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Sensitivity of the dissipated energy of asphalt concrete to the testing environment

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ABSTRACT

Asphalt concrete practices fatigue failure throughout its service life due to the dissipated energy. The service environment plays a major part in the control of the dissipated energy. The present work is concerned with monitoring the sensitivity of the asphalt concrete dissipated energy to the variation of microstrain level and the testing environment through the application of dynamic flexural stresses. Three microstrain levels (250, 400 and 750) have been implemented and two testing environments of (5 and 30) °C were used for monitoring the dissipated energy with the aid of four points repeated flexural stresses apparatus. Beam specimens of asphalt concrete were obtained from roller compacted slab samples. The asphalt concrete Specimens have practiced the repeated flexural stresses under constant strain levels. It was observed that higher microstrain level exhibit lower fatigue life and higher dissipated energy regardless of the testing temperature. It was concluded that higher testing temperature exhibit higher dissipated energy regardless of the microstrain level.

Keywords: Asphalt concrete, Testing environment, Microstrain level, Dissipated Energy

1. INTRODUCTION

Sarsam, (2016) revealed that the fatigue life of asphalt concrete could be enhanced by the control of the dissipated energy; which can be implemented to explain the decline in mechanical properties of the asphalt mixture, such as flexural stiffness. Dissipated energy, as explained by Hamed, (2010), is considered as a measure of the lost energy of the material or altered through its mechanical performance, or damage of the sample. In asphalt concrete pavement, a certain amount of work is used to deform the surface layer of asphalt concrete during each repetition of vehicular tire loading. Part of this initiated work is considered recoverable while the remaining work is dissipated. The dissipated work can be identified by one or more damage mechanisms such as the initiation of fatigue cracking and its propagation and permanent deformation. Maggiore et al., (2014) stated that micro-cracks initiation at the bottom part of the pavement layer and start to propagate towards the upper layers under repeated loading which can lead to pavement failure.

One method to explain the fatigue behavior in asphalt concrete materials is the dissipated energy approach. The fatigue resistances were assessed for different models of the dissipated energy using 2-point bending which was undertaken under different environmental and loading conditions in order to evaluate the dissipated energy property of the mixtures. Shen et al., (2005) addressed that the change in the dissipated energy ratio in asphalt concrete mixtures is suitable in investigating and defining the presence of a fatigue endurance limit with a unique relation to fatigue life, regardless of the mixture type, loading modes, strain–damage levels, and other testing conditions. A new fatigue failure criterion was presented by Miao-Miao et al., (2013) using the four-point bending beam fatigue test system which indicate that asphalt concrete materials failure happens when the dissipated energy ratio increases sharply. The change in the dissipated energy ratio was calculated to give an indication of the damage evolution in asphalt mixtures. Moreover, based on the correlation of the change in the dissipated energy ratio and load cycles under these failure criteria, the fatigue life prediction model is accepted and this model does not depend on constant stress and constant strain modes.

Sarsam, (2023) investigated the microstrain level and environment impacts on the fatigue life and permanent deformation of asphalt concrete. It was stated that the fatigue life increases by (14, 2.3 and 12.3) folds under microstrain levels of (250, 400 and 750) respectively when the testing environment rises from (5 to 30) °C. Ghuzlan and Carpenter, (2006) presented a new approach on asphalt concrete damage–energy fatigue based on the dissipated energy change concept. Failure was defined as the accumulated repetitions of load at which the percentage of dissipated energy increases rapidly which indicate instability. It was concluded that the dissipated energy concepts may be used in fatigue analysis which makes it possible to cause the accumulation of damage. Based on the internal damage produced within the asphalt concretes mixture, a dissipated energy method was used by Pasetto and Baldo, (2017) for the fatigue analysis. The damage curves were expressed with the aid of the change in the Dissipated Energy ratio, for both the strain and stress control modes. They were analyzed so that the fatigue analysis could be unified. The aim of the present work is to monitor the sensitivity of the dissipated energy of asphalt concrete mixture to the variation of microstrain level and the testing environment through the application of dynamic flexural stresses. Three microstrain levels (250, 400 and 750) will be implemented and two testing environments of (5 and 30) °C will be used for monitoring the dissipated energy with the aid of four points repeated flexural stresses apparatus.

2. MATERIALS AND METHODS

The materials used in this study are selected from the quarries that are currently used for road paving construction in Iraq.

Asphalt Cement

Asphalt cement binder of (40-50) penetration graded was used in this study. It is manufactured at AL-Nasiriya oil Refinery. The details of the physical properties can be referred to Sarsam and Alwan, (2014).

