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Effect Of The Actıvatıon Force On The Healıng Level Of Asphalt Mıxture Wıth Embedded Capsules

Erkut YALCIN[1], Mehmet YILMAZ[2], Beyza Furtana YALCIN[3]
[1,2]Firat University, Engineering Faculty, Department of Civil Engineering, Elazig/TURKEY
[3]Munzur University, Engineering Faculty, Department of Civil Engineering, Tunceli/TURKEY
erkutyalcin@firat.edu.tr[1]; mehmetyilmaz@firat.edu.tr[2]; beyzafurtana@munzur.edu.tr[3]

Abstract **-** By increasing the asphalt mixtures' inherent capacity for self-healing, encapsulated rejuvenators can extend the service lives of asphalt pavements. The capsules are shattered when crack damage occurs, allowing the rejuvenator ingredient to seep into the cracks. In this work, a brand-new kind of capsule was created. Sunflower oil was a rejuvenator in these capsules. We looked at how well asphalt mixture samples with and without capsules self-healed under static loading. The capacity for self-healing of asphalt mixtures incorporating a novel class of capsules that contain sunflower oil as a rejuvenating agent. For this reason, the ability of the rejuvenating ingredient to diffuse inside of samples of virgin bitumen and the healing potential of combinations of cracked asphalt containing capsules have both been assessed. Due to the mechanical properties of the polymeric capsules examined. Then, using a unique mechanical test, the impact of capsule content on the crack-healing characteristics of asphalt mixtures was assessed at various healing durations (from 5 to 216h) and loads (from 0 to 85kN). As the applied load increases, the healing levels of the asphalt samples with capsules rise; later, the healing levels of the asphalt samples with capsule remain constant. According to the findings, the maximal healing level was typically attained after 96 hours and remained constant until 216 hours.

Keywords**:** Self-healing, Asphalt, Capsules, Sunflower oil

1. Introduction

Asphalt mixture is the most used material to build road pavements worldwide. The capacity of road pavements to carry loads depends on the bond between aggregate particles provided by the bitumen. Nevertheless, this bond degrades over time due the most significant issue that bitumen faces, which is the damage from aging [1]. Aging results from oxidation and loss of the volatiles from bitumen composition, which causes stiffness and an increase in viscosity. This leads to the appearance of microcracks which evolve to form macrocracks and the detachment or ravelling of aggregates [2]. One recently used technique to resolve the problem of the maintenance of aging pavement is the use of encapsulated rejuvenators to restore the original properties of the bitumen via self-healing processes [3-5]. This technique is supported by the fact that bitumen is a self- healing material with the ability to close microcracks by itself [5]. The principle behind this approach is that these capsules containing rejuvenators will remain inactive in the asphalt road for several years until external damage happens to the asphalt pavement [4]. Then, cracks will break the capsule shells at the appropriate time, leading to the release of the rejuvenator into the asphalt, which will diffuse and reduce the bitumen viscosity to allow it to easily flow into the open cracks [6]. With this objective, different methods have been used to manufacture microcapsules, or capsules with encapsulated rejuvenators, for asphalt self-healing. Su et al. [3] prepared microcapsules containing rejuvenator droplets by in-situ polymerization of urea-formaldehyde making a methanol-melamine-formaldehyde (MMF) prepolymer as a shell. Furthermore, Garcia et al. [6] prepared capsules of a larger size by saturating porous sand with sunflower oil as rejuvenator material and protected by a hard shell of cement and epoxy resin. Details of another type of polymeric capsule were published by Al-Mansoori et al. [4] and Micaelo et al. [7]. These capsules were made by the ionotropic gelation of sodium alginate in the presence of calcium chloride solution. In these capsules, the encapsulated material was also sunflower oil and their size was a few millimetres. Broadly, these studies demonstrated that the capsules are resistant to asphalt fabrication and release the rejuvenators only when broken, but they did not show the effect on the asphalt self-healing properties for capsule content greater than 0.5% by total weight of mixture.

In this study, novel polymeric capsules for asphalt self-healing have been designed and tested in asphalt mixtures. These capsules have a greater amount of calcium-alginate structure where the oil is stored, which also improves their mechanical behaviour. As a result, of the polymeric capsules mechanical characteristics investigated. Then, the effect of capsule content on the crack-healing properties of asphalt mixtures was quantified at different healing times (from 5 to 216h) and loads (from 0 to 85kN) by using a novel mechanical test.

