Civil Engineering Beyond Limits 2 (2024) 1898
Civil Engineering Beyond Limits
journal home: www.acapublishing.com/journals/1/cebel
Research Article

Verification of Sustainable Asphalt Concrete through the Energy Dissipation

Saad Issa Sarsam*,[1]
[1]*Professor, Sarsam and Associates Consult Bureau (SACB), Baghdad-IRAQ. Former head, Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq*

Keywords

Additives,
Constant strain level,
Energy dissipation,
Asphalt concrete,
Dynamic stress.

Abstract

The kinetic energy created in the asphalt concrete due to practicing dynamic loading is absorbed and consumed to retain the properties of the asphalt mixture through its flexibility; however, part of the energy is dissipated in the initiation of microcracking and other types of distresses. In this work, the influence of additives (fly ash and silica fumes) on controlling the energy dissipation of asphalt concrete mixtures was assessed. Beam specimens of asphalt mixture were obtained from the roller compacted slab samples and tested for fatigue under three constant strain levels by implementation of the four points bending beam. It was noticed that for fly ash treated mixture, the consumed time for energy dissipation decline by (75, and 97.5) % while the dissipated energy declines by (84.8, and 99.5) % when the constant strain level increases from (250 to 400 and 750) micro strain respectively. However, for silica fumes treated mixture, the energy dissipation declines by (3.3, and 95) % when the constant strain level rises from (250 to 400, and 750) micro strain respectively. It was noticed that the damage resistance as indicated by the increment in dissipated energy increases by (60, and 140) % when fly ash and silica fumes were implicated respectively. However, the silica fumes additive consumes the energy at lower time of 60 seconds than the case of control mixture. The fly ash additive exhibits no significant variation in consuming the energy when compared with the control mixture.

1. Introduction

Fatigue life assessment of asphalt concrete is susceptible to environmental conditions which must be incorporated into the assessment to ensure an accurate prediction of the service life of the pavement. The Dissipated energy concept was implemented in assessing the fatigue life prediction of asphalt concrete as addressed by Subhy et al., (2017) [1]. Such concept state that the energy created by the vehicular loading is absorbed and dissipated by the asphalt concrete material causing damage. The fatigue life of asphalt mixture is related to the energy dissipated during the testing process. The dissipated energy approach for detecting the damage and failure of asphalt concrete was assessed by Shen and Carpenter, (2007) [2]. It was reported that the cumulative dissipated energy of an asphalt mixture can be related to its failure life significantly. Strong relationship exists between the number of cycles of the applied load to failure and the total dissipated energy. Such relationship is not affected by frequency, loading mode, or temperature, but it is significantly dependent on the type of material.

Sarsam, (2016) [3] investigated the impact of the variations in the energy dissipation on the resistance to fatigue of asphalt concrete. Beam specimens of asphalt concrete were tested using the four-point flexure repeated bending test in controlled strain mode. The energy dissipation per load cycle was noticed through the damage accumulation and the changes in the behaviour of the mixture. The impact of binder content and constant strain level on the energy dissipation was assessed. Sarsam and Mashaan, (2022) [4] investigated the impact of asphalt binder modification by implementing fly ash and silica fumes additives on the fatigue life of asphalt concrete mixture. It was revealed that implication of Fly ash exhibit lower susceptibility to ageing process, while the addition of silica fumes exhibits lower susceptibility to moisture damage as compared to other mixtures.

Khan et al. (2020) [5] investigated the impact of various additives on the behavior of asphalt concrete. Silica fumes were implemented to study the impact of filler / asphalt ratio on the characteristics of asphalt concrete. It was addressed that the mixtures with 50% silica fumes shows greater stability and proper flow as compared with other percentages used in a Marshall mixture. Onyelowe et al., (2020) [6] assessed the implication of fly ash as a modifier to enhance the stability of Marshall and other physical and engineering properties of Asphalt binder for pavement construction. The results exhibited that 15 % of fly ash addition by weight in the asphalt mixture exhibit increase in the stability by 3.7 %. It was revealed that adding fly ash to the asphalt concrete mixture can improve the performance and rheological characteristics while reducing unfavorable environmental and cost impacts.