Coarse and Fine Aggregates

A crushed coarse aggregate, was obtained from AL-Ukhaydir- Karbala quarry. The aggregates are retained on sieve No.4. A combination of natural sand and crushed sand were obtained from the same quarry are used as Fine aggregates. Such fine aggregates have a particle size between sieve No.4 and sieve No.200. The physical properties of aggregates are listed in Table 1.

Table 1 The Physical Properties of Fine and Coarse Aggregates

Property	Value	ASTM, (2015) Designation No.	Value	ASTM, (2015) Designation No.
Coarse Aggregates			Fine Aggregates	
Bulk specific gravity	2.542	C127-01	2.558	C128-01
Apparent specific gravity	2.554	C127-01	2.563	C128-01
Water absorption %	1.076	C127-01	1.83	C128-01
Wear % (los Angeles abrasion)	18%	C131-03	-----	-----

Mineral Filler

Limestone dust was obtained from lime plant at Karbala and implemented in this work; the physical properties of the filler are presented in Table 2.

Table 2 The Physical Properties of Filler (Lime stone dust).

Property	Value
Bulk specific gravity	2.617
% Passing Sieve No. 200	94

Selection of Aggregates Gradation

The aggregate gradation which was considered, as per SCRB, (2003) Specifications for wearing course pavement layer with 12.5 (mm) nominal maximum size. Figure 1 exhibits the selected aggregates gradation.

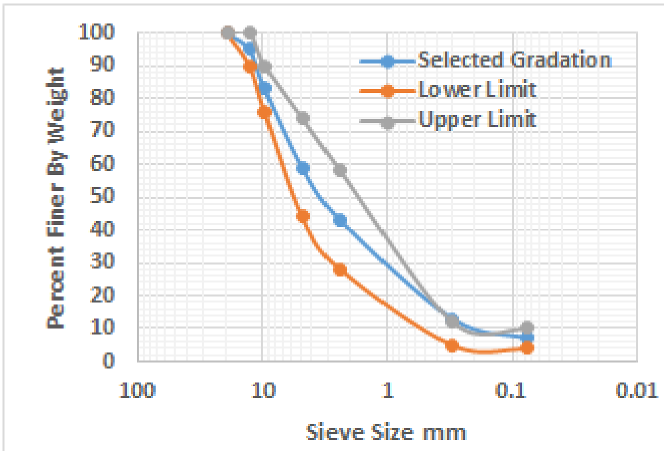

Figure 1 Aggregates Combined Gradation for Wearing Course According to SCRB, (2003)

Preparation of Asphalt Concrete Mixture

The aggregates were washed, dried to constant weight at 110°C and sieved to different sizes. Aggregates were recombined and the mineral filler was added to meet the specified gradation. The combined aggregate was heated to a temperature of (160ºC) before mixing with asphalt cement. The asphalt binder was also heated to a temperature of (150°C) then, the predetermined amount of asphalt cement was added to the heated aggregate and mixed thoroughly in mixing bowl by hand using a spatula for two minutes until all aggregate particles were coated with thin layer of asphalt cement. The optimum asphalt binder content was 4.8%. Details of obtaining the optimum asphalt content could be found at Sarsam and Alwan, (2014).

The asphalt concrete mixtures have been compacted in a steel slab mold of (30 x 40 x 6) cm using a laboratory roller compactor to the target bulk density as per EN12697-33, (2007). The applied static load was 5 kN while the number of roller passes were based on the target bulk density of the mixture and the asphalt content in the mixture. Details of the compaction process are presented at Sarsam, (2005). The temperature of compaction was maintained to 150°C. The slab samples of asphalt concrete are left to cool overnight. Beam specimens of 5 ± 2 cm height, 6.3 ± 2 cm width and 40cm length were extracted from the compacted asphalt concrete slab sample with the aid of the Diamond-saw. The total number of the obtained beam specimens was twelve, while the number of prepared slab samples was three. The prepared beams were divided into two sets; the first set was assessed at 5°C environment under three constant microstrain levels of 750, 400 and 250. The second set was tested at 30°C environment under three constant microstrain levels of 750, 400 and 250.

Repetition of the Flexural Bending Beam Test

Repeated flexural bending stresses were applied by implementing the four-points repeated flexural bending beam test apparatus according to the procedure recommended by AASHTO T-321, (2007). The influence of the testing environment was monitored on the changes in the cumulative dissipated energy of asphalt concrete beam specimens. The testing was implemented at temperatures of (5 and 30) °C and under various constant micro strain levels of 750, 400 and 250, which simulate various traffic mode of loading in the field. The asphalt concrete beam specimens were subjected to dynamic four-point loading. The frequency of loading was set to 5 Hz. A repeated sinusoidal (compression-tension) load was applied to the beam specimen. Figure 2 exhibits the dynamic flexural bending beam test setup.