2. Manufacturing of Asphalt Mixture Specimens

Asphalt mixture beams with, and without, capsules were manufactured. In the asphalt, mixture with capsules of 0.5% by total mass of the asphalt mixture was added to the specimens. This amount provides an approximate oil-to-bitumen content of 6.89% by mass of bitumen. The asphalt mixture was produced in the laboratory in batches of approximately 14 kg, using a lab mixer equipped with a helical horizontal mixing shaft. The aggregates and bitumen were pre-heated at 160ºC for 12 h and 4 h, respectively, while the capsules were left to defrost for two hours at 20ºC prior to the mixing process. The materials were mixed for 2 minutes at 125 rpm at 160ºC, ensuring an adequate dispersion. Then, capsules were added to the drum and mixed for 20 seconds to obtain their uniform dispersion. Then, the mixture was poured into the molds and compacted to the design for air voids by using a roller slab compactor to produce an asphalt slab with dimensions of 306 × 306 × 60 mm. Each slab was cut into six identical asphalt beam samples of 150 × 100 × 60 mm. Likewise, to facilitate the creation of a single crack surface during crack-healing tests, a transverse notch of 5 × 5 mm was carved at the mid-point, on the bottom surface of the beams.

3. Influence of Loads on the Healing Properties

Figure 3.1 shows the relationship between displacement and compressive force in asphalt mixtures. As can be seen in the figure, as the static force increases, the displacement value of the asphalt mixture increases. The maximum displacement value (5 mm) is approached at the static load of 85 kN. Figure 3.2 shows the healing level results for all asphalt mixture beams without capsules tested at three different healing loads (Figure 3.2(a)) and with capsules tested at nine different healing loads (Figure 3.2(b)), in the healing time range from 5 to 216 h. Results of Figure 3.2 show that the healing level of asphalt increased with the time until a maximum value where it remained constant. As can be seen in Figure 3.2 (a), the healing level remains constant after the healing level of asphalt mixtures without capsules at three different loads increase linearly up to 120h. In Figure 3.2 (b), the level of healing for the other loadings applied is linearly increasing from 5 to 216 h, although the maximum healing level of the asphalt mixtures with capsules is about 96 h for three different loads (65, 75 and 85 kN). The mean maximum healing levels for mixtures with capsules varied from 31.59% to 34.54%, 35.13%, 45.23%, 47.35%, 55.17%, 44.52%, 53.42% and 57.70% for the loads between 0 kN and 85 kN, respectively. The difference was due to higher loads that reduce the mastic viscosity and allow the bitumen to flow and fill the surrounding micro-cracks. Therefore, the flow of bitumen to the crack is easier and faster. This can be observed in Figure 3.6 where a higher percentage of oil release from broken capsules is reached at the highest loads (85 kN), which improves the healing process in the cracked asphalt mixture. In this figure, it appears that the healing levels in such asphalt samples with capsules are higher than those of samples without capsules.

In summary, from Figure 3.2 it can be observed that 1) there is a proportional increase in the level of healing when there is a load increase of 65 kN in the asphalt mixture samples with or without capsules 2) the healing level at 65, 75 and 85 kN loads is stable after 96 h 3) there is a proportional relationship between the healing level results of asphalt mixture with and without capsules, independent of the load and time evaluated.

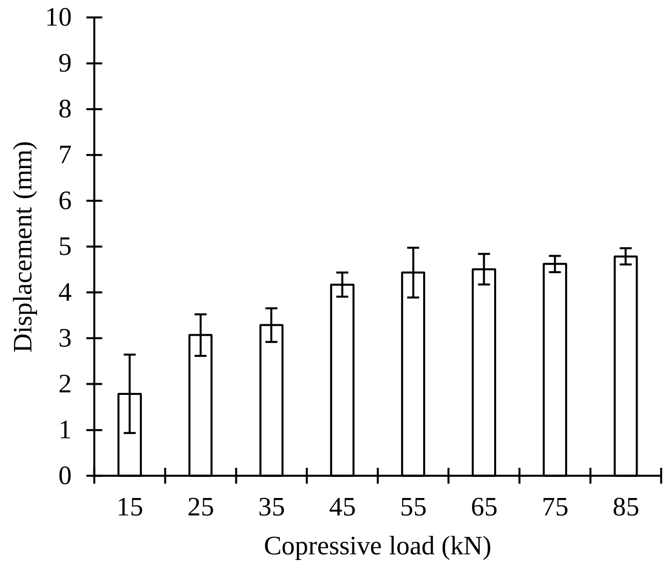

Fig. 3.1: Compressive load-displacement different healing loads for a sample with capsules.

