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Evaluation of moisture conditioning effect on damage recovery of asphalt mixtures during rest time application

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HIGHLIGHTS

- Using energy methods in assessing the damage recovery of asphalt concrete.
- Studying the interaction of moisture damage and healing phenomenon.
- Studying the effects of aging, temperature and rest time on the moisture susceptibility.
- Introducing a recovery index based on the energy parameter of (NDCSE).

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ABSTRACT

In the present research it has been attempted to investigate how the damage recovery potential of asphalt mixture scan be affected by moisture conditioning. To this end, the cyclic IDT tests were conducted on moisture conditioned and dry specimens under a combination of parameters such as temperature, aging and rest time and a new energy parameter named as normalized dissipated creep strain energy was used. According to this new parameter, moisture conditioning the specimens does not significantly affect their damage recovery potential for a constant load to strength ratio. Rest time and aging are the most influential factors on the damage recovery potential. Aging the specimens, considerably decreases their ability to recover and also decreases the effects of moisture conditioning and temperature change on this ability.

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1. Introduction

Recovery potential of asphalt concrete mixture, sometimes is referred to as self-healing potential, is a spontaneous behavior of these mixtures during which the distress level in the asphalt concrete decreases. This recovery that can be due to micro damage healing, linear visco-elasticity and thixotropy behavior of asphalt concrete, improves its mechanical properties [1,2]. Moisture damage, which has been the focus of this study, can be considered as an environmental solicitation. Moisture sensitivity of asphalt mixture is among the most important causes of distresses in asphaltic pavements. Although the effect of moisture on asphalt mixtures, unlike the traffic loading and thermal stress, is not considered as a major solicitation, penetration of moisture through the asphalt mixtures can increase the pavements vulnerability to the other two solicitations [3–5]. The moisture susceptibility of the asphalt concrete can be influenced by a variety of factors. A part of these factors are related to the characteristics of the asphalt mixture and its constitutive components and another part of the factors are dictated by the construction and prevailing environmental conditions that have been extensively discussed in literature [6–8].

There are a considerable number of researches that have a consensus on the positive effects of rest periods on asphalt concrete fatigue life. Sterling and Raithby were among the first researchers who evaluated this effect [9]. This potential in asphalt concrete improves its mechanical properties. A glance over literature indicates that there are different mechanical criteria and responses through which the effect of rest time on mixtures mechanical behavior can be investigated. Methods relying on fracture mechanics framework and energy concepts have gained a great attention in the recent decades. Research of Dijk and Visser [10] was one of the first works that used energy concepts in evaluating the rest time effects on fatigue behavior of asphalt concrete. Since then, the energy methods have been extensively studied and used in interpreting the mechanical characteristics of asphalt concrete. Shen and her coworker have studied different energy criteria in

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evaluation of rest time effect on fatigue behavior of asphalt concrete [11]. Initial dissipated energy approach, cumulative dissipated energy approach, work ratio, dissipated energy ratio, and finally the ratio of dissipated energy change were the five energy criteria that were investigated by them. Shen and her coworker believed that, energy dissipation was a promising tool to evaluate materials fatigue behavior [11]. Among the introduced energy approaches, the ratio of dissipated energy change (RDEC) was developed by Shen and Carpenter [11]. This parameter was an improved version of DER (dissipated energy ratio) parameter that had been primarily introduced by Carpenter and Jansen [12].

During the load application to a material, the area under stress–strain curve indicates the amount of its energy intake. When the load is applied cyclically to a visco-elasto-plastic material such as asphalt concrete, the stress–strain curve creates a loop called hysteresis. The area inside the loop could be an exhibitor of the amount of energy that creates damage and plastic deformation in the material. In various studies [13–15] the mentioned area inside the loop was introduced as Dissipated Creep Strain Energy (DCSE) parameter and was used to study the mechanical behavior of asphalt concrete and to develop its certain fracture characteristics. Lytton and his coworker have conducted extensive work on modeling the healing behavior of asphalt concrete mixtures. Their model was based on a relationship among stiffness changes in the mixtures as damage occurs, the Dissipated Pseudo Strain Energy (DPSE) rate of change and the mixtures' fracture properties such as micro-crack length changes and mixtures' cohesive surface energies [16]. Kim and his coworkers' researches can be also considered as one of the pioneers of using DPSE changes as a criterion for healing potential of asphalt concrete [1]. In this work the chemical healing of asphalt concrete with the elimination of viscoelastic properties of the binder was studied [1].

