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Variation of initial stiffness under variable strain levels and binder content

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ABSTRACT

At moderate pavement temperature, the initial stiffness of asphalt concrete is controlled by the asphalt binder content and can sustain the various vehicular loading. The aim of the present investigation is to monitor the variation in the initial flexural stiffness percentage throughout the asphalt concrete fatigue life among variable constant strain levels and asphalt binder content. Mixtures of Asphalt concrete were prepared in the laboratory using the optimum binder content and extra mixtures were prepared with a variation in the binder content of ± 0.5% within the optimum asphalt contents as a service tolerance during the asphalt mixture preparation process. The mixtures were compacted in a slab mold using laboratory rollers. Beam specimens of asphalt concrete have been obtained from the prepared slab samples and tested under dynamic flexural stresses under three constant microstrain levels of (750, 400 and 250) and tested for flexure at 20℃ environments. It was noticed that the asphalt concrete fatigue life at 400 microstrain level decline by (95, 86.6 and 96.5) % for mixtures prepared with (4.8, 4.3 and 5.3) % asphalt cement binder respectively as compared with mixtures sustaining constant microstrain level of 250. However, the fatigue life at 750 microstrain level decline by (98.1, 83.3 and 96.5) % for mixtures prepared with (4.8, 4.3 and 5.3) % asphalt cement binder respectively as compared with mixtures sustaining constant microstrain level of 250.

Keywords: Constant strain level, asphalt concrete, binder, stiffness, fatigue life, flexure

1. INTRODUCTION

Ziari et al., (2020) assessed the impact of using various microstrain levels on the behavior in fatigue of asphalt concrete mixtures. The four-point dynamic flexural stress test results revealed that the strain levels had a significant influence on the fatigue life of asphalt concrete mixtures with proper level of significance. The mechanical characteristics of asphalt concrete mixtures were studied by Poulikakos and Hofko, (2021) by implementing the four-point bending beam test to measure the fatigue life. It was stated that such testing method induces bending stresses and therefore, it was considered as a more significant indication of fatigue induced in the asphalt concrete mixtures.

Specimens of Asphalt concrete beam were tested by Sarsam, (2022) under dynamic flexural stresses at 20 º environment using the constant microstrain mode. The following constant microstrain levels have been used as a target amplitude, (1000, 700, 500, 200 and 100) microstrain. It was revealed that the permanent microstrain declines regardless of the microstrain level implemented as the flexural stiffness of the mixture increases. Maggiore et al., (2012) used various strain-controlled tests for the same asphalt concrete mixture under the same loading condition and at the testing temperature of 20˚C. The variations in the test results were noticed in the determination of stiffness and fatigue life.

Beam specimens of Asphalt concrete were investigated by Varma et al., (2017) under three different micro strain amplitudes of 600, 400 and 200. A linear viscoelastic model was implemented. It was addressed that the stress–strain plot is considered for evaluation of the fatigue damage. The asphalt concrete fatigue life was assessed by Shafabakhsh et al., (2020) using the four-points bending beam test at constant strain levels of (500, 700 and 900) microstrain at 20˚C testing temperature. The failure condition was equivalent to a reduction by 50% in the stiffness modulus of asphalt concrete throughout the load repetition. The load was applied at a frequency of 10 Hz without rest period.

Sarsam, (2023) assessed asphalt concrete flexural stiffness and fatigue failure under controlled stress and strain modes. It was noticed that higher flexural stiffness is reached under the mode of constant strain. It was revealed that the choice of the testing mode for asphalt concrete is important in the verification of its properties while such properties varies significantly among the testing mode. Ameri et al., (2016) conducted the dynamic bending beam test on asphalt concrete mixtures using different rates of loading (1000, 800, 600 and 400) micro-strain levels. The test results exhibited that the viscoelastic parameter of binder exhibits a strong correlation with the resistance to fatigue of asphalt concrete mixtures.