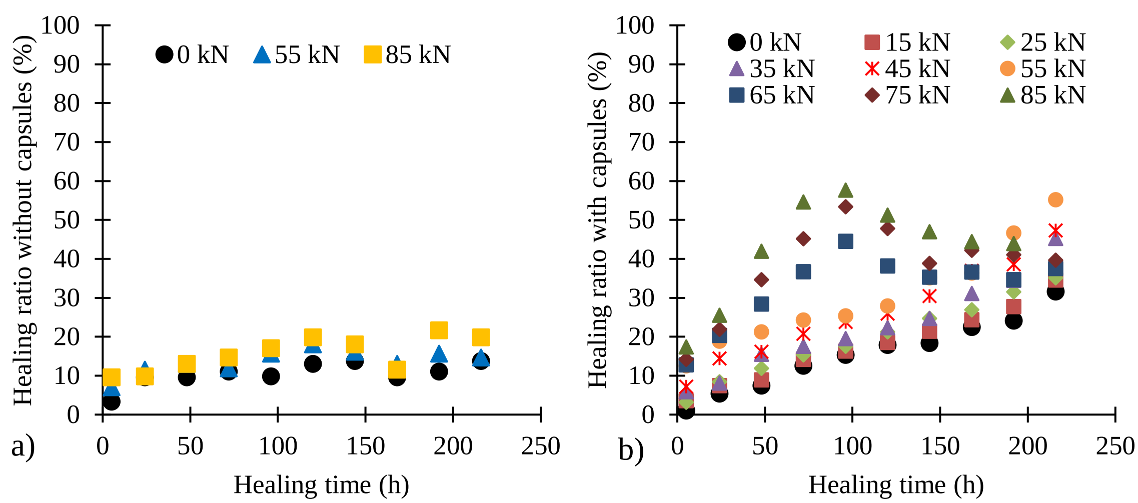

Fig. 3.2: Healing level results of asphalt mixture a) without and b) with capsules different healing loads.

Figure 3.3 (a) shows the healing level results for all asphalt mixture samples with or without capsules tested at a recovery temperature of 20 ° C and a recovery time of 5 to 216 h. In this figure, it is seen that 1) the healing levels of the asphalt samples with capsules increases as the applied load increases 2) the healing level of the asphalt samples with capsule remains constant later. Based on the results, this maximum healing level value was generally reached at 96 hours and remained stable until 216 hours. In Figure 3.3 (b), the average healing results are shown as 38.80%, 43.83% and 48.69% for the asphalt mixture samples with capsules of 65 kN, 75 kN and 85 kN, respectively. These results show that 1) as the static load ratio applied increases, the asphalt mixture with capsules has higher crack-healing levels and 2) that the asphalt is a self-healing material by its nature. It is hypothesized that the healing level reached by cracked asphalt mastic samples with capsules, can be directly related to the amount of oil released from the capsules and diffused into the bitumen. As the amount of load applied increases, the amount of oil released from the capsules increases. This, in turn, increases the rate of healing in asphalt mixtures. To prove this hypothesis, Figure 3.6 shows the results of the amount of broken capsules as a percentage of the total capsules used for the asphalt samples containing capsules and tested at healing temperature of 20 ºC.

