



Effect of aging conditions on the fatigue behavior of hot and warm mix asphalt

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HIGHLIGHTS

- The aging process has a significant effect on fatigue life asphalt.
- Warm mixtures containing sasobit had a higher fatigue life than hot mix.
- Simple performance test failed to predict fatigue life of asphalt aging.
- DE method, were able to characterize the fatigue behavior of mixtures aging.

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ABSTRACT

The aging process has a significant effect on the mechanical properties of asphalt mixtures, especially on fatigue parameter. Many approaches have been suggested to better understanding of the fatigue behavior of asphalt mixes. However, in many of these cases, the effects of aging are not considered. In this study, investigations were conducted to more accurately predict the fatigue life of asphalt mixes, independent of their ages. In this regard, the responses of the existing fatigue models in a wider range of asphalt mixtures were validated. For this purpose, hot and warm asphalt mixtures were used in both aged and unaged conditions. For the production of warm mixtures, Sasobit and RheoFalt were used as modifier additives. Indirect tension (IDT) test, resilient modulus and four-point bending fatigue beam test were performed separately WMA and HMA specimens. The results indicated that in all specimens, the aging of the asphalt mixture was always accompanied by increasing fracture energy and failure resistance. In addition, it was also found that those fatigue models that were based on simple performance tests failed to well predict the fatigue life of mixtures independently of the type of compounds, aging and loading conditions. Eventually, validations indicated that the behavior of dissipated energy during repeated loading to failure, have a significant role to precisely characterize the fatigue behavior independent of their age.

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1. Introduction

It is generally believed that fatigue cracking initiates at the bottom of the asphalt mixture layer (where the tensile stress is the highest) and then prorogates up to the surface and eventually a network of cracks at the surface of the pavement will be created. Fatigue behavior of asphalt mixtures is affected by some factors such as type of bitumen, type of mixture, type of aggregate, air void percentage and stiffness [1]. Also, the results of previous research

indicate that the aging process of bitumen significantly affects the performance of asphalt mixtures and it can change the physical/chemical properties of bitumen and causes a failure mechanism and accelerates the deterioration process in asphalt mixtures [2]. One of the key parameters that characterizes the failure mechanism is the fatigue life, which is one of the most important mechanical properties to determine the service life of the asphalt pavement, in this purpose, many researchers have proposed several fatigue models in order to better understand the fatigue behavior and predict the service life of asphalt mixtures. Most of these approaches are based on traditional phenomenological approach and the model coefficients may be varied depending on loading, laboratory conditions, and the type of materials [3].

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Fatigue behavior is generally analyzed in both phenomenological and mechanistic approaches. The mechanistic approach involves the dissipated energy, fracture mechanics, and continuum failure damage methods [4].

The studies on fatigue behavior of HMA based on dissipated energy concepts indicated that there is a strong relationship between the cumulative dissipated energy and the number of loading cycles to failure. However, it was highly material-dependent and had to be a special mixture to be made and used [5].

The initial dissipated energy-based approach as one of methods to characterize fatigue behavior of HMA indicated a fairly strong relationship between the initial dissipated energy at 50th cycle and fatigue behavior in HMA. However, this approach does not consider the effects of healing [6].

The ratio of dissipated energy change (RDEC) method is strongly able to predict fatigue life in a HMA. So that the value of (P) defined as the rate of dissipated energy change in (PV), is directly related to the fatigue life, and this relationship is independent of the loading conditions and the type of mix. However, repeated complex experiments are required to obtain a full characterization of the fatigue behavior in a wider range [7].

The fracture energy parameter obtained by measuring the area under the stress-strain curve of indirect tension test as a simple performance test-based parameter was able to predict the fatigue life of HMA near field condition. In this purpose the fracture energy-based model has been suggested that was able to prove a relatively strong correlation with the fatigue life of HMA [8]. Also a model has been previously proposed based on amount of the fracture energy density and initial dissipated energy at the 50th loading cycle for better characterization of asphalt mixture behavior. The main advantage of this method is achieving to the results through simple performance tests. However, this model depends on the type of materials and mixture condition as well [9].

The effects of hot and warm asphalt mixture have been evaluated and compared through different fatigue approaches. Investigations proved that energy approaches, such as ratio of dissipated energy change (RDEC) and the Rowe-Bouldin method were able to accurately estimate the fatigue life of hot and warm asphalt mixtures with approximately same accuracy, and the result indicated that the 50% reduction criterion is not a suitable method for determining the fatigue fracture point of hot and warm asphalt mixtures [10].

