BloEx - Journal
Britain International of EXACT Sciences Journal
Publish: | January - May - September |
E-ISSN: 2686-1208
P-ISSN: 2686-1216
http://biarjournal.com/index.php/bioex

Influence of Additives on the Viscoelastic Behavior of Asphalt Concrete

Saad Issa Sarsam*
[1*]Professor, Sarsam and Associates Consult Bureau (SACB), Baghdad, Iraq
Former Head, Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
*Corresponding Author Email: saadisasarsam@coeng.uobaghdad.edu.iq

Abstract:

Implication of mineral additives into the asphalt concrete mixture can influence the viscoelastic behavior; change the density, gradation, and strength properties. In the present investigation, fly ash and silica fumes were added to the asphalt concrete mixture. Slab samples were compacted with the aid of laboratory roller, and then beam specimens were sawed from the slab samples. The asphalt concrete beam specimens were subjected to repeated flexural stresses through the four-points bending test at 20℃ and under 400 micro-strain level until failure. The influence of the additives was monitored and compared. It was concluded that the phase angle, flexural stiffness, and the fatigue life declines while the cumulative dissipated energy increases after implication of the additives. However, the silica fumes additives exhibit a significant impact on the viscoelastic properties as compared with the control or the fly ash treated mixtures.

Keywords:
viscoelastic properties; asphalt concrete; additives; fly ash; silica fumes; flexural stress

I. Introduction

The viscoelastic properties of asphalt concrete can characterize the mechanical properties and the durability of the asphalt pavement mixture. Alama and Hammoum, (2015) assessed the relationship between individual material properties, the macroscopic properties of asphalt concrete mix, and their interaction within the microstructure through micromechanical modeling. It was stated that the analytical model allows calculating the phase angle and complex modulus of the mixes from the mechanical properties of its constituents and designed mix data. It was revealed that the thermo-mechanical nature of asphalt coupled with the viscoelasticity offers temperature-time dependence to the mechanical properties of asphalt concrete mixtures. Tapkin, (2014) estimated the fatigue live of fly ash modified asphalt concrete mixtures using artificial neural networks. Different types of fly ash have been implemented as filler replacing agents in a dense asphalt concrete mixture. Repeated indirect tensile stress under controlled stress conditions was used for the evaluation of the fatigue behavior.

The experimental data were used as training set and reasonable estimates of fatigue lives of asphalt concrete mixtures have been obtained. Khodary, (2016) assessed the effect of silica fumes on the properties of asphalt concrete which was used for base course. Structure and morphology of the Silica fume were investigated by a series of laboratory experiments. Specimens with different modification levels of silica fume (2, 4, 6, 8 and 10) % by weight were tried. The test result revealed that adding silica fumes can improve both stability and strength. Mandula and Olexa, (2017) assessed the asphalt mixture problems which are caused by its inner properties and the behavior of material under dynamical loading. The phase angle was also studied as an indicator of viscoelastic behavior. It was stated that phase angle observation is important for better understanding of structural material behavior. It was observed that the phase angle value became stabilized after one third of the test duration while strong increase in the phase angle started slightly before failure point. It was concluded that sudden increase in the phase angle is one of the indicators of material lifespan ending. Sarsam, (2016) assessed the variations in the dissipated energy through the process of fatigue resistance of asphalt pavement. Beam specimens were tested using the dynamic four-point flexure bending beam test in controlled strain mode. The dissipated energy per load cycle was monitored through the changes in the behaviour of the mixture and through the damage accumulation. The impact of strain level, asphalt content, and testing temperature on dissipated energy was discussed and compared. Dissipated energy concept was successfully implemented in the asphalt fatigue life prediction as revealed by Shen and Carpenter, (2007); and Subhy et al., (2017). Such methods assume that the energy is absorbed by the asphalt concrete material causing damage, and the number of loading cycles at failure is related to the amount of energy dissipated during the testing process.