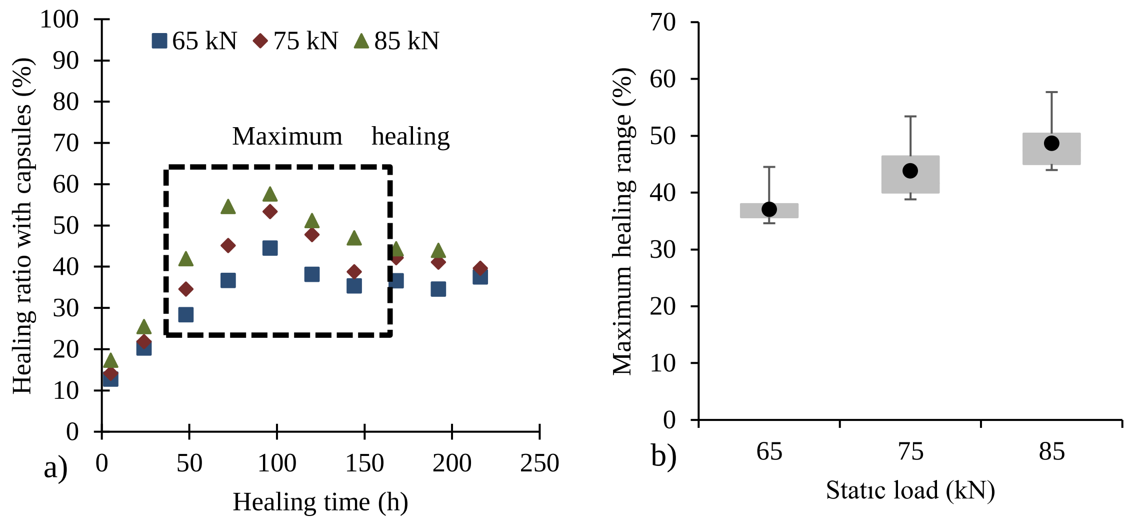

Fig. 3.3: Self-healing results for asphalt mixture samples with capsules: a) healing level with healing time and b) box plots of the maximum healing range.

Figure 3.4 shows the rates of healing between the asphalt mixture samples with and without capsules under three static loads selected to evaluate the effect of the capsule distribution on the healing of the asphalt mixtures. A linear increase is seen in the rate of healing as the load applied to the asphalt mixtures tested in this way increases. As seen in the figure, the healing rate of the mixtures with capsules was determined to be higher than that of the samples without capsules. While the healing rate of the asphalt mixture samples without capsules is between 0-20%, the healing rate of the asphalt mixture samples with capsules is between 0-60%. This change seems to depend on the amount of static load applied.

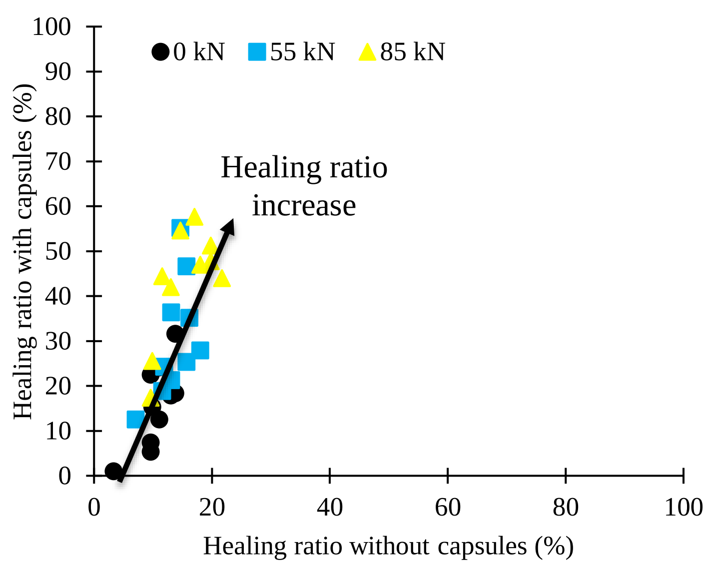

Fig. 3.4: Comparison of healing rates of asphalt mixtures with and without capsules under different loads.

A Force Effect Ratio (FER) has been defined in this study as the quotient between the i-th rest time value (FER_i) reached by a mortar sample with capsules for 0 kN ($FER_{i-0\ kN\ with/without\ capsules}$), and the healing level value reached of the equivalent mortar sample with ($FER_{i-with/without\ capsules}$), evaluated at a certain loads and time, as follows:

$$FER = \frac{FER_{i-\ with/without\ capsules}}{FER_{i-0\ kN\ with/without\ capsules}} \tag{3.1}$$

Figure 3.5 shows the change in the force effect ratio over time for both samples with and without capsules. As can be seen in Figure 3.5 (a), the FER healing changes over time. As the applied static load and the healing time increase, there is not much change in the FER. The FER is approximately similar under the applied loads of 55 and 85 kN. In Figure 3.5 (b), however, the FER changes at various healing times of the asphalt mixtures with capsules are being investigated. As the static load value applied to the asphalt mixtures increases, there is no significant increase in the FER value. However, the healing time increases about 48 h and then decreases down to 216h. The FER values at 48h varied by 1.20, 1.60, 2.08, 2.17, 2.86, 3.81, 4.65 and 4.65, respectively. As the static charge applied to the encapsulated mixtures increased depending on the healing time, no significant change was observed in the FER values. The FER values were found to be approximately close to each other.