Ghuzlan and Carpenter, (2000) [7] addressed that the energy dissipation energy per loading cycle is responsible for the fatigue damage in the asphalt mixtures. Shen and Carpenter, (2005) [8] addressed that there is a strong relation between the fatigue life and initial dissipated energy of asphalt mixtures. It was concluded that the concept of dissipated energy that was generated by an external work may be used as a visualized and direct way to describe the development of damage in asphalt concrete mixtures. Khodary, (2016) [9] investigated the impact of silica fumes on the physical behavior of asphalt concrete. Structure and morphology of the Silica fume were investigated by a series of laboratory experiments. Different modification levels of silica fume (2, 4, 6, 8 and 10) % by weight were tried. The testing result revealed that adding silica fumes can improve both strength and stability of asphalt concrete. Wu et al., (2014) [10] revealed that there is a significant relationship between the dissipated energy ratio and the stiffness ratio of asphalt concrete, while the relationship is not significant between the fatigue life of asphalt concrete and the cumulative dissipated

*Corresponding Author: saadisasarsam@coeng.uobaghdad.edu.iq
Received 18 Jan 2024; Revised 04 Jun 2024; Accepted 04 Jun 2024
https://doi.org/10.36937/cebel.2024.1898

energy. Shafabakhsh et al., (2020) [11] revealed that the implication of modified binder modified with Nano-silica in asphalt mixture can improve some of the properties such as improved dynamic modulus.

Kakar et al. (2019) [12] studied the significance of binder additives for improving the adhesion properties of the binder with aggregate. Shafabakhsh et al., (2021) [13] investigated the influence of using nano silica on the cracking behavior of asphalt concrete mixtures at different temperatures. Testing results exhibited that the specimens having both angular and vertical cracking are significantly improved by the implication of additive at all of the testing temperatures. Azarhoosh, et al. (2018) [14] assessed the mechanism which influences the adhesive bond and cohesion between aggregate and binder after the implication of additives using the surface free energy concept. It was concluded that implementation of additives leads to decline the acid component of surface free energy and increase of the basic component of the binder which enhances the adhesion between the binder and aggregates.

Li et al., (2022) [15] assessed the viscoelastic properties of grouting material with different content of fly ash and silica fumes. It was revealed that the silica fumes reduce the shear stress while the fly ash increases the shear stress significantly. It was concluded that such additives exhibit higher specific surface area and higher chemical adhesion respectively. Al-Mohammedawi and Mollenhauer, (2020) [16] investigated the impact of silica fume additives on the fatigue behavior of cold bitumen emulsion mastic. The test results show that the resistance to the fatigue damage of asphalt concrete depend on the filler inclusions the chemistry of the filler type.

Sobolev et al., (2014) [17] addressed that the implication of fly ash in asphalt concrete mixtures may positively upgrade the performance of the pavement and reduce the environmental impacts. It was revealed that the crack-arresting process was induced by the fly ash particles when it is evenly distributed within bitumen matrix. It was concluded that the addition of fly ash had improved the rutting resistance and changed the performance grade of the binders to a higher grade. Jie et al. (2017) [18] stated that the implication of additives may enhance the adhesion properties of the interface of the asphalt-aggregate. Raufi et al., (2020) [19] investigated the influence of Nano additives modification to asphalt binder. It was concluded that such additives can decline the asphalt binder content, while the stability of the mixture was slightly improved with such modification.

The aim of the present assessment is to assess the influence of implication of additive (silica fumes and coal fly ash) on controlling the energy dissipation of asphalt concrete mixtures. Beam specimens of asphalt concrete will be extruded from roller compacted slab samples and tested for fatigue under three constant strain levels of (750, 400, and 250) using four-point dynamic bending beam technique. The dissipated energy will be monitored after each repetition of the flexural stresses and compared.

2. Materials and Methods

The raw materials implemented in this work are locally available and are currently used for asphalt concrete pavement construction in Iraq.

2.1. Asphalt Cement

Asphalt cement with a softening point of 49℃, penetration grade of 42, and ductility of 136 Cm, was obtained from AL-Nasiriya oil Refinery and implemented in the present work. After implementation of the thin film oven test, the ductility and penetration declines to 83 Cm and 33 respectively while the softening point increases to 53℃. The test of physical properties of binder was conducted according to the ASTM, (2015) [20] procedures.