Ishaq and Giustozzi, (2021) addressed that the four-point bending beam test have proved to be the best apparatus for fatigue life assessment and it can simulate the true fatigue process of the field in the laboratory. It was revealed that the levels of applied strain might be further investigated to achieve better correlations. Testing for resistance to fatigue has been conducted on asphalt concrete mixtures by Artamendi and Khalid, (2005) using constant strain load applications. It was stated that in the constant strain mode, the strain is maintained constant and the stress is allowed to vary.

Karami, (2020) assessed the strength of asphalt concrete at fatigue using the four-point bending beam under dynamic flexural bending test. The beam specimens of asphalt concrete were tested under the controlled-strain mode of loading at 20°C test temperature. Continuous haversine loading mode, three different peak tensile strain including 800, 600 and 400 microstrain and 10 Hz loading frequency were implemented. Test results showed that the initial flexural stiffness of asphalt concrete can influence the fatigue life for the mixtures through the strain-stiffness approach.

Carmo et al., (2021) assessed the structural sensitivity of asphalt concrete, which can show variations in the mechanical properties due to the variations of asphalt cement binder content. The indirect tensile strength was implemented as an indicator for the structure analysis. Test results revealed that the asphalt binder content variations may influence the variations in the mechanical properties and structural responses of the investigated flexible pavement.

This work aimed to monitor the variation in the initial flexural stiffness percentage throughout the asphalt concrete fatigue life among variable constant strain levels and variation in the binder content of ± 0.5% within the optimum asphalt contents. The asphalt concrete mixtures will be compacted in a slab mold using laboratory rollers. Beam specimens will be taken from the asphalt concrete slab samples and subjected to dynamic flexural stresses under three constant microstrain levels of (750, 400 and 250) and tested for flexure at 20℃ environments.

2. MATERIAL PROPERTIES AND TESTING METHODS

Asphalt Cement

Asphalt cement binder with a penetration grade of 42, ductility of 150 Cm and a softening point of 49 was obtained from AL-Nasiriya oil Refinery. After conducting the thin film oven test, the penetration and ductility declines to 33 and 83 Cm respectively while the softening point increases to 53℃. The test of physical properties of binder was conducted according to the ASTM, (2015) procedures.

Fine and Coarse Aggregates

Crushed coarse aggregates and mixed crushed and natural fine aggregates were obtained from AL-Ukhaider quarry. Such aggregates were washed and then air dried and sieved to different sizes. The bulk specific gravity of the coarse and fine aggregates are (2.542 and 2.558) respectively while the water absorption was (1.076 and 1.83) % for coarse and fine aggregates respectively. The test of physical properties of aggregates was conducted according to the ASTM, (2015) procedures.

Mineral Filler

The implemented mineral filler in the present investigation is limestone dust. It was obtained from Karbala quarry. 94% of the filler passes sieve No.200 (0.075mm). The filler has a specific gravity of 2.617.

Selection of the Aggregate Gradation for Preparation of Asphalt Concrete mixture

The aggregates gradation which is selected in the present assessment follows SCRB, (2003) specification for dense graded wearing course pavement layer. It has 12.5 mm of nominal maximum size of aggregates. Figure 1 presents the selected combined gradation for wearing course.

