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# Comparative evaluation of fatigue resistance of warm fine aggregate asphalt mixtures

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## HIGHLIGHTS

- Using WMA additives increased the stiffness of the asphalt mixture.
- Sasobit mix has dissipated less energy with cycles than other mixes.
- VECD method showed insignificant difference between HMA and WMA in fatigue resistance.
- FAM samples showed less variability among replicates than AMPT-sized samples.

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## ABSTRACT

Fatigue cracking is one of the crucial distresses in asphalt pavements that affect its service life and rehabilitation process. The resistance of asphalt mixtures to fatigue failure in the laboratory experiments is influenced by several factors such as temperature, loading frequency, loading mode, sample type and geometry. This study focused on the evaluation of fatigue performance of different types of warm mix asphalt (WMA) mixture and comparing them with a hot asphalt mixture (control mixture). Warm fine aggregate mixtures (W-FAM) were fabricated using three different WMA additives: Advera, Sasobit, and Rediset which were short-term aged in the laboratory. Then, the W-FAM specimens were exposed to shear stress oscillation test by applying damaging stress level in the dynamic mechanical analyser (DMA) to examine the material fatigue resistance. The test results were analysed using the viscoelastic continuum damage (VECD) approach. The W-FAM exhibited lower dissipated pseudo-strain energy (DPSE) than the control mixture. However, there was no statistical significant difference between the W-FAM and control mix in terms of the number of cycles to failure resulted from the VECD analysis.


## 1. Introduction

Fatigue cracking is one of the main distresses in the asphalt pavements that affect its service life. Studying fatigue performance attracted the attention of many researchers since 1858 due to its complexity and importance in rehabilitation or replacement decision of the entire pavement [1–3]. More robust understanding of factors that affect fatigue cracking would advance the design of long lasting pavements.

The resistance of asphalt mixtures to fatigue failure in laboratory experiments is affected by various factors: temperature, loading frequency, loading mode, sample type and geometry. Evaluation of fatigue resistance can be performed using Asphalt Mixture Performance Tester (AMPT) apparatus on full mixture field-cut or lab-fabricated specimens. However, the heterogeneity of full asphalt mixture specimens causes high variability in fatigue testing results, which makes it difficult to predict field performance with reasonable reliability [4,5]. An alternative is to test fine aggregate mixture (FAM) specimens, which contain the fine portion of the mixture. FAM specimens have higher uniformity and yield less variability in fatigue testing results than full mixture-sized samples [6].

Several analytical approaches have been used to determine fatigue performance; however, the viscoelastic continuum damage

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(VECD) approach that implements Schapery's theory is the most developed and used [7]. The main principle of VECD is calculating the dissipated pseudo-strain energy (DPSE), which is based on the concept of separating the dissipated energy due to damage from energy dissipated because of viscoelastic behaviour. Masad et al. used that concept and identified three main components for DPSE that are associated with change in phase angle between load cycles; change in phase angle within single cycle; and change in stiffness between cycles [8]. Masad et al. showed that the VECD approach can unify the predictions from the strain and stress controlled loading modes.

The fatigue performance of warm mix asphalt (WMA) is of interest because of the significant increase in using WMA additives given their environmental and energy-saving advantages. For example, Zelelew et al. used the fatigue factor ($|E^*|\cdot\sin\delta$) which combines the dynamic modulus ($|E^*|$) and the phase angle ($\delta$) [9] to study fatigue resistance of WMA. The study concluded that using WMA additives reduced the fatigue cracking resistance for asphalt mixtures. Kim et al. used the Dynamic Shear Rheometer (DSR) to test asphalt binders mixed with two WMA additives: Aspha-min and Sasobit [10]. The study compared the shear complex fatigue factor ($|G^*|\cdot\sin\delta$) and also concluded that WMA additives reduced the fatigue resistance of the asphalt binders. Haggag et al. tested long-term aged WMA mixtures by the uniaxial cyclic direct tension–compression test [11]. The experimental results were analysed by the VECD analysis approach to evaluate the fatigue performance. The results showed that there was no significant difference between hot mix asphalt (HMA) and WMA samples in fatigue cracking resistance except for the WMA prepared using Advera additive. Safaei et al. also tested long-term aged WMA and HMA and showed that HMA has better fatigue performance compared with WMA mixtures [12].