2.2. Additives

In this investigation, two types of Additives were implemented in different percentages as partial substitute of mineral filler. Fly ash which has a micro size and Silica fumes which has a Nano size.

2.3. Coal Fly Ash

The coal fly ash of class F was used as an additive and modifier. This fly ash has specific surface area of 600 m^2/Kg, and specific gravity of 2.016, while 98 % of the fly ash passes sieve of 75 microns. The major Chemical components of fly ash are (61.9 % SiO_2 and 28.8 % Al_2O_3). All the testing was conducted as per ASTM requirements.

2.4. Silica Fumes

The silica fumes were implemented as an additive and modifier. The specific surface area of silica fumes was 200000 m^2/Kg. The specific gravity is 2.134, while 100 % of the silica fumes is finer than sieve of 75 microns. The major chemical composition of the silica fumes is (90 % of SiO_2 and 3 % of Al_2O_3). All the testing was conducted as per ASTM requirements.

2.5. Coarse and Fine Aggregate

The Crushed coarse aggregates have been obtained from AL-Ukhaider quarry. A mixture of crushed and natural fine aggregates was obtained from the same quarry of aggregates. The bulk specific gravity of the fine and coarse aggregates is (2.558 and 2.542) respectively while the water absorption was (1.83 and 1.076) % for fine and coarse aggregates respectively. The test of physical properties of aggregates was conducted according to the ASTM, (2015) [20], procedures.

2.6. Mineral Filler

The limestone dust was obtained from Karbala quarry and implemented as mineral filler. Testing for physical properties shows that the bulk specific gravity of the mineral filler was 2.617. However, 94 % of the filler passes 75-micron sieve.

2.7. Selection of Combined Aggregate Gradation

The dense gradation of wearing course pavement layer was selected in the present assessment. It follows SCRB, (2003) [21] specification. The aggregates gradation exhibit 12.5 mm of nominal maximum size of aggregates as demonstrated in Figure 1.

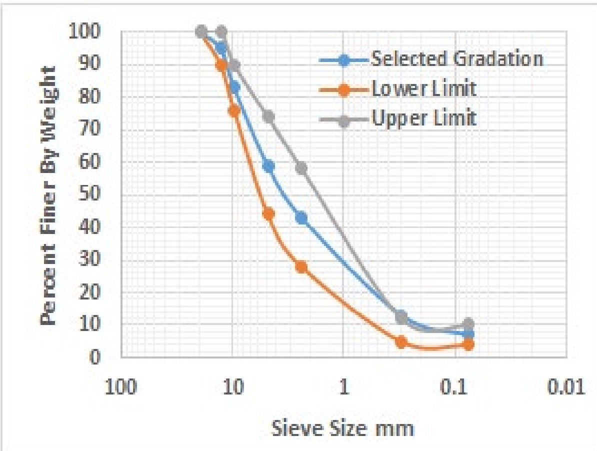

Figure 1. Combined Aggregates Gradation for Wearing Course According to SCRB, (2003), [21].

2.8. Preparation of Asphalt Concrete Mixture, slab samples and beam specimens

The asphalt cement was heated to 150°C, and then it was mixed with the combination of the fine and coarse aggregates and mineral filler which was heated to 160◦C. The 4.9 % binder was the optimum asphalt binder content and was obtained based on Marshall Test. Details of the procedure of obtaining the optimum binder requirement can be referred to Sarsam and Alwan; (2014) [22].

The prepared asphalt concrete mixtures were compacted in a rectangular slab mold of (40 × 30) Cm while the depth of the mold was 6 Cm. Laboratory roller compaction was conducted to the target bulk density according to procedure described by EN12697-33, EN12697-33, (2007) [23]. The details of conducting the process of compaction can be referred to Sarsam, (2023) [24]. The temperature of the compaction was maintained at 150°C throughout the rolling compaction process. The asphalt concrete slab samples were left to cool overnight. Beam specimens of 5.6 Cm height, 40 Cm length, and 6.2 Cm width, were obtained from the prepared slab sample with the aid of diamond-saw. The total number of the prepared slab samples of asphalt concrete was six, while the number of the asphalt concrete beam specimens was eighteen; the average value of testing duplicate beam specimens was considered for the analysis.