The viscoelastic properties of geopolymer grouting material with different content of silica fumes and fly ash are studied by Li et al., (2022). It was observed that the fly ash significantly increases the shear stress while the silica fumes reduce the shear stress. It was concluded that such additives exhibit higher chemical adhesion and specific surface area, respectively. Onyelowe et al., (2020) investigated the influence of using fly ash as a modifier to enhance the mechanical properties of Asphalt for a sustainable pavement construction. The Marshall Stability behavior of the hot mix asphalt when mixed with fly ash was assessed. The results showed that the addition of fly ash of 15% by weight in the asphalt mixture was observed to have increased the stability by 3.7 %. It was concluded that incorporating fly ash in the asphalt concrete mixture had improved the rheological and performance characteristics while reducing cost and unfavorable environmental impacts. Sobolev et al., (2014) demonstrates that the use of fly ash (class C and F) in asphalt mixtures is an attractive option since it improves the pavement performance and reduces costs and environmental impacts. The micro structural investigation demonstrated that the crack-arresting process was induced by the fly ash particles evenly distributed within bitumen matrix. A dynamic shear rheometer was implemented to measure the binder's resistance to shear deformation. It was revealed that the addition of fly ash had improved the rutting factor and reached a higher performance grade of the binders.

Sarsam and Mashaan, (2022) assessed the influence of modification of the asphalt cement binder by fly ash and silica fumes additives on the durability and fatigue life of asphalt concrete mixture. It was concluded that the Fly ash treated mixture exhibit lower susceptibility to ageing process as compared to other mixtures, while the silica fumes treated mixture exhibit lower susceptibility to moisture damage as compared to other mixtures. Al-Mohammedawi and Mollenhauer, (2020) assessed the impact of active fillers such as limestone, cement, and silica fume on the fatigue behavior and rheological properties of cold bitumen emulsion mastic. The assessment was accompanied by the chemical analysis of the filler emulsified bitumen. The test results show that the rheological performance and the fatigue damage resistance of asphalt concrete depend not only on the filler inclusions but also on chemistry and filler type. Kakar et al. (2019) demonstrated the significance of additive to improve the asphalt binder adhesion properties with aggregate. Jie et al. (2017) addressed that the incorporation of additives can enhance the adhesion properties of the asphalt-aggregate interface. Khan et al. (2020) studied the influence of different fillers on the properties of asphalt concrete mixtures. Two filler types, marble dust and silica fumes were implemented to investigate the effect of filler / asphalt ratio on the characteristics of asphalt concrete mixtures. It was concluded that the mixtures with 50% marble dust and 50% silica fumes exhibit greater stability than all the other percentages used in a Marshall mixture. All other percentages of filler have lower stability and voids which are out of range. Mixture having 50% silica fumes and 50% marble dust has only 13.5 mm flow value which is greater than all other percentages.

The aim of the present work is to assess the influence of fly ash and silica fumes additives on the viscoelastic properties of asphalt concrete. The influence of such additives on the phase angle, cumulative dissipated energy, permanent deformation, and flexural stiffness will be assessed and compared.

II. Research Methods

The materials implemented in this work are locally available and usually used for asphalt pavement construction.

2.1 Asphalt Cement

Asphalt cement of penetration grad 40-50 was assessed in this work. It was obtained from AL-Nasiriya Refinery. Table 1 presents the physical properties of asphalt binder.

Table 1. Physical Properties of Asphalt Cement

Property	**Testing condition**	**ASTM, (2015) Designation No.**	**Value**	**SCRB, (2003) Specifications**
Penetration	25°C, 100 gm 5 sec	D5-06	42	40-50
Softening Point	(ring &ball)	D36-895	49	-
Ductility	25°C,5cm/mi	D113-99	100 +	>100
Specific Gravity	25˚C	D70	1.04	-
After thin film oven test properties D1754-97				
Penetration	25°C, 100gm, 5 sec	D5-06	33	-
Ductility of Residue	25°C,5cm/mi	D113-99	83	-

2.2 Fine and Coarse Aggregates

Crushed coarse aggregateswith a nominal maximum size of 19 mmand retained on sieve No. 4 was obtained from AL-Ukhaider quarry. The fine aggregates consist of crushed and natural sand mixture (passing sieve No.4 and retained on sieve No.200). It was obtained from the same source. The aggregates were washed, and then air dried and separated into different sizes by sieving. Table 2 present the physical properties of aggregates.