2. Research background

Although the results obtained from some of these models indicated a strong correlation with the tests responses, but the majority of these studies have been restricted to the HMA and the effects of aging were not considered. Therefore, further studies are required to determine long-term performance of asphalt mixtures. The aging of Bitumen is a chemical oxidation process that results in the formation of carbonyl and sulfur oxide, which affects some of the properties of bitumen such as stiffness, adhesion and flexibility, and consequently makes the asphalt mix brittle, and also reduces the service performance of pavement [11,12]. The weather conditions have a significant effect on aging process of asphalt mixtures. The effect of temperature on the aging process was measured and three temperatures of 30, 50 and 70 °C were selected for this purpose. The results showed that the effect of temperature on the aging process caused by UV radiation could be ignored at 50 °C. When the temperature reaches 70 °C, the interaction between temperature and UV-induced aging increases the rate of oxidation and evaporates volatile matters of bitumen [12].

The ray of sunlight and UV radiation leads to aging of bitumen over the service life of asphalt pavement. Therefore, when pave-

ments are exposed to these rays for a long time, they will be brittle and cracked [13]. The applicability of WMA has been increasing in recent years due to its ability to reduce the temperature of mixing asphalt. WMA is produced at temperatures between 15 °C and 40 °C less than the HMA. This reduction in the mixing temperature of WMA directly decreases the energy needed to produce this mixture. Its major benefits involve reducing production costs and greenhouse gases emissions [14–15].

The comparison that previously performed between WMA and HMA based on the energy method by a four-point bending test and at four levels of controlled strain indicated that the amount of initial dissipated energy and cumulative dissipated energy in WMA is less than the HMA one [16]. Comparison between hot and warm mix asphalt containing recycled aggregates showed that the performance of these two types of mixture were similar in rutting behavior, moisture sensitivity and cracking [17]. Also, Safaei et al. concluded that the difference between the fatigue performance of WMA and HMA are reduced after applying long-term aging [18].

In 2017, a study was conducted with different methods to compare the fatigue life of these two types of mixtures with a four-point bending fatigue beam at four levels of controlled strain 650, 800, 1000 and 1200. The test frequencies were 7.5 and 15 Hz. The test was carried out at 20 °C, the results indicated that at the test frequency of 15 Hz, fatigue life of the WMA was higher than the HMA one [10].

As mentioned, most existing fatigue approaches have both strengths and weaknesses. However, the results obtained from some models successfully predict the response of the experiments, but most of these researches were limited to asphalt mixtures, and the aging effects in asphalt mixtures were not considered. In this study, the effect of long-term aging on mechanical properties of a wide range of hot and warm mix asphalt was investigated. For this purpose, the relationship between aging and key engineering parameters such as resilient modulus, fracture energy, failure resistance and dissipated energy was evaluated. Therefore, the main objective of this study is evaluating the performance of these approaches and validation of their models by considering the wider range of specimens such as modified hot and warm asphalt mixtures with the effect of long-term aging on specimens.

3. Experimental program

In this study, four types of tests, including four-point bending fatigue beam, indirect tensile strength and resilient modulus, as well as aging simulating experiment were performed. Fatigue beam test was used to characterize the fatigue behavior of asphalt mixtures similar to field conditions. Indirect tensile strength test was used to measure the fracture energy density of the mixture under maximum load. And, resilient modulus was obtained by indirect tensile experiment under cyclic loading, and the aging simulating experiment was performed using the Sharp method instruction to simulate long-term aging of the asphalt.

3.1. Material properties

The asphalt binder used in this study is a pure bitumen with penetration point of 60–70. This binder is used for the preparation of hot and warm specimens. Also, two types of additive involve, Sasobit and RheoFalt, have been used separately for preparation of modified warm asphalt mixtures. The stone materials were limestone aggregates obtained from Asbcheran Mine of Tehran Province in Iran. Specifications and properties of additives and stone materials are shown in Tables 1 and 2, respectively.

3.2. Mixing design

Generally, two types of (continuous) dense grading range, namely grading (1) and (2), were selected for the production of asphalt mixtures according to the international standard AASHTO T27. The optimum asphalt binder content for each of these aggregates was calculated according to the Marshall mixing design. Based

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