2.9. Testing for Fatigue by Implementing the Dynamic Flexural Bending Beam Test

The four-point dynamic flexural beam bending test was conducted according to AASHTO T321, (2010) [25] at 20 ℃ environment. Figure 2 exhibit the test setup. Three constant strain levels of (250, 400, and 750) microstrain were implemented to simulate the actual loading of the pavement in the field. This testing technique can show the influence of additives in controlling the energy dissipation of asphalt concrete mixture. The beam specimens were stored in the testing chamber for three hours at the specific testing temperature before practicing the dynamic flexural stresses.

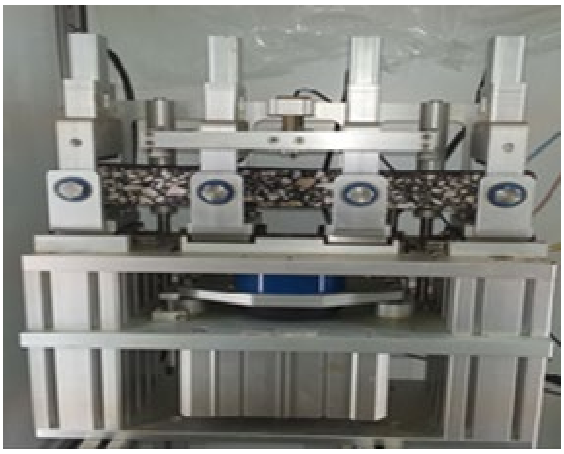

Figure 2. The dynamic flexural bending beam test setup.

3. Test Results and Discussions

3.1. Impact of Constant Strain Levels on Energy Dissipation of Asphalt Concrete

Dissipation of energy which is created due to the dynamic flexural stresses is taken into consideration as a proper engineering parameter of asphalt concrete. It can also be considered to represent the internal structural damage developed within the asphalt concrete mixture during practicing the repeated flexural stresses loading. Wu et al., (2014) [10] revealed that the dissipated energy through the fatigue life test is usually represented by a mathematical model curve, which presents three different phases. The first phase is characterized by a gentle increase of the cumulative energy dissipation with elapsed time up to 100 seconds of loading, whereas it is substantially exhibit sharp increase the loading proceeds in the second phase. Therefore, in such part of the test, a considerable rate of input energy is dissipated to cause internal damage. However, the transition between the second phase and the third one (after 100 seconds of dynamic loading), which is denoted by a high rate of increment in dissipated energy with the elapsed time, may allow to identify the fatigue failure of the asphalt concrete.

Figure 3 exhibits the energy dissipation of control asphalt concrete while practicing three levels of constant strain. It may be noticed that more time is consumed to dissipate the energy generated under dynamic flexural stresses when low constant strain level is implemented. However, the elapsed time for energy dissipation decline as the constant strain level rises. On the other hand, the dissipated energy decline by (67.5, and 91.9) % when the constant strain level increases from (250 to 400 and 750) microstrain respectively. The time consumed to dissipate the energy decline by (80, and 97.1) % when the constant strain level increases from (250 to 400 and 750) microstrain respectively. Similar behavior of the resistance to damage of asphalt concrete was reported by Sarsam, (2021) [26].