Table 2. Physical Properties of Course and Fine Aggregate

Property	**Value**	**ASTM, (2015) Designation No.**
Coarse Aggregate		
Bulk specific gravity	2.542	C127-01
Water absorption %	1.076%	C127-01
Wear % (lose Angeles's abrasion)	18%	C131-03
Fine Aggregate		

Bulk specific gravity	2.558	C128-01
Water absorption %	1.83%	C128-01

2.3 Mineral Filler

Limestone dust is implemented as mineral filler in the present investigation. It was obtained from Karbala governorate. The filler passes sieve No.200 (0.075mm). Table 3 present the physical properties of the mineral filler.

Table 3. Physical Properties of Mineral Filler (Limestone dust)

Bulk specific gravity	% Passing Sieve No.200
2.617	94

2.4 Fly Ash

Fly ash of class F was obtained from local market. Table 4 present the physical properties of fly ash.

Table 4. Physical Properties of Fly Ash

Sieve size (micron)	% passing	Specific gravity	Specific surface area (m^2/kg)
0.075	98	2.645	650

2.5 Silica Fumes

Silica fumes were obtained from local market as a fluffy powder, Table 5 presents its physical properties.

Table 5. Physical Properties of Silica Fumes

Maximum sieve size	PH value	Density (kg/m^3)	Specific surface area (m^2/kg)
Passing sieve (0.075 mm)	4.5	2.6455	200000

2.6. Selection of Aggregate Gradation for Asphalt Concrete

The selected aggregates gradation in the present investigation follows SCRB, (2003) specification for dense graded wearing course pavement layer. It has 12.5 mm nominal maximum size of aggregates. Table 6 shows the selected aggregate gradation.

Table 6. Gradation of Aggregate for Wearing Course as per SCRB, 2003

Sieve size (mm)	19	12.5	9.5	4.75	2.36	0.3	0.75
Selected gradation	100	95	83	59	43	13	7
SCRB, (2003) Specification limits	100	90-100	76-90	44-74	28-58	5-12	4-10

2.7 Preparation of Modified Asphalt Cement

Modified asphalt cement binder is prepared by using the wet process. In the wet process, asphalt cement was heated to 150°C and then the fly ash or silica fumes were added in powder form using various percentages of each additive. The mixture was blended in a mixer at a blending speed of about 1300 rpm and the mixing temperatures of 160°C was maintained for 20 minutes to promote the chemical and physical bonding of the components.

The optimum percentages of fly ash and Silica fumes are (4 and 2) % by weight of binder respectively. Details of the mixing procedure and selection of the optimum percentages of additives could be found in Sarsam and Al-Lamy, (2015).

2.8 Preparation of Asphalt Concrete Mixture and Specimens

The fine and coarse aggregates were combined with mineral filler to meet the specified gradation for wearing course. The combined aggregates were then heated to 160ºC before mixing with asphalt cement. The asphalt cement or the modified asphalt binder was heated to 150ºC to produce a kinematic viscosity of (170±20) centistokes as recommended by SCRB, (2003). Then, the binder was added to the heated aggregate to achieve the desired amount and mixed thoroughly by hand using a spatula for two minutes until all aggregate particles were coated with thin film of the asphalt binder. The optimum asphalt content of 4.9% was implemented. The optimum binder percentage was determined based on Marshall Trial mixes using various asphalt percentages. Details of obtaining the optimum binder content could be found in Sarsam and Al-Lamy, (2015). The asphalt concrete mixtures were casted in a slab mold of (400 × 300 × 60) mm and subjected to roller compaction to the target bulk density for each additive type according to EN12697-33, (2007). The applied static load was 5 kN while the number of load passes depended on the additive type in mixture and was determined based on trial-and-error process. Details of the compaction process could be referred to Sarsam, 2016. The compaction temperature was maintained to 150°C. Slab samples were left to cool overnight. Beam specimens of 50±2 mm high, 63±2 mm wide and 400 mm length were obtained from the compacted slab sample using the diamond-saw. The total number of beam specimens obtained was twelve, while the number of casted slabs was three. Similar procedure was reported by Sarsam and Hamdan, (2020).

