asphalt by 29% when no relaxation intervals have been used

4.2 Temperatures of asphalt test samples before and after heating

During induction heating, the samples' temperature was constantly watched just use a thermal sensor (Fig.5(a)). Fig.5(b) depicts the temperature progression of an asphalt sample having 1.1 percent steel after being heated for 2 minutes at the top, center, and bottom of the sample.

It must have been discovered that the temperature increase had been made linearly proportional at any point on the asphalt's surface (see Fig. 4 (b)).

The test specimens' surface temperatures after 90 seconds of The temperature were around 100 degrees Celsius. According to the authors, the thermal resistance among different parts of the test specimens has no effect on crack healing as the temperature rises in all points of the test sample.

According to the authors, the temperature differential between parts of the test samples has no effect on crack healing as the temperature rises in all points of the test sample. Reference [24] by (Salih et al., 2018) in regard shows a test sample heated with infrared light, likely to result in a surface temperature greater than the bottom temperature. The possible explanation for this is that bitumen expands and drains in to the cracks when the temperature rises at normal asphalt electro-thermal rates . The minimum heating rate required for self-healing asphalt is still unknown.

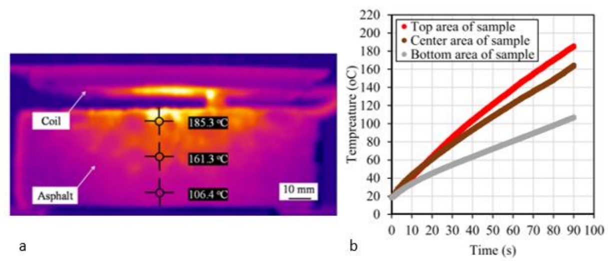


Figure 5. (a) Infrared camera image using of asphalt mixture sample containing 1.1% steel wool under induction heating. (b) Evolution of the asphalt's mixture surface temperature over heating time**.**

4.3 Oil poured from the capsules through the several loading tests.

Fig. 6 depicts the area under the FTIR curve after various of blending amounts of oil in bitumen. A similar diagram, although for a various type of bitumen, may be seen in reference [26] (Al-Mansoori et al., 2018b). To calculate the quantity of oil in the mix combination, the linear fitting was employed as a reference.

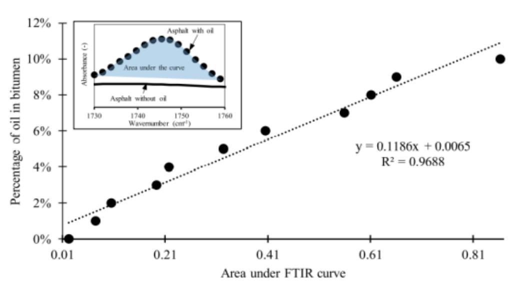


Figure 6. FTIR test curve for bitumen that has been changed with varying amounts of sunflower oil

The amount of oil in the asphalt may be used to determine the percentage of capsules shattered throughout blending and compression, which came to 8.27 percent. 0.81 percent was the standard deviation. These figures show that the majority of the capsules were resistant to blending and compressing. Moreover, during the cyclic loading experiments, the oil diffusing by the capsules in PA is depicted in Fig.7 (a) (see Fig. 4 (a) for more information). the quantity of diffused by the capsule is usually approximately 80% of the total quantity of oil in the capsules. According to Fig.7, the number of cycles when macro-cracks began to form in the mixture corresponded to the step rise in oil release PA shown findings. This, according to the authors, could be confirmation that the capsules utilized in the article were inactive until macro-cracks emerged. This will be investigated more in the future. To demonstrate this, Fig.8(b) compares the diffusion of oil from capsules to the likelihood of the PA breaking. All of the trends derived from varied loading rates may be proven to be primarily coincidental. If the likelihood of breaking is proportional to the propagation of cracks in the asphalt, this graph depicts how the capsules steadily deteriorate in the mixture until they reach a maximum that is dependent of the various loading level. From the Fig.4 and Fig.7 according to the researchers, this is the optimal environment for maximizing healing capability