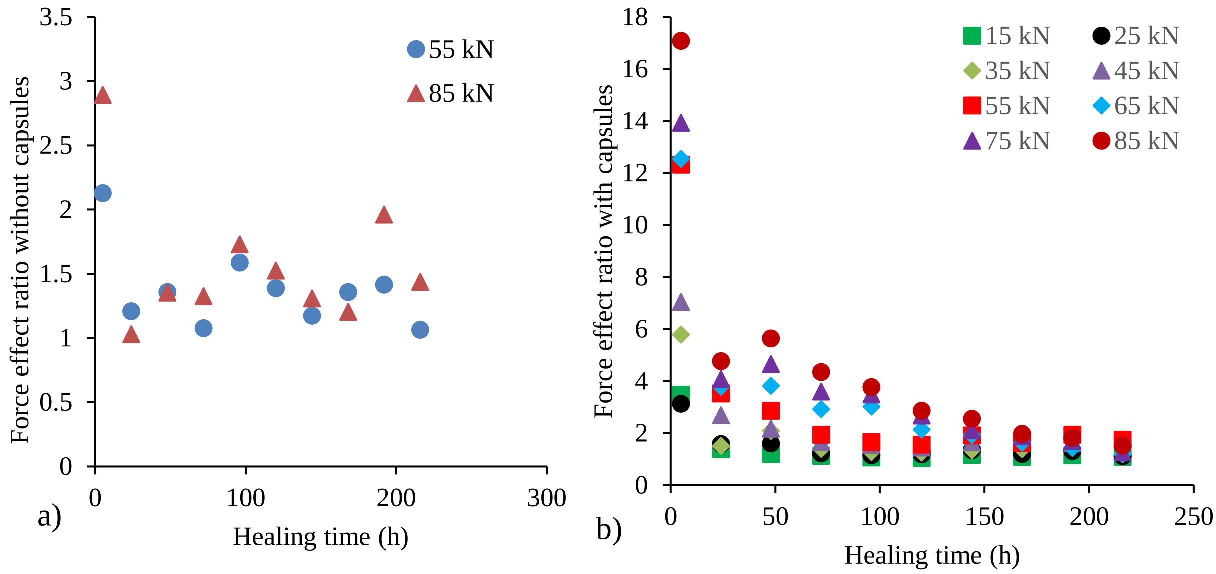

Fig. 3.5: Force Effect Ratio results for all asphalt mixture beams (a) without and (b) with capsules tested at different healing loads.

3.1. Amount of rejuvenator in the bitumen and broken capsules

In this chapter, Fourier Transform Infrared spectroscopy (FTIR) tests were used to assess the modification of bitumen in asphalt mastic when the capsules release their content. Figure 3.6 presents the results of the number of broken capsules as a percentage of the total capsules used for asphalt mixtures with 0.5% capsule content and tested at healing temperature of 20ºC. The results of broken capsules were represented only after the external compression load. As seen in Figure 3.6, as the amount of static load applied to the asphalt mixtures increases, the breakage ratios of the capsules found in the asphalt mixtures increase. The amounts of breakage of the capsules in the asphalt mixtures under static loads varied from 2.8% to 7.7%, 17.9%, 30.2%, 35.6%, 43.6%, 56.0%, 60.8% and 65.4% for the loads between 0 kN and 85 kN, respectively. As seen in the figure, static loads have a great effect on the breakage of the capsules. As the ratio of the broken capsules increases, the diffusion of the oil contained in the capsules as the rejuvenator increases. Therefore, the rate of healing also increases. As shown in Figure 3.7, the maximum healing rate increases as the ratio of broken capsules increases. This proves the theory of healing. As the static load applied to the asphalt mixtures increases, both the maximum healing rate and the percentage of fractures of the capsules in the asphalt mixtures increase. The maximum healing rate varies between 30% and 60% depending on the applied load, while the percentage of broken capsules in asphalt mixtures ranges from 0% to 70%. As can be seen in Figure 3.7, as the percentage of broken capsule content increases, the maximum healing rate also increases. This depends on the amount of oil that is emitted during breakage. This figure clearly shows the relationship between the rate of healing and the number of broken capsules.