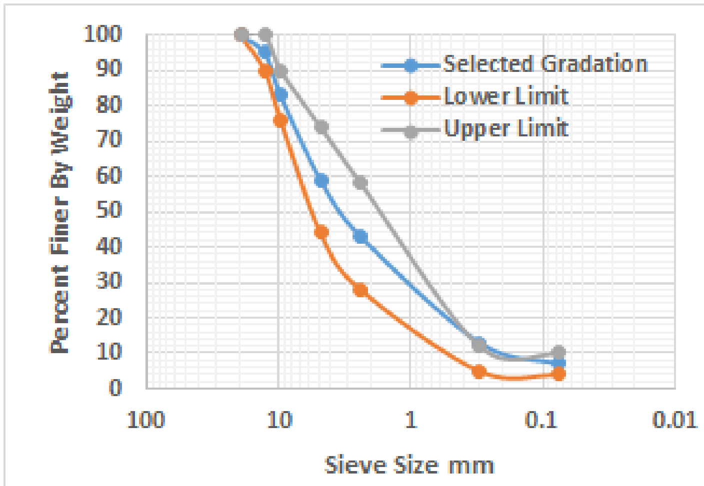

Figure 1 The Selected Combined Aggregates Gradation

Preparation of Asphalt Concrete Mixture and Specimens

The fine and coarse aggregates and mineral filler were combined and heated to 160ºC before mixing with the asphalt cement which was heated to 150ºC. The optimum asphalt binder content of 4.8 % was implemented. Mixtures with ± 0.5 % binder of the optimum were also prepared for comparison. Details of obtaining the optimum asphalt binder content may be referred to Sarsam and Alwan, (2014). The asphalt concrete mixtures have been casted in a slab mold of (40 × 30) Cm while the depth of the mold was 6 Cm. The asphalt concrete mixture was compacted in the mold using the laboratory roller compactor to the target bulk density according to the procedure described by EN 12697-33, (2007).

The detailed compaction process could be found in Sarsam, (2016). The temperature during compaction was maintained to 150°C. The slab samples of asphalt concrete were left overnight to cool. Beam specimens of 40 Cm length, 5.6 Cm height and 6.2 Cm width were cut from the compacted slab sample using the diamond-saw. The total number of the obtained asphalt concrete beam specimens was fourteen; however, the number of casted asphalt concrete slab sample was four. Beam specimens were tested in duplicate and the average value of test results was considered.

Testing for Fatigue by Implementing the Dynamic Flexural Bending Beam Test

The four-point beam dynamic flexural bending beam test according to AASHTO T321, (2014) was implemented to verify the influence of additives and dynamic flexural stresses on the fatigue life and to detect the contributing factors of failure of beam specimens of asphalt concrete at the pavement operating temperature of 20°C and under three target amplitude constant strain levels of (750, 400 and 250) microstrains. Figure 2 demonstrates the four-point flexural bending beam test setup.

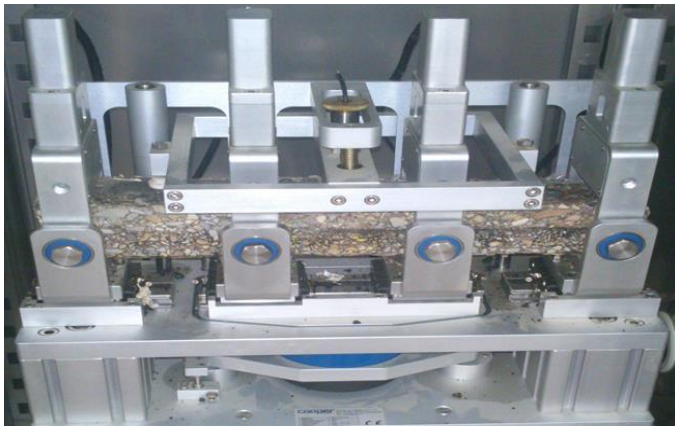

Figure 2 Four-point flexural bending test setup

3. RESULTS AND DISCUSSIONS

Figure 3 demonstrate the variation in the initial stiffness of asphalt concrete when subjected to 250 constant microstrain levels. A gentle decline in the initial flexural stiffness is shown at the early stages of loading. However, the rate of decline exhibit sharp trend after 400 seconds of practicing the dynamic flexural stresses. It can be noticed that asphalt concrete mixture prepared using the optimum binder content of 4.8% exhibit higher fatigue life which is represented by the elapsed time since the start of loading as compared with asphalt concrete mixtures prepared with higher or lower binder contents. The fatigue life decline by (91.5 and 60) % for mixtures prepared with lower and higher binder content as compared with mixture prepared using the optimum binder content. This could be related to the higher density and better orientation of particles of the mixture prepared with optimum binder content.