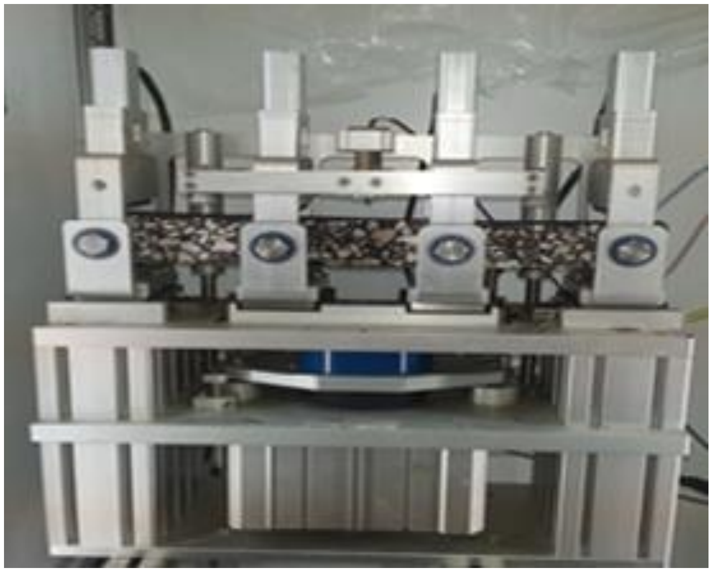

Figure 2 The dynamic flexural bending beam test setup.

3. RESULTS AND DISCUSSION

Impact of Strain Level on Dissipated Energy at cold environment

Figure 3 summarizes the impact of microstrain level on dissipated energy at cold testing environment of 5°C. It can be observed that while the strain level increases, the cumulative dissipated energy also increases throughout the fatigue process.

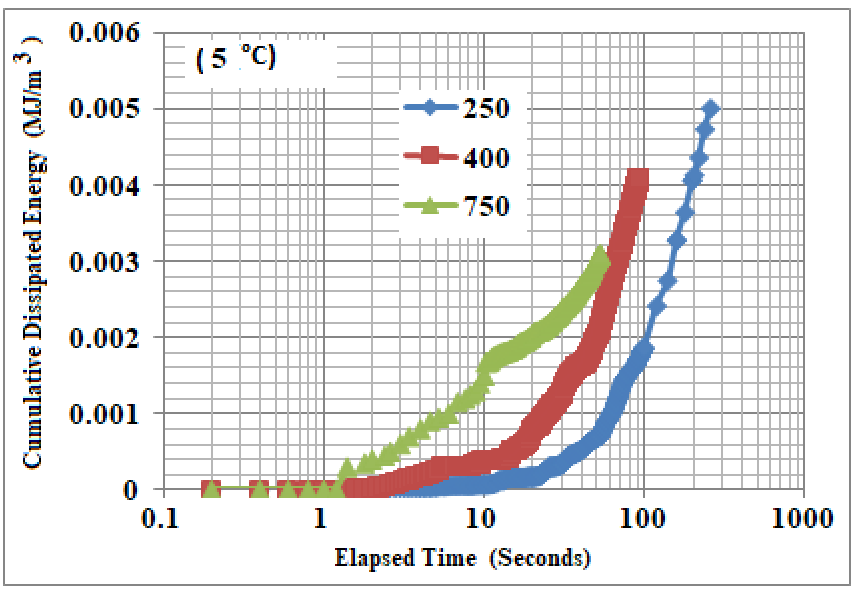

Figure 3 Influence of microstrain level on dissipated energy at cold environment

More energy is dissipated at lower microstrain level of 250 as compared with other higher microstrain levels. However, fatigue life declines and the dissipated energy increases. The fatigue life decreases by (80 and 60) % when the microstrain level increases from 250 to 750 and 400 respectively. At the initial stages and up to one second of elapsed time of loading, the variation in the cumulative dissipated energy with microstrain level is not significant. After 10 second of flexural stresses repetitions, a sharp increment in the dissipated energy is noticed and a non-linear behavior of the trend line could be detected. It can be revealed that the point where the trend line leaves the linear slope corresponds to the point where the possible fatigue cracks are initiating in the asphalt concrete mixture. This point is referred as crack initiation point. Beyond this point, the variation in the energy dissipation is higher and the impact of visco-elastic properties is pronounced. The cumulative dissipated energy at failure declines by (36 and 16) % when the microstrain level increases from 250 to 750 and 400 respectively.