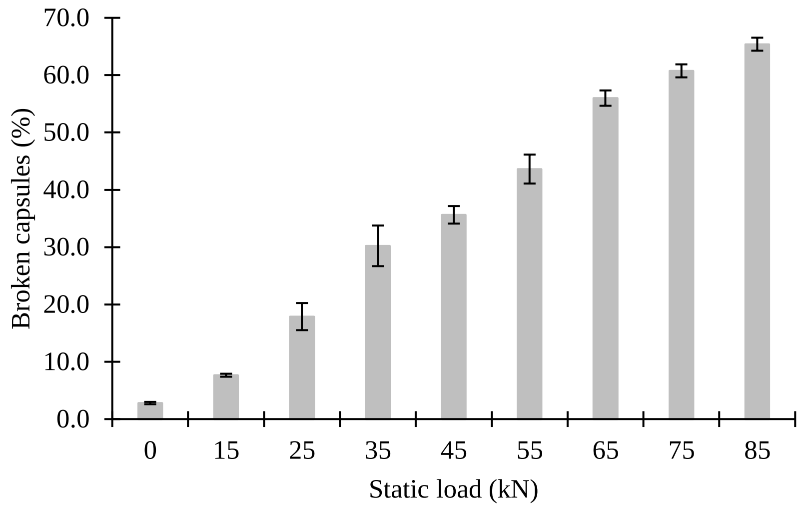

Fig. 3.6: Percentage of broken capsules for asphalt mixture samples with different loads after compression at 20ºC.

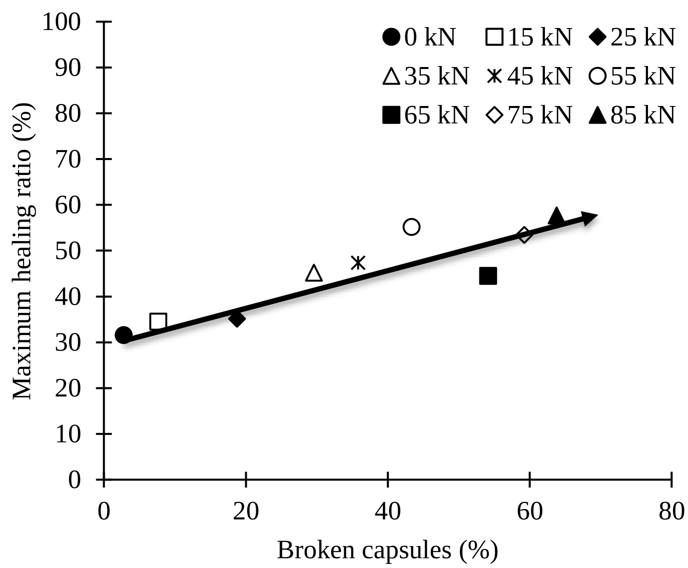

Fig. 3.7: Broken capsules for maximum healing ratio.

4. Conclusion

Under various static loads, the impact of asphalt mixtures with capsules on self-healing characteristics was examined. The following conclusions have been reached as a result of the findings:

- The amount of healing rises as more load is placed on the asphalt samples using capsules. The amount of healing in the capsule-containing asphalt samples seems to have stayed consistent over time. According to the findings, the maximum amount of healing was typically attained at 96 hours and remained consistent for up to 216 hours.
- A linear increase in the rate of healing is observed as the load applied to the tested asphalt mixture samples increases. It was discovered that the combinations containing capsules had a better healing rate than the samples without capsules.

- There is no appreciable increase in the FER value when the static load and healing time rise. The FER value rises as the static stress placed on the asphalt mixes rises. However, the healing period lengthens by around 48 hours before shortening to 216 hours.
- The rate at which the capsules in asphalt mixtures fracture increases as the static load applied to them rises. As the proportion of shattered capsules rises, the maximum healing rate rises as well. This supports the healing theory. Both the maximum healing rate and the percentage of fractures of the capsules in the asphalt mixtures increase as the static force placed on the mixtures rises.

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