However, failure occurred in the asphalt concrete specimens when the initial stiffness reaches 50% of the original stiffness of the mixtures prepared with (4.8 and 4.3) % asphalt binder. The asphalt concrete mixture prepared with high binder content of 5.3% exhibit failure when the initial stiffness reaches 75% of the original flexural stiffness. This may be related to the flexible mixture created at such high binder content. Such finding is in agreement with the work reported by Rondón-Quintana et al., (2021) and Colpo et al., (2020).

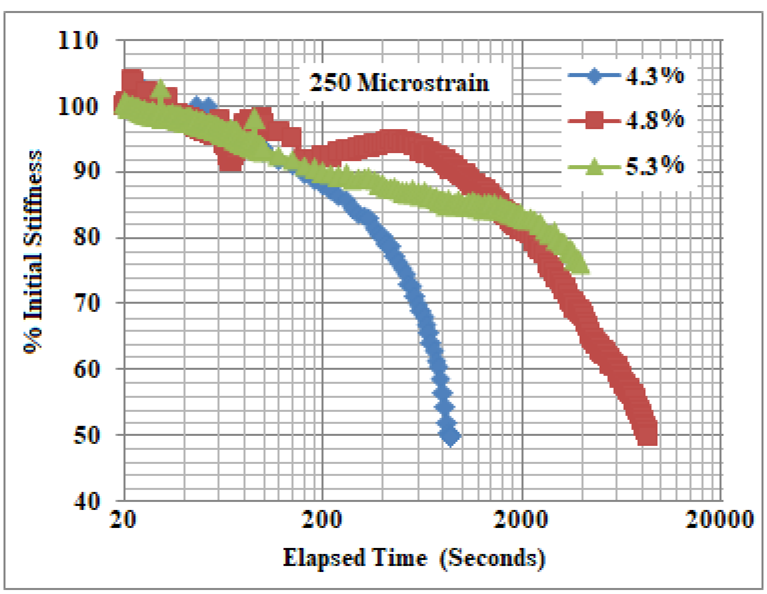

Figure 3 Variation of initial flexural stiffness under 250 microstrain

Figure 4 exhibit the variation in the initial flexural stiffness of the specimens of asphalt concrete when tested under 400 constant microstrain levels. It can be noticed that the rate of decline in the initial flexural stiffness is sharp regardless of the binder content. Asphalt concrete mixture prepared using the optimum binder content shows longer fatigue life as compared with those mixtures prepared with higher or lower binder percentages. The fatigue life decline by (76 and 72) % for mixtures prepared with lower and higher binder content as compared with mixture prepared using the optimum binder content. It can be noted that the failure pattern of the mixtures follows the same behavior as that presented at 250 microstrain level.

On the other hand, if the asphalt concrete fatigue life sustaining constant microstrain level of 400 is compared with those of the mixtures sustaining constant microstrain level of 250, it can be noticed that the fatigue life decline by (95, 86.6 and 96.5) % for mixtures prepared with (4.8, 4.3 and 5.3) % of asphalt binder respectively as compared with mixtures sustaining constant microstrain level of 250. Similar finding was reported by Seitllari et al., (2022).