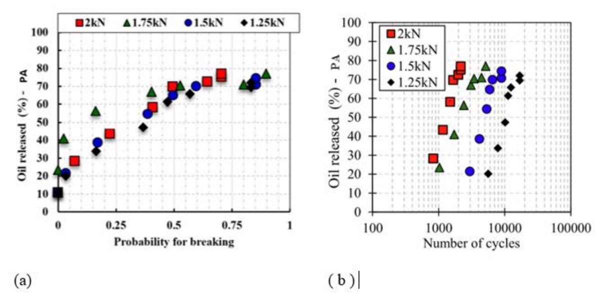


Figure 7. (a) Oil spread from the capsules inserted in PA samples that had been supplied using the arrangement depicted . (b) Oil spilled from capsules inside PA beams vs the likelihood of the asphalt beams breaking

4.4 Induction heating has an effect on the healing index.

After N_h cycle, the treatment is done., the healing index, which reflects the prolongation of fatigue life, for the different loads such us 1250N, 1500N, 1750N, and 2000N is shown in Fig.9(a). The healing rate, as shown in Figure, in all conditions, it followed cone distribution, showing there is an ideal. The maximum increase of fatigue behavior is achieved when the healing treatment is used. This happened in every case at around 35% of the asphalt's entire durability, regardless of

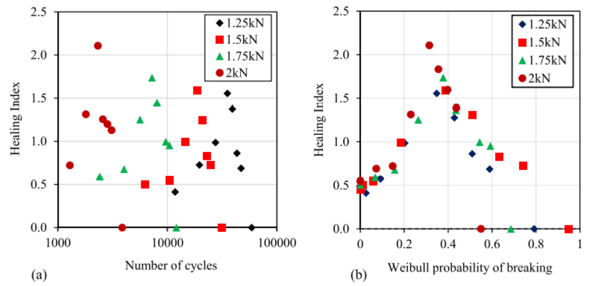


Figure 8. (a) For 1.1 percent steel wool-coated asphalt mix, healing index vs. cycle number (N_h). (b) Healing index versus Weibull likelihood for test sample breaking .

the applied load (see Fig.8(b)). The number of cracks is insufficient to achieve a significant fatigue life extension when the induction heating therapy is administered too early. When the induction heating treatment is done too late, however, the cracks become so large that the therapy becomes ineffective. Similar findings for various kinds of ascites were described in references [24] . The ideal number of cycles for maximal fatigue life extending decreases with load, from 35,316 cycles, 18,760 cycles, 7236 cycles, and 2318 cycles, respectively, for 1250 N, 1500 N, 1750 N, and 2000 N. This means that when the road is subjected to larger loads, the healing treatment should be given more frequently, at least 35 percent of the time required to ensure the road's longevity.

It is additionally observable that the development of fatigue failure gained could be larger than 100 percent (HI > 1) as well as in the instance of 2000N, also greater than 200 percent (see Fig.9). Because the HI number is more than 1, dynamical load and induced heating can be assumed. begins by introducing changes in the road surface that go beyond simply eliminating the conventional flaws This is most likely due to the test samples stiffening, which could be caused by bitumen aging or solid skeleton densification.

The effects of self-healing and cyclical loads on the bitumen will be examined in the sections that follow.

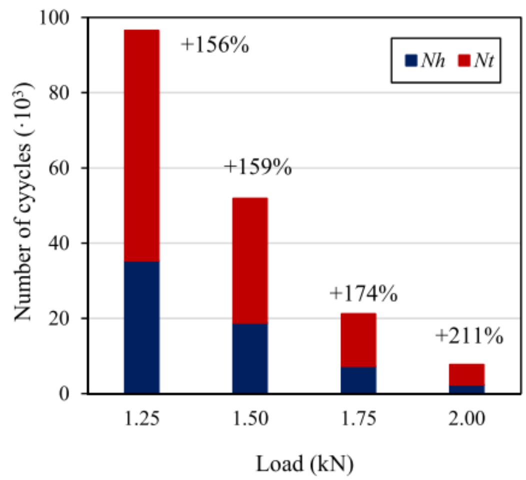


Figure 9. The number of cycles required to apply the healing treatment (N_h) and the number of further cycles surviving following induction heating (N_t)