2.9 Repeated Flexural Bending Beam Test

The four-point repeated flexural bending beam test according to AASHTO T321, (2010) was implemented to identify the influence of additives on the fatigue life of asphalt concrete beam specimens at intermediate pavement operating temperature of 20°C and under constant strain level. During the flexural fatigue test, the beam is subjected to repeated four-point loading. The load frequency is usually set to 5 Hz. A repeated haversine (sinusoidal) load is applied to the two inner clamps on the beam specimen with the outer clamps providing a reaction load. This setup produces a constant bending moment over the center portion of the beam (between the two inside clamps). Beams were subjected to a repeated flexural bending load. Micro strain level of 400 was tried to simulate the moderate mode of loading in the field. Figure 1demonstrates the four-point flexural bending test setup.

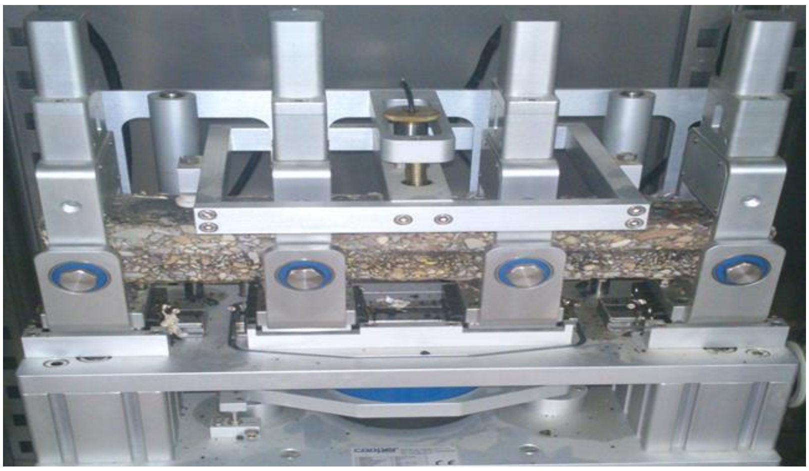

Figure 1. *Four-Points Flexural Bending Test Setup*

III. Discussion

3.1 Influence of Additives on Cumulative Dissipated Energy

Dissipated energy is considered as a measure for evaluation of the fatigue life of asphalt concrete mixtures. The dissipated energy was measured after each load cycle, and the change in dissipated energy for different cycles can indicate the initial state of failure and cracking of the material. The cumulative dissipated energy is the sum of dissipated energy in every cycle until collapse of the material. Figure 2 demonstrates the influence of additives on the cumulative dissipated energy of asphalt concrete. It can be noticed that up to 1000 load repetitions, there is no significant variation in the cumulative dissipated energy between the control and the mixtures with additives. However, a dramatic increase in the cumulative dissipated energy could be noticed for mixtures with fly ash or silica fumes as compared with the control mixture. This may be attributed to the possible initiation of micro cracking in the mixtures which indicates the start of failure and the end of the fatigue life. After 3000 repetitions of flexural stresses, the cumulative dissipated energy increases by (200 and 700) % for fly ash and silica fumes treated mixtures respectively.