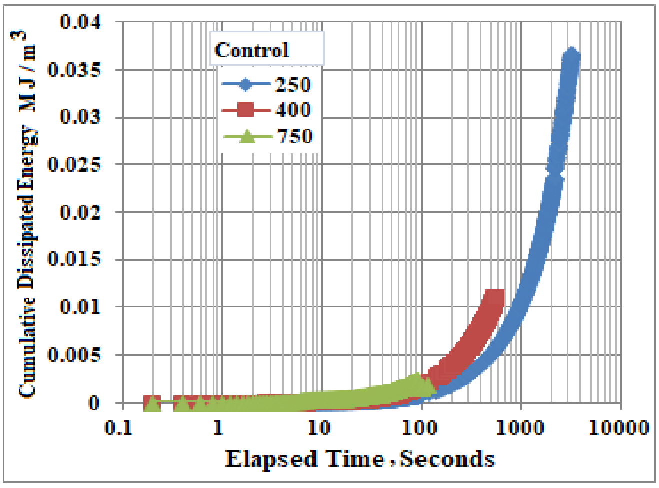

Figure 3. Energy dissipation of control mixture

3.2. Impact of Implementation of Coal Fly Ash on Energy Dissipation of Asphalt Concrete

Figure 4 demonstrates the energy dissipation of the coal fly ash treated asphalt concrete mixtures. It may be noticed that in general, the cumulative dissipated energy is ten folds of that of the control mixture. The consumed time for energy dissipation decline by (75, and 97.5) % when the constant strain level increases from (250 to 400 and 750) microstrain respectively. However, the dissipated energy decline by (84.8, and 99.5) % when the constant strain level increases from (250 to 400 and 750) microstrain respectively. It may be noticed that the time consumed to dissipate the energy is longer than that of the control mixture by (133, 185, and 66.6) % for (250, 400, and 750) constant microstrain levels respectively. It is revealed that under the dynamic loading throughout the fatigue test, part of the energy created from the test has been dissipated, causing some damage or plastic strain to the asphalt concrete mixture after 100 seconds of loading. As the loading proceeds, it was believed that cracks initiate and propagate while the energy dissipation changes continuously and dramatically especially at 250 microstrain level throughout the fatigue process. However, the variation in the energy dissipation to exhibit reduction in fatigue life is not significant under 750 constant microstrain levels. Such finding is in a full agreement with the work reported by Shen et al., (2007) [2].

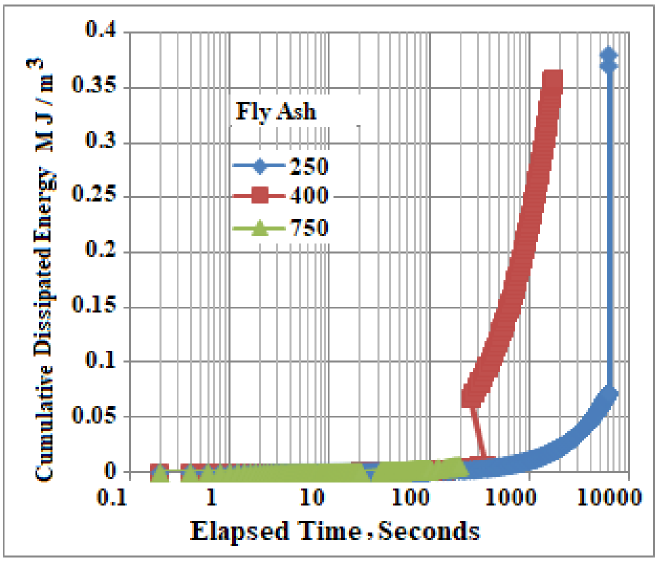

Figure 4 Energy dissipation of fly ash treated mixture

3.3. Impact of Implementation of Silica Fumes on Energy Dissipation of Asphalt Concrete

Figure 5 exhibit the impact of silica fumes and microstrain levels on energy dissipation for asphalt concrete mixture.