Literature study thus far shows that dissipated energy is an important factor in gaining comprehensive information about the materials mechanical behavior. Using the same concept, Birgisson and his co-workers have attempted to find the effect of moisture damage on fracture mechanics of asphalt concrete [13]. Birgisson and his co-workers and Roque and his co-workers defined the concept of DCSE threshold [13,15]. According to them and some other researchers, taking DCSE into account has the advantage of considering the real behavior of the asphalt concrete over a wide range of stresses including destructive and non-destructive stresses [13,17,18]. According to the presented studies, fracture energy and DCSE show the threshold for sudden fracture and the micro-cracks accumulation before damage respectively. Birgisson believed that the energy responses can not only control the initiation and propagation of crack in asphalt concrete, but can also be effectively used to evaluate the detrimental effects of water [13].

Gaining a comprehensive perspective on pavements mechanical behavior in field entails gathering data about the asphalt concrete behavior under different environmental conditions as a determining structural part of the pavement. There are various environmental and external parameters that can affect the mechanical traits and damage recovery potential of asphalt concrete such as moisture infiltration, temperature, aging, and rest time duration. Moisture damaged asphalt can have a certain behavioral and mechanical properties which have been extensively studied in previous researches; however, it is almost unknown that how the moisture can affect the damage recovery potential in asphalt concrete. In the other words, can a moisture damaged asphalt concrete specimen recover from damage? Although the energy concepts of adhesion have long been used in recognition of moisture susceptibility of asphalt-aggregate system [19–21], there seems to be few researches in which the damage recovery potential of moisturized asphalt concrete specimens has been studied. The works performed by Birgisson and his coworkers [13], Apeagyei and his coworkers [22], and Sol-Sanchez et al. [23] are among those investigations. There are even fewer works that have used the energy based responses in this regard. In the present study, the cyclic IDT tests have been conducted on dry and moisture conditioned samples. In order to consider the effect of some important external and environmental factors on the tests results, temperature, aging and rest time duration were applied as the variable parameters. Afterwards, the samples ability to recover from moisture damage has been investigated using a modified energy response named as normalized dissipated creep strain energy (NDCSE).This parameter is obtained by dividing the dissipated creep strain of the specimens by their permanent deformation [24]. In other words, it is the average energy consumption of the material to sustain 1 μm/m deformation. According to previous studies, the DCSE of the specimens in IDT strength test can be remarkably influenced by their permanent deformation [24]. In a specimen with a tendency to greater permanent deformation the strength would be low while a specimen with larger strength is expected to be more resistant to permanent deformation. Since the DCSE is obtained from two components of deformation and strength, it is possible that the two different mentioned types of specimens exhibit an almost the same DCSE. Therefore, using the DCSE in IDT strength test could be misleading criteria [24]. Mehrara and Khodaii have studied the applicability of the NDCSE parameter in IDT strength test and have shown that the NDCSE can better interpret the specimens' behavior under different testing circumstances [24]. On the other hand, it is believed that NDCSE can provide comparable results with the DCSE response in cyclic tests [25].

2. Objectives and test procedures

In the present research, it is intended to compare the damage recovery potential (because of combined effect of healing, viscoelasticity and thixotropy) of dry and moisture conditioned hot mixed asphalt concrete using the NDCSE response and to study the effect of rest time, aging and temperature on this potential. Therefore, the application of a new energy based parameter and studying the damage recovery behavior of dry and moisture conditioned specimens during load application process can be considered as the main contributions of the work. During the research, cyclic IDT tests were conducted on asphalt concrete specimens and their energy intake was obtained under different conditions. Then the NDCSE versus load cycle was drawn for each sample. The test parameters were the ratio of rest time to loading time (0, 1, 2, 4), ageing (un-aged, aged) and temperature (4.4 °C, 21.1 °C). It is worth mentioning that the findings of the paper can lay the foundation for finding an answer for the question whether application of dry periods after raining can enhance the recovery potential of real pavements? Or can the moisture infiltration itself have an irreversible effect on asphalt concrete damage recovery potential?

The results of pilot tests (which are not presented here for the sake of brevity) indicated that the stress to strength levels lower than 0.3 cannot initiate damage after reasonable loading cycles (particularly at lower temperature 4.4 °C). This could be explained by the higher elasticity of the specimens at that lower temperature. The formation of damage can be detected when the cumulative strain curve versus the load cycles enters its linear phase or when the hysteresis loops area (the dissipated energy) start to increase with a constant rate from one cycle to another. According to these tests, stress to strength levels higher than 0.3 resulted in a premature macroscopic damage (especially at higher temperature of 21.1 °C) and prevented the rest periods to have an effective recovery effect on specimens. Due to these explanations, the stress to strength ratio was chosen equal to 0.3 for cyclic IDT tests.

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