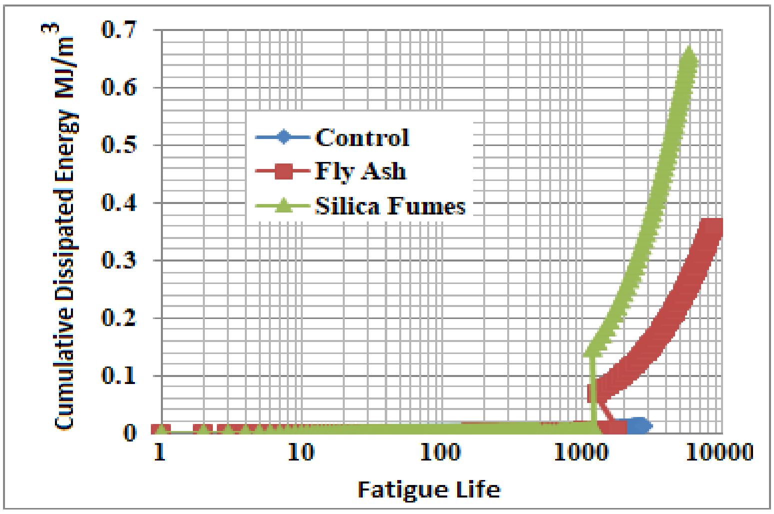

Figure 2. *Influence of Additives on Dissipated Energy*

The dissipated energy changes during the fatigue life test due to the initiation of micro crack. It can be concluded that the incorporation of additives increases the cumulative dissipated energy which increases the fatigue life of the asphalt concrete mixture from the dissipated energy point of view by (233 and 100) % for mixtures treated with fly ash and silica fumes respectively. Test results agree with Maggiore et al., (2014).

3.2 Influence of Additives on Permanent Micro-strain

As demonstrated in Figure 3, the influence of both additives was not significant in controlling the permanent deformation. However, the fatigue life as related to permanent deformation was also decreased after incorporation of the additives. Such behavior agree with Sarsam and Al Nuaimi, (2020).

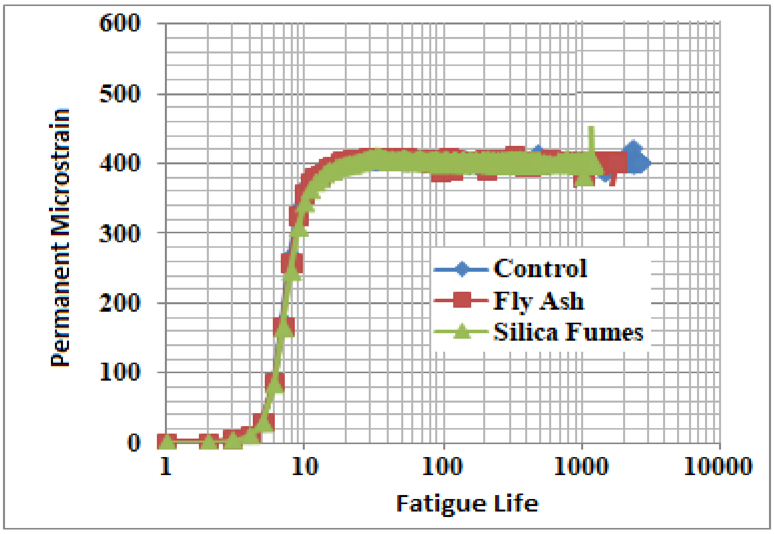

Figure 3. *Influence of Additives on Permanent Deformation*

The fatigue life declines by (33.3 and 60) % after treatment of asphalt concrete with fly ash and silica fumes additives respectively. Such behavior does not match with the work reported by Abdulrahman et al., (2019). Such variation in the fatigue life after incorporating the fly ash could be attributed to the geopolymer implemented in addition to the fly ash.

3.3 Influence of Additives on the Phase Angle

Figure 4 exhibits the influence of additives on the phase angle of asphalt concrete mixture. The phase angle can be considered as an indicator of viscoelastic behavior. The observation of Phase angle is important for understanding the structural material behavior. Significant decline in the phase angle could be observed when the silica fumes additive was implemented; however, the phase angle was declined after 50 repetitions of flexural stresses when fly ash was incorporated as a filler material in asphalt concrete as compared with the control mixture. The fatigue life from the phase angle point of view increases after implementation of silica fumes as an additive. However, it declines when the fly ash additive was introduced. Such finding agrees with the test results addressed by Mandula and Olexa, (2017).