Impact of Strain Level on the Dissipated Energy at hot environment

Figure 4 demonstrates the variation in the cumulative dissipated energy of asphalt concrete at various microstrain levels when tested at hot environment of 30°C.

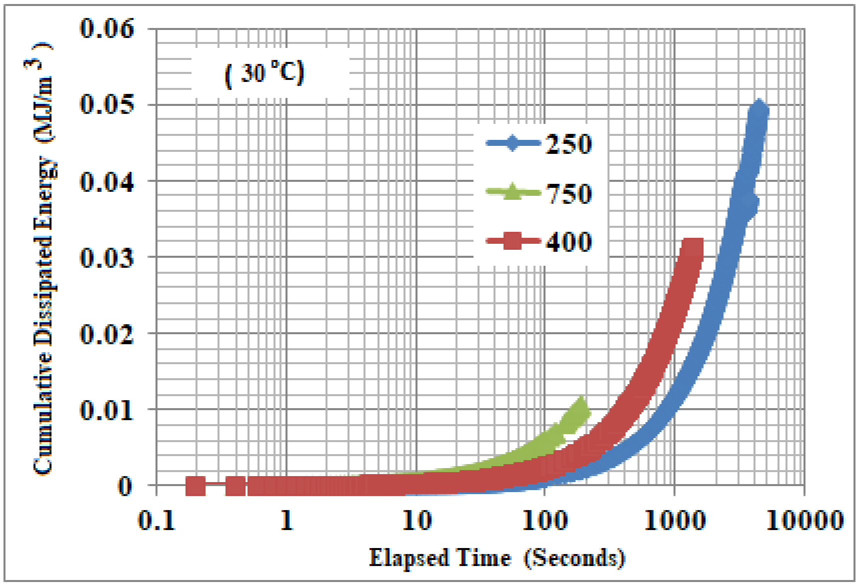

Figure 4 Influence of microstrain level on the energy dissipation at hot environment

It can be noticed that the variation in the cumulative dissipated energy among various microstrain levels is not significant up to 20 seconds of elapsed time of repeated flexural stresses. However, a sharp trend is detected after 100 seconds of loading. The fatigue life of asphalt concrete declines by (95 and 62.5) % when the microstrain level increases from 250 to 750 and 400 respectively. The cumulative dissipated energy at failure declines by (76 and 36) % when the microstrain level increases from 250 to 750 and 400 respectively. Such behavior is in agreement with the work reported by Ghuzlan and Carpenter, (2006).

Impact of testing environment on Dissipated Energy

Table 3 demonstrates a summary of the impact of testing environment on the cumulative dissipated energy of asphalt concrete. It can be clarified that higher energy is dissipated at hot environment of 30°C as compared with that at cold environment of 5°C. However, as the microstrain level increases, the cumulative dissipated energy declines regardless of the testing environment. This could be attributed to the fact that the accumulation of strain due to higher loading causes premature cracking or distress. Such behavior may be attributed to the higher viscosity and stiffness of asphalt cement binder gained at low testing temperature of 5°C. The resilient property of asphalt concrete is limited at low testing temperature and the visco-elastic response of the asphalt concrete is reduced. This can exhibit a fracture and a sudden type of damage occurs. At higher testing temperature of 30°C, the asphalt concrete resumes its flexibility and elastic properties. The high temperature can increase the elastic component of the asphalt cement binder. This will reduce the viscose component. More loading repetitions are still required to start the distress while more loss of energy could be expected to cause a specific type of distress. Similar findings are reported by Miao-Miao et al., (2013).

Table 3 Impact of testing temperature on cumulative dissipated energy

Testing temperature °C	Cumulative dissipated energy MJ/ m^3		
	250 microstrains	400 microstrains	750 microstrains
30°C	0.0500	0.0320	0.0120
5°C	0.0050	0.0042	0.0032

4. CONCLUSIONS

The following conclusions may be addressed based on the limitations of materials and testing program.

1- More energy is dissipated at lower microstrain level of 250 as compared with other higher microstrain levels.

2- The fatigue life of asphalt concrete mixture declines by (80 and 60) % when the microstrain level increases from 250 to 750 and 400 respectively at cold testing environment.

3- The cumulative dissipated energy at failure at cold testing environment declines by (36 and 16) % when the microstrain level increases from 250 to 750 and 400 respectively.

4- The fatigue life of asphalt concrete at hot testing environment declines by (95 and 62.5) % when the microstrain level increases from 250 to 750 and 400 respectively.

5- The cumulative dissipated energy at failure at hot testing environment declines by (76 and 36) % when the microstrain level increases from 250 to 750 and 400 respectively.

6- Higher energy is dissipated at hot environment of 30°C when the mixture is compared with that tested at cold environment of 5°C.

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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