## 2. Objectives

The main purpose of this work is to evaluate the fatigue cracking resistance of short-term aged warm fine aggregate mixtures (W-FAM) modified with different WMA additives. Shear stress oscillation test was performed on control FAM without WMA additive and W-FAM modified with three additives (Advera, Sasobit, and Rediset). The test results were analysed using the VECD approach to determine the number of cycles to fatigue failure.

## 3. Sampling and testing scheme

In order to study the influence of WMA additives on fatigue resistance of asphalt mixtures, a testing scheme was developed by fabricating fine aggregate mixture (FAM) samples in the laboratory. Samples were prepared using "Gabbro" aggregate and polymer modified PG 76-22 asphalt binder. Gabbro aggregate is imported to the State of Qatar from the United Arab Emirates. The bitumen was originally imported from the Kingdom of Bahrain and locally modified with SBS polymers to produce PG76-22 grade. The modified asphalt binder was mixed with three WMA additives: Sasobit, Advera, and Rediset using high shear mixer at dosages of 2%, 5%, and 0.5% of binder's weight, respectively.

Sasobit, is an organic (wax) WMA additive produced from natural gas using the Fisher Tropsch process of polymerisation by Sasol Wax in South Africa. It has the potential to increase the stiffness of asphalt binder and reduce its viscosity in order to help mixing and compaction at lower temperatures [13]. Advera is a water-based additive that releases water particles while mixing with binders to lower its viscosity by foaming mechanism [14]. On the other hand, Rediset LQ is a chemical liquid additive that has no influence on the mechanical properties of asphalt binder; however, it lessens the viscosity to allow lower mixing and compaction temperatures [15].

Dynamic Shear Rheometer (DSR), shown in Fig. 1(a), from Malvern (Kinexus Pro model), was used to perform the fatigue testing. The instrument was provided with a special fixation for finger samples end connections as shown in Fig. 1(b). The upper fixation rotates while the lower is fixed. The maximum shear force the machine can reach is 600 kPa. In addition, the machine was provided with a temperature chamber (Fig. 1(a)) that keeps the temperature uniform at 25 °C during the test.

The aggregate gradation for the FAM design is based on the proportional ratio of Job Mix Formula (JMF) from the full HMA gradation. Table 1 shows the original mix design and FAM gradation [16,17]. FAM gradation was calculated starting from 1.18 (N16) sieve size by dividing the retained value of all sieves from 0.6 (N30) sieve by the passing percentage of 1.18 (N16) sieve size. The mixture was prepared in the laboratory to achieve the required sample height of 110 mm after compaction and provide enough height for cutting it for testing at 50 mm height.

Asphalt binder content was estimated for the FAM design by burning the binder content from a prepared and separated loose HMA sample using the ignition oven. Loose HMA mix was separated by hand and then sieved to obtain the portion of the mix with particles passing sieve 1.18 mm (N16). This fine mix was placed in the ignition oven to burn the binder and determine its weight. The results showed that the binder content of fine mix part was 7.3% of the total mix weight. Two samples of 150 mm diameter were prepared for each additive type. Table 2 shows the mixing and compaction temperatures for different additives used in this study.

Mixing and compacting asphalt mixtures at lower temperatures reduces the ageing that could occur in the material due to heating. The WMA mixtures were mixed at 145 °C based on common practice and previous knowledge with polymer modified binders with WMA additives. The specimens were compacted at 116 °C following the recommendations of the NCHRP 763 report and it also meets the typical criteria of compacting the WMA samples at least 15 °C below of the HMA compaction temperature [18,19].

A total of six cylindrical specimens were extracted from the compacted samples by coring and cutting them to 12 mm diameter and 50 mm height. A drilling machine (Cardi brand) was used with 12 mm inner diameter coring bit to extract the specimens from each mixture sample. On average, the percentage of air voids was about 3% in the cylindrical samples.

## 4. Experimental work

### 4.1. Stress sweep test

Categorising the linear and nonlinear viscoelastic properties of tested materials was done by performing stress sweep test [20]. The test was started from a stress value of 1 kPa and increased by 25 kPa every 20 s until it reached 589 kPa before termination.

Experimental data were analysed by calculating the strain slope at each stress level and plotting it against stress level as shown in Fig. 2. The figure indicates that any oscillation stress level before 150 kPa can be considered to be in the linear viscoelastic region of the materials, while any stress level above 150 kPa oscillation stress might expose the material to nonlinearity and then damage. This test was performed at 25 °C temperature and 10 Hz frequency.

### 4.2. Relaxation test

Relaxation test, which involves applying constant strain for a certain period of time, was performed to measure the relaxation modulus of the material. The strain amplitude value used was