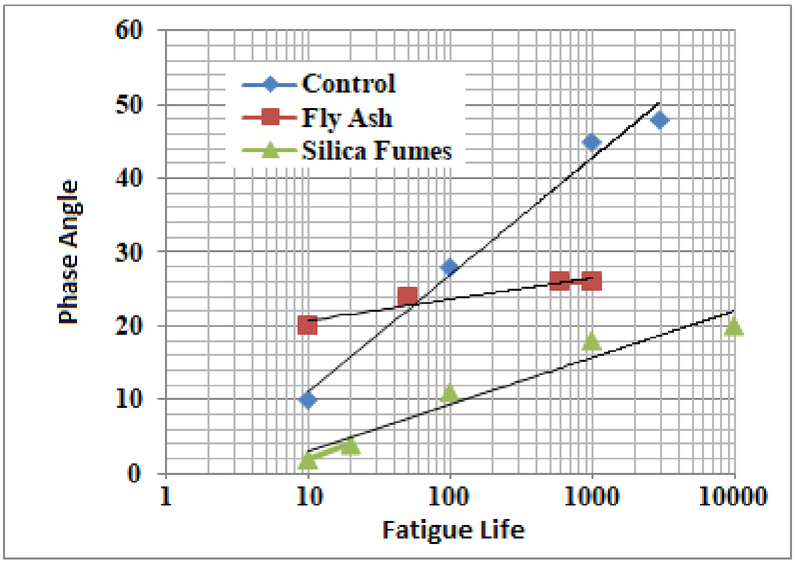

Figure 4. *Influence of Additives on the Phase Angle*

3.4 Influence of Additives on Flexural Stiffness

Figure 5 shows that the flexural stiffness decline after implementation of both additives. Silica fumes additive exhibit a significant lower flexural stiffness at early stage of loading as compared with the control asphalt concrete mixture. On the other hand, the fly ash additive exhibits a gentle rate of decline in the stiffness as the fatigue life proceeds. After 100 repetitions of repeated flexural stresses, the impact of additives was not significant. Such behavior agree with the work revealed by Sarsam (2022). The fatigue life as related to the flexural stiffness increases by (233, and 100) % after implementation of fly ash and silica fumes respectively. Such finding agrees with the work reported by Sarsam, (2021).