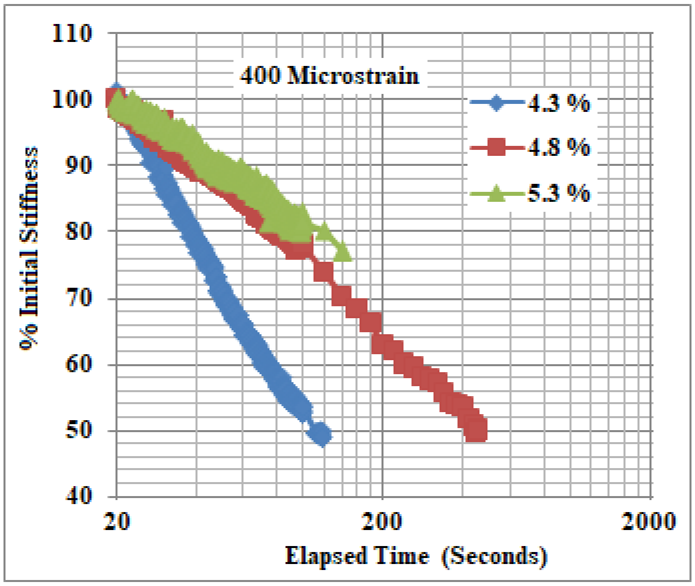

Figure 4 Variation of initial flexural stiffness under 400 microstrain

Figure 5 demonstrates the variation in the asphalt concrete initial flexural stiffness when tested under constant microstrain level of 750. A very sharp rate of decline in the initial flexural stiffness could be noticed as the loading proceeds regardless of the binder content. However, failure of asphalt concrete specimens prepared with various binder percentages occurs when the flexural stiffness reaches 50% of its original value. The asphalt concrete fatigue life decline by (21 and 26.3) % for mixtures prepared at lower and higher binder content as compared with the mixture prepared using the optimum binder content.

On the other hand, if the asphalt concrete fatigue life sustaining constant microstrain level of 750 is compared with those of the mixtures sustaining constant microstrain level of 250, it can be noticed that the fatigue life decline by (98.1, 83.3 and 96.5) % for mixtures prepared with (4.8, 4.3 and 5.3) % of asphalt cement binder respectively as compared with mixtures sustaining constant microstrain level of 250. Moreno-Navarro and Rubio-Gámez, (2016) addressed similar behaviour.

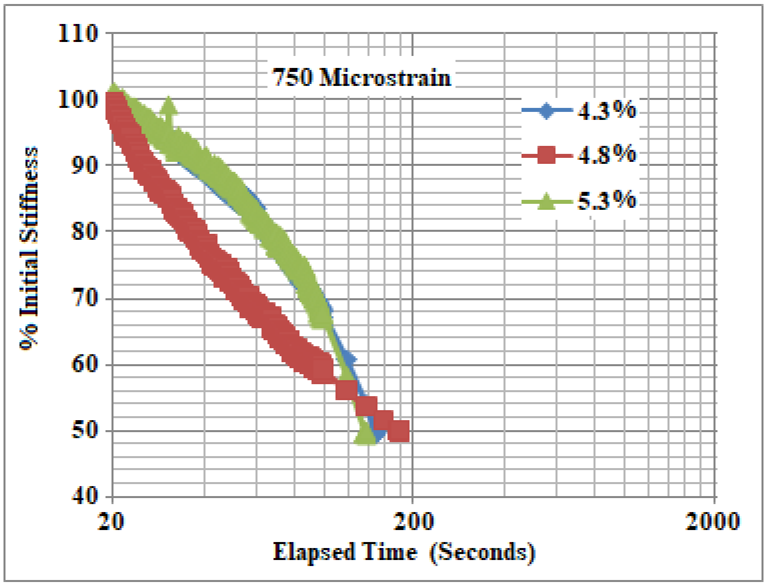

Figure 5 Variation of initial flexural stiffness under 750 microstrain

4. CONCLUSIONS

The following comments may be addressed based on the conducted testing and limitations of materials.

At 250 constant strain level, failure in the asphalt concrete specimens occurred when the initial stiffness reaches 50% of the original stiffness of the mixtures prepared with (4.8 and 4.3) % asphalt binder. The asphalt concrete mixture prepared with high binder content of 5.3% exhibit failure when the initial stiffness reaches 75% of the original flexural stiffness.

At 400 constant strain level, the fatigue life decline by (95, 86.6 and 96.5) % for mixtures prepared with (4.8, 4.3 and 5.3) % of asphalt cement binder respectively as compared with mixtures sustaining constant microstrain level of 250.

At 750 constant strain level, the fatigue life decline by (98.1, 83.3 and 96.5) % for mixtures prepared with (4.8, 4.3 and 5.3) % of asphalt cement binder respectively as compared with mixtures sustaining constant microstrain level of 250.

Ethical issues

Not applicable.

Informed consent

Not applicable.

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This study has not received any external funding.

Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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