4.5 Active cracking in PA is self-healing due to the action of encapsulated oil.

As an example, Fig 10(a) displays for a variety of loading levels, the Healing Index of PA without capsules was examined. investigated. A similar diagram was previously published in [22]. The healing index rises to a maximum and subsequently falls as the number of cycles increases.

According to Menozzi, et al.,2015 [22], this is an indicator that there is a best time to apply the healing treatment. When can be seen in the Figure, the perfect time for self-healing is dependent on amount of loads, and the maximum healing index drops as the load is reduced; this is likely due to fewer capsules being broken, however more research is needed to confirm this point. Because of the ecological environment spread in terms of loading condition findings amongst the test specimens, some specimens have Healing Index values below.

As between outcomes of the test samples, in addition, Fig.10 (b) depicts the PA healing rate vs the breaking chance among the test specimens. The authors used this method to highlight the similarities between the curves produced from various loading quantities, which had the same optimum period for healing and a similar likelihood of breaking, about 0.34. The greatest healing rate effect achieved by the types of asphalt investigated is shown in Fig 6 (a). The capsules boost the PA healing index by 30% when used at 2000N..

The highest healing index achieved by various forms of asphalt, according to the authors, is proportional to the number of capsules shattered and the type of damage to the mixture at the maximum healing index. In the test specimens have loaded at 2000N. The scientists assume that this is because cracks mend after repeated loading despite the absence of a resting interval, though this will have to be verified in future studies.

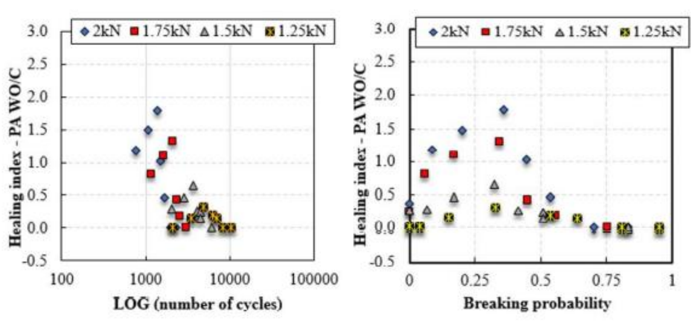


Figure 10. (a) Recovery index for PA without (a) Recovery index for PA without capsules versus number of loading cycles, (b) With PA without capsules, the healing rate vs the likelihood of cracking.

5- Conclusions

This study describes two methods for closing cracks in asphalt pavements. Both are wholly novel systems that have never been tested before in Iraq . Although none of them are done as of this writing, positive findings are being achieved on a daily basis. The first concept will provide a method for rejuvenating asphalt binder with a considerably better volumetric distribution than all previous methods. The second will attack the cracks immediately, closing them and sealing the asphalt concrete pavement. Both technologies will constitute a revolution in road construction, with the potential to treble the lifespan of new pavements. The integrated healing technique can successfully repair cracks and rejuvenate the binder, which results in more long-lasting healing in porous asphalt concrete.Finally , The link between green technology and sustanible asphalt pavement is the biggest barricade to achieving better environmental processes and controls. Without green technology , advances in pavement sustanible are impossible. Therefore, the self healing technology plays an important role as a link between the environment and green technology.

Authors contribution

Siham Salih , organized of the experiments, performed the experiments, and wrote the paper. Alvaro Garcia , planed the research, organized the experiments. J. Norambuena-Contrerasorganized part of the experiments, and wrote sections of the paper.

Conflict of interest

The authors declare that they have no conflicts of interest to report regarding the present study.

Appendex A

$$HR = \frac{N_f - N_{0.5}}{N_{0.5}} \quad (1)$$

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