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Establishment of a universal healing evaluation index for asphalt binder

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HIGHLIGHTS

- Long rest periods and few loading cycles result in improved healing.
- The effect of terminal cases on healing is greater than the effect of rest periods.
- We established a universal healing evaluation index for asphalt binder.
- The healing ranking of binders suggested by $HI_{m\text{-}c}$, $HI_{em\text{-}c}$ and $HI_{vm\text{-}c}$ are the same.
- The healing ranking of the binders is the same as the ranking of the corresponding.

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ABSTRACT

The healing performance of asphalt binder is important to the overall performance of asphalt pavement. A suitable healing evaluation index is critical in order to compare the healing performance of different asphalt binders and choose the binder with the best healing properties. However, current studies focus primarily on the healing performance of asphalt binder and seem to ignore the importance of the healing evaluation index.

In this paper, the healing performance of four different asphalt binders is analyzed. By comparing the healing curve to the initial curve, a ratio that is based on the areas created by the curves is found to reflect the healing performance of asphalt binders. Once the healing evaluation indices are established, they are also used to evaluate the mastics, and the applicability of the indices is analyzed. Also, a healing function for asphalt binder is established. The results show that the $HI_{m\text{-}c}$ index (based on the curve of the normalized modulus versus load cycles), the $HI_{em\text{-}c}$ index (based on the curve of the elastic modulus versus load cycles) and the $HI_{vm\text{-}c}$ index (based on the curve of the viscous modulus versus load cycles) suggest the same rankings for the healing of the studied binders. The healing ranking of the binders is also the same as that of the corresponding mastics evaluated by the $HI_{m\text{-}c}$ index. Based on the established healing function, it is found that the effect of terminal cases on the healing performance of asphalt binder is greater than the effect of rest periods.

1. Introduction

The ability of asphalt materials to heal (recover) has attracted the attention of many researchers and, as a result, some valuable studies have been performed [1–8]. It is clear that asphalt materials with good healing properties can extend the service life of asphalt pavement. So, it is necessary to establish criteria for selecting asphalt materials that exhibit good healing properties. Therefore, a suitable healing evaluation index needs to be established.

The existent healing evaluation indices for asphalt materials can be classified into three categories. The healing evaluation index in the first category is defined as the ratio of the recovered property (described by a certain parameter) following a rest period to that property measured prior to the rest period. Kim and his colleagues used dissipated pseudo strain energy (PSE) to describe this property [3,9]. Si et al. used pseudo stiffness [10,11], and Tan et al. used the dynamic modulus [12] to describe this property. It is well known that the number of load cycles that asphalt materials can bear increases after rest periods, and that such rest periods extend the service life of the pavement. The second category of healing indices is specifically service life-related [13–15]. The percentage of increase in the number of cycles to failure was used by Daniel and Kim to evaluate the healing characterization of different asphalt mixtures [13]. They calculated this index based on the differences between control tests without rest periods and healing tests

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in which the specimens were allowed three times of rest. A similar idea was employed by Tan et al. to evaluate the healing of asphalt binder, but the loading mode was different, and the index was normalized by the decrease in the percentage of the dynamic modulus value when the loading stopped [12]. Liu et al. used the ratio of the number of load cycles after the rest period to the number of load cycles before the rest period to express healing, provided that the resilient modulus value after the rest period reached the same value as before the rest period [14]. Santagata et al. considered the loading frequency and defined the relative healing index as the increased number of cycles divided by the rest period and loading frequency [15]. The third category of healing indices uses the healing rate or damage rate after healing as the criterion [16,17]. Breysse and his colleagues used the re-damaging rate that they defined as the ratio of the loss in modulus value to the duration of time required to lose the modulus values in order to study the effects of rest time [16]. The slope of the healing curve, called the healing rate, was established by Kim and Roque to evaluate the healing properties of different asphalt mixtures [17].

These healing indices can reflect the healing characteristics of asphalt materials to some extent and are useful in ranking the healing properties of different asphalt materials under certain conditions. But these indices have two disadvantages. One is that the healing index in the first category is useless when the loading stops early and the rest periods are sufficient, because under that condition the measured properties (dynamic modulus, pseudo stiffness, etc.) of asphalt materials can recover totally after a certain amount of time, after which the index cannot change. The other disadvantage is that in controlled strain mode for fatigue testing, the damage rate decreases with an increase in the number of load cycles, and the healing performance worsens with an increase in the rest time and decrease in the number of load cycles, as evaluated by the index. In order to solve these problems, Shan compared the three healing indices and established one that can solve the problems [18]. However, the index that was chosen as the best lacks theoretical meaning, and a more precise definition is needed.

Based on this previously assimilated information, the healing performance of four different asphalt binders is studied in this research. The positions and shapes of the curves of the modulus versus the number of load cycles before and after healing are analyzed. A healing evaluation index that is based on the areas created by the curves is established, and a healing ranking of the studied binders is obtained. The healing function is established based on the index and the healing results. Finally, the applicability of the index is examined.