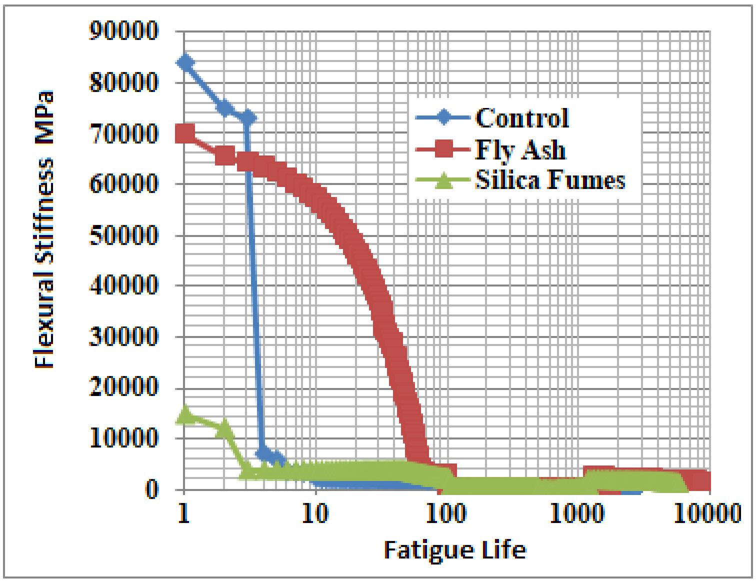

Figure 5. *Influence of Additives on Flexural Stiffness*

IV. Conclusions

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

1. Additives increases the cumulative dissipated energy by (200 and 700) % for fly ash and silica fumes treated mixtures respectively. This increases the fatigue life of the asphalt concrete mixture from the dissipated energy point of view by (233 and 100) % for mixtures treated with fly ash and silica fumes respectively.
2. The influence of both additives was not significant in controlling the permanent deformation. However, the fatigue life as related to permanent deformation declines by (33.3 and 60) % after treatment of asphalt concrete with fly ash and silica fumes additives respectively.
3. Significant decline in the phase angle could be observed when the silica fumes additive was implemented; however, the phase angle was declined after 50 repetitions of flexural stresses when fly ash was incorporated in asphalt concrete as compared with the control mixture. The fatigue life from the phase angle point of view increases after implementation of silica fumes as an additive.
4. Silica fumes additive exhibit a significant lower flexural stiffness at early stage of loading as compared with the control asphalt concrete mixture. The fly ash additive exhibits a gentle rate of decline in the stiffness as the fatigue life proceeds. The fatigue life as related to the flexural stiffness increases by (233, and 100) % after implementation of fly ash and silica fumes respectively.

References

AASHTO T-321. (2010). Method for Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending, AASHTO Provisional Standards. Washington, D.C.

Abdulrahman H., Hassan B., Mohab E. (2019). Enhancing asphalt cement properties using geopolymer based on fly ash and glass powder. Proceedings, CSCE Annual Conference, Laval (Greater Montreal) June 12 - 15.

Alama S., Hammoum F. (2015). Viscoelastic properties of asphalt concrete using micromechanical self-consistent model. Archives of Civil, and Mechanical Engineering. Volume 15, Issue 1, January, Pages 272-285. https://doi.org/10.1016/j.acme.2014.02.005.

Al-Mohammedawi, A. and Mollenhauer, K. (2020). A Study on the influence of the chemical nature of fillers on rheological and fatigue behavior of bitumen emulsion mastic. Materials 13: 4627; MDPI. doi:10.3390/ma13204627. www.mdpi.com/journal/materials.

ASTM. (2015). Road and Paving Materials, Annual Book of ASTM Standards, Volume 04.03, American Society for Testing and Materials. West Conshohocken. USA.

EN 12697 – 33. (2007). Bituminous Mixtures – Test Methods for Hot Mix Asphalt – part 33: Specimen prepared by Roller Compactor. European Committee for Standardization.

Jie, J., Yao, H., Liu, L., Suo, Z., Zhai, P., Yang, X. and You, Z. (2017). Adhesion evaluation of asphalt-aggregate interface using surface free energy method. Appl. Sci. 7: 156. doi:10.3390/app7020156. www.mdpi. com/journal/applsci.

Kakar, M., Hamzah, M., Akhtar, M. and Saleh, J. (2019). Evaluating the surface free energy and moisture sensitivity of warm mix asphalt binders using dynamic contact angle. Hindawi Advances in Civil Engineering, Article ID 9153603, 15 pages. http://doi.org/10.1155/2019/9153603.

Khan, A. A., Ullah, N., Ahmad, A. & Ali, S. (2020). Evaluation of mechanical properties of hot mix asphalt by replacing the combination of marble dust and silica fume as a filler. GSJ 8(9): 681-690. www. globalscientificjournal.com.

Khodary F. Impact of Silica fumes on the properties of Asphalt pavement base course. (2016). International Journal of Engineering Trends and Technology (IJETT) – Volume 35 Number 10 - May. P. 487. http://www.ijettjournal.org.

Li L., Wei Y., Li Z., (2022). Farooqi M. Rheological and viscoelastic characterizations of fly ash/slag/silica fume-based geopolymer. Journal of Cleaner Production. Elsevier, Volume 354, 20 June. https://doi.org/10.1016/j.jclepro.2022.131629.