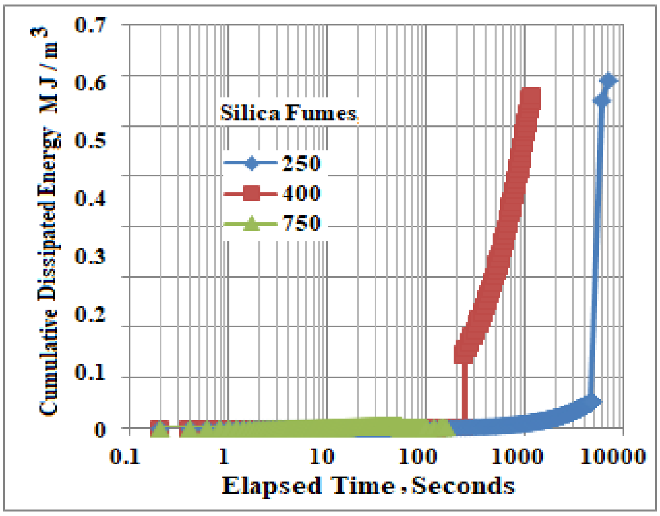

Figure 5. Energy dissipation of silica fumes treated mixture

It is noted that more energy dissipation occurred when the silica fumes was implemented as an additive and modifier as compared with the control or fly ash treated asphalt concrete mixtures. No significant change in the energy dissipation occurred during the initial stages of loading especially when testing under constant strain level of 750 microstrain, however, after 200 seconds, a sharp trend in the energy dissipation is exhibited for the asphalt concrete beam specimens when tested under the constant strain levels of (250, and 400) microstrain. The energy dissipation decline by (3.3, and 95) % when the constant strain level rises from (250 to 400, and 750) microstrain respectively. This could be explained as during the fatigue test, large part of the energy from the test has been dissipated, causing some damage to the asphalt mixture before 200 seconds of loading. As the loading cycles increase, the dissipation in the energy follows a sharp trend and changes continuously especially regardless of microstrain level throughout the fatigue process. Such behavior agrees well with Sarsam, (2016) [27].

Figure 6 demonstrates a summary of the impact of implementing the additives on the energy dissipation of modified asphalt concrete mixtures when tested at 750 constant microstrain levels. It may be detected that implementation of additives for modification of asphalt concrete exhibit higher and quicker energy dissipation as compared with that of the control mixture. The energy dissipation increases by (60, and 140) % when fly ash and silica fumes were implicated with the asphalt concrete mixture respectively. However, the silica fumes additive consumes the energy at lower time of 60 seconds than the case of control mixture. The fly ash exhibits no significant variation in consuming the energy when compared with the control mixture. Similar findings were reported by Mandula and Olexa, (2017) [28], Maggiore et al., (2014) [29], Tapkin, (2014) [30], Sarsam (2024) [31], and Sarsam (2024) [32].

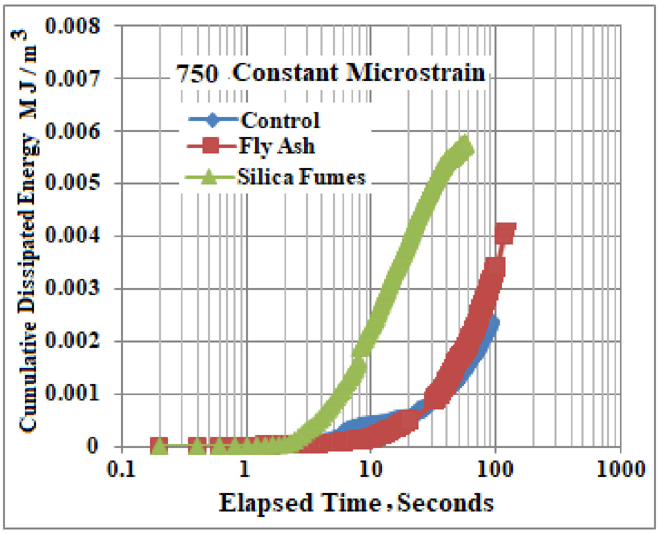

Figure 6. Summary of Energy dissipation of the asphalt concrete mixture

4. Conclusions

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

- For control asphalt concrete mixture, the energy dissipation decline by (67.5, and 91.9) % while the time consumed to dissipate the energy decline by (80, and 97.1) % when the constant strain level increases from (250 to 400 and 750) microstrain respectively.
- For fly ash treated mixture, the consumed time for energy dissipation decline by (75, and 97.5) % while the dissipated energy decline by (84.8, and 99.5) % when the constant strain level increases from (250 to 400 and 750) microstrain respectively.
- For silica fumes treated mixture, the energy dissipation decline by (3.3, and 95) % when the constant strain level rises from (250 to 400, and 750) microstrain respectively.
- The energy dissipation increases by (60, and 140) % when fly ash and silica fumes were implicated with the asphalt concrete mixture respectively. However, the silica fumes additive consumes the energy at lower time of 60 seconds than the case of control mixture. The fly ash exhibits no significant variation in consuming the energy when compared with the control mixture.
- More work is required to investigate the durability of the modified asphalt concrete mixtures.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. He has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Sarsam S. Verification of Sustainable Asphalt Concrete through the Energy Dissipation, Civil Engineering Beyond Limits, 2(2024), 1898. https://doi.org/10.36937/cebel.2024.1898