2. Proposed methodology

By comparing the curve after rest (referred to as the *healing curve*) to the curve before rest (referred to as the *initial curve*), it is found that the healing curve becomes closer to the initial curve with an increase in the duration of the rest period and a decrease in the number of loading cycles. If the healing curve is closer to the initial curve, the area between the two curves decreases. And the closer the two curves are to each other, the better the healing performance of asphalt binders. In addition, the area below the initial curve should also be considered. If this area is large, it is difficult for the binder to heal. Based on this hypothesis, the ratio of the area between the two curves (A_d) to the area below the initial curve ($A_{\text{after}} + A_d = A_{\text{before}}$) is established as the healing index, as shown in Fig. 1a. The equation is shown as follow

$$HI = A_d/A_{\text{before}} \quad (1)$$

where HI is the healing index, A_d the area between the healing curve and the initial curve and A_{before} is the area below the initial curve.

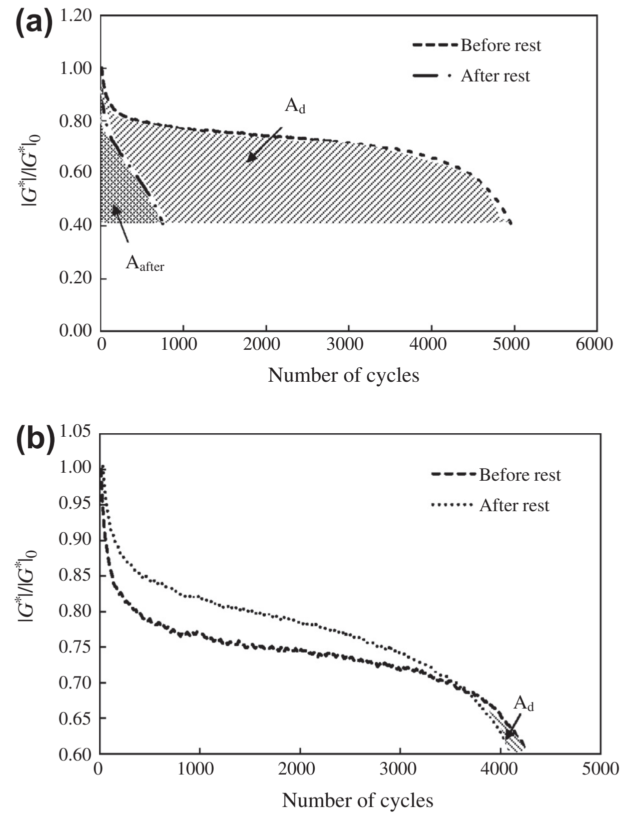

Fig. 1. Schematic of the healing index calculation for: (a) normal conditions and (b) special conditions.

Based on the curve of the normalized modulus versus number of load cycles, the index is defined as $HI_{m\text{-}c}$. In order to analyze the index for asphalt binder and study the applicability of the index, the area ratio of the curve of the elastic modulus versus the number of load cycles and the area ratio of the curve of the viscous modulus versus the number of load cycles are also calculated, and the indices are $HI_{em\text{-}c}$ and $HI_{vm\text{-}c}$, respectively. The healing function is established based on the healing results and $HI_{m\text{-}c}$ index. To prove the applicability of the index, the index is applied for mastic, which is composed of asphalt binders and mineral powders. The healing ranking of the asphalt binder and the ranking of the mastics made with the same asphalt binder are the same, which means that the index is reasonable.

Some special conditions occur whereby the healing curve is above the initial curve, as shown in Fig. 1b. It is believed that this occurrence is caused by hardening, and it is assumed that the two curves overlap in this part. Then, the A_d is calculated, as shown in Fig. 1b.

3. Materials and test methods

Two PG70-22 asphalt binders and two PG64-22 asphalt binders were selected for this study. All are standard, unmodified asphalt materials. For the reminder of this paper, these materials are labeled as generic binders A, B, C and D. The performance grade (PG) of binders A and B is PG70-22, and that of binders C and D is PG64-22. The detail information about the binders can be found in reference [12]. These binders were aged in a rolling thin film oven (i.e., RTFO-aged) prior to testing to simulate the effect of mixing and compaction. Two kinds of mastics were also used for this study. One is labeled as A_m, which is made of binder A and mineral powders, and the other is labeled as B_m, which is made of binder B and the same mineral powders. The ratio of mineral powder to binder is 1.2 by weight.

Laboratory testing was performed using a TA rheometer. Two types of tests were conducted: the stress (strain) sweep test and the healing test. All tests were conducted using an 8 mm diameter parallel plate and 2 mm gap setting. The test temperature used is 25 °C.