Maggiore C., Airey G., Marsac P. (2014). A dissipated energy comparison to evaluate fatigue resistance using Two-point bending. Journal of Traffic and Transportation Engineering (English Edition), 1(1):49 – 54. https://doi.org/10.1016/S2095-7564(15)30088-X.

Mandula J., Olexa T. (2017). Study of the Viscoelastic Parameters of Asphalt Concrete. Procedia Engineering 190. Elsevier, Science Direct, Structural and Physical Aspects of Construction Engineering. P. 207 – 214. http://creativecommons.org/licenses/by-nc-nd/4.0/.

Onyelowe K., Onyia M., Onukwugha E., Ikpa C. (2020). Mechanical properties of fly ash modified asphalt treated with crushed waste glasses as fillers for sustainable pavements. Epitoanyag-Journal of Silicate Based and Composite Materials 72(6): P. 219-222. DOI: 10.14382/epitoanyag-jsbcm.2020.35.

Sarsam S. (2016). Monitoring dissipated energy through the fatigue process of asphalt concrete. Applied research journal ARJ, Vol.2, Issue, 6, P.275-282, June. http://arjournal.org.

Sarsam S. I. and AL-Lamy A. K. (2015). Fatigue life assessment of Modified Asphalt Concrete. International Journal of Scientific Research in Knowledge, 3(2). P. 030-041. http://dx.doi.org/10.12983/ijsrk-2015-p0030-0041.

Sarsam S., and AL Nuaimi S. (2020). Influence of Ageing on Flexible Pavement Interface Bond under Repeated Shear Stresses. Britain International of exact sciences journal. (BloEx Journal). Vol. 2, No. 2, May, P. 462-475.Doi: https://doi.org/10.33258/bioex.v2i2.219.

Sarsam S. I. (2016). Monitoring dissipated energy through the fatigue process of asphalt concrete. Applied research journal, ARJ. Vol.2, Issue, 6. P.275-282, June. http://arjournal.org.

Sarsam S., and Hamdan R. (2020). Modeling the Influence of Surface Free Energy on Moisture Damage of Recycled Asphalt Concrete. Budapest international research in exact sciences (BirEx. Journal). Vol.2, No. 2. April P.168-183. https://bircu-journal.com/index.php/birex.

Sarsam S., Mashaan N. (2022). Detecting the Influence of Additives on Asphalt Concrete Durability. Jurnal Kejuruteraan 34(1): 51-58. https://doi.org/10.17576/jkukm-2022-34(1)-05.

Sarsam S. (2022). Modeling the Thermal Behavior of the Viscoelastic Properties of Asphalt Concrete. Britain International of Exact Sciences (BIoEx) Journal Vol. 4, No. 2, May 2022, Page: 79-91. DOI: https://doi.org/10.33258/bioex.v4i2.729.

Sarsam S. (2021). Assessment of Fatigue Life and Stiffness of Asphalt Concrete After Implementation of Additives. Civil Engineering Beyond Limits 4, 8-12. www.acapublishing.com.

SCRB. (2003). State Commission of Roads and Bridges. Standard Specification for Roads & Bridges, Ministry of Housing & Construction. Iraq.

Shen, S.; Carpenter, S. H. (2007). Dissipated Energy Concepts for HMA Performance: Fatigue and Healing. COE report No. 29. Centre of Excellence for Airport Technology, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Champaign-Urbana Metropolitan Area, Illinois, USA.

Sobolev K., Vivian I., Saha R., Wasiuddin N., Saltibus N. (2014). The effect of fly ash on the rheological properties of bituminous materials. Elsevier, Fuel. Volume 116, 15 January. P. 471-477 https://doi.org/10.1016/j.fuel.2013.07.123.

Tapkin S. (2014). Estimation of Fatigue Lives of Fly Ash Modified Dense Bituminous Mixtures Based on Artificial Neural Networks. Materials Research.; 17(2): 316-325 DDOI: http://dx.doi.org/10.1590/S1516-14392014005000040.