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Detecting the Influence of Additives on Asphalt Concrete Durability

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ABSTRACT

Modification of asphalt cement with additives is a sustainable issue. An attempt was made in the present assessment to detect the influence of modification of the asphalt binder by 2 % silica fumes and 4 % fly ash additives on the durability in terms of fatigue life of asphalt concrete mixture under short-term and long-term ageing processes and moisture damage. Asphalt concrete slab samples of wearing course was prepared and compacted by roller. The beam specimens of 400 mm length and 50 mm height and 63 mm width were extracted from the slab samples. The beam specimens had practiced the four-point repeated flexural bending beam test. The fatigue life was monitored as the number of load repetitions to reach the failure under three constant micro strain levels of (250, 400, and 750). The reduction in fatigue life after long-term ageing for control, silica fumes modified, and fly ash modified mixtures was (74.7, 38.4, and 60) %, (66.2, 52.4, and 64.3) %, (63.9, 63.1, and 57.5) % under 250, 400, and 750 microstrain levels respectively. However, the reduction in fatigue life after practicing moisture damage for control, silica fumes modified, and fly ash modified mixtures was (71.2, 59.6, and 37.2) %, (37.1, 64.9, and 11.2) %, (71, 84.8, and 32.2) % under (250, 400, and 750) microstrain levels respectively. It was concluded that Fly ash exhibit lower susceptibility to long-term ageing process as compared to other mixtures, while silica fumes exhibit lower susceptibility to moisture damage as compared to other mixtures.

Keywords: Modified Asphalt, Fatigue Life, Flexural Bending, Ageing, Asphalt Concrete.

INTRODUCTION

The asphalt binder quality decline throughout the pavement service life due to ageing, load, and environmental impact. Glover et al. 2009 revealed that ageing of asphalt concrete occurs in three stages, the first stage which is called short-term ageing occurs very fast through the production process of asphalt mixtures. The second ageing stage occurs at a slower rate during the transportation, laying down, and compaction of the mixture.

The third stage occurs after construction when the asphalt concrete pavement is in service, and it is exposed to the surrounding environment. Golchin and Mansourian, 2017 evaluated the fatigue properties and fatigue life of asphalt mixtures by implementing the four-points beam bending. It was revealed that the mixtures tested at low rate of strains, had high final stiffness while the asphalt concrete fatigue life of the specimens increased, when the strain level of test decreased. Al-Khateeb and Alqudahaims, 2018 investigated the impact of laboratory aging on the fatigue performance of asphalt concrete. The asphalt mixtures have practiced the short- term and long-term ageing processes, then tested for fatigue life using indirect tensile at various initial strain levels. It was revealed that the short-term ageing had increased the fatigue life. Sarsam and AL-Lamy, 2016 reported that the fatigue in asphalt concrete pavement occurs by accumulation of damage while it is a major cause of cracking in asphalt concrete pavement.

The fatigue approach of flexible pavement assumes that the pavement damage usually occurs in a specimen because of the dynamic repetition of loading which leads to fatigue failure in the asphalt specimen. The load repetitions number to failure equal to the fatigue life, and may be calculated based on stress, or strain. The impact of ageing on the fatigue life of the polymer modified asphalt was assessed by (Zhu et al. 2009). Two types of ageing procedures were adopted, the short time ageing and natural ageing when the asphalt specimen is exposed to the sunlight, moreover, it is subjected to the impact of temperature changes and rain for various periods. Four-Point Bending test has been conducted for evaluation of fatigue life of aged asphalt concrete mixtures at 15°C and compare its behavior with the control specimens. The testing results had indicated that the fatigue life of the aged asphalt concrete specimen declined significantly as compared with the control specimen, especially of the naturally aged specimens. Sarsam and Alwan, 2014 revealed that fatigue life of asphalt concrete declines by 70 % after subjecting asphalt specimen to the damage by moisture process. For the microstrain level ranges from 400 to 250, the fatigue life declines by 87 % as compared to reference mixture. Kleiziene et al. 2019 studied the short-term and long-term ageing impact on the properties of polymer-modified and control asphalt mixture. The aging indices were evaluated based on the rheological and chemical properties of the mixtures to verify the age of unknown asphalt. Wang et al. 2020 assessed the impact of laboratory long-term and short-term ageing on the chemical and rheological properties of asphalt binder modified by crumb rubber. Chaala et al. 1996 revealed that high levels of modifiers can form hard gels with the asphalt binder. This was further evaluated in terms of the bond within the bitumen and the chemical composition (maltenes and asphaltenes) and that the bitumen could become more fluid because of the high maltene oil content due to the greater bonding occurred between asphaltenes and modifier particles. Chebil et al. 2000 stated that higher viscosity obtained in modified binder is related to greater stiffness and decreased penetration.

Control binder and binder modified by crumb rubber were investigated. Rubber binders exhibited improved ageing resistance when compared with control binder as the lower change in rheological parameters. It was concluded that higher resistance against ageing was achieved when the crumb rubber content increases. Cui et al. 2018 assessed the residual fatigue life of asphalt concrete pavement after practicing long-term field service. Fatigue life behavior of asphalt pavement specimens with different failure types, service time, and traffic load, were collected and evaluated. It was concluded that surface layer exhibits longer fatigue life of the mixture when practicing small stresses level, while it exhibits shorter fatigue life when practicing large stress levels. Longer service time exhibited greater sensitivity to the loading stresses; however, heavier traffic exhibits shorter fatigue life.

Almeida et al. 2018 studied the impact of water and temperature on the rheological behavior of the mixtures, fatigue resistance and the complex modulus of asphalt mixture prepared with a control asphalt binder. It was concluded that it is possible to evaluate the impact of the temperature and water on the reduction in the fatigue life and the graphical representation of the complex modulus of the asphalt concrete mixture. Al-Mohammedawi and Mollenhauer, 2020 identified the influence of active fillers such as limestone, cement, ladle slag, and silica fume on the resulting fatigue behavior and on the rheological properties of cold bitumen emulsion mastic. The assessment was accompanied by the chemical analysis of the filler-emulsified bitumen. Emulsified bitumen binder was mixed with fillers separately for preparation of the mastics.

Results exhibits that the fatigue damage resistance and the rheological performance of asphalt concrete depend not only on the filler inclusions but also on chemistry and filler type. Khan et al. 2020 assessed the influence of different fillers on some properties of asphalt concrete mixtures. Two filler types, silica fumes and marble dust were used to investigate the effect of filler / asphalt ratio on the characteristics of asphalt mixtures. It was concluded that the mixtures with 50% silica fume and 50% marble dust have greater stability than all the other percentages used in a Marshall mix. All other percentages of filler have lower stability and voids which are out of range. Mixture having 50% silica & 50% marble dust has only 13.5 mm flow value which is greater than all other percentages. Jie et al. 2017 revealed that the incorporation of additives can enhance the adhesion of the asphalt-aggregate interface. Kakar et al. 2019 highlighted the significance of additive to improve the asphalt binder adhesion properties with aggregate.

The aim of the present assessment is to detect the impact of silica fumes and fly ash on the durability of asphalt concrete mixtures through the fatigue life. The influence of asphalt binder modification on long-term and short-term ageing processes and the resistance of the mixtures to moisture damage will also be investigated.

MATERIALS PROPERTIES

The materials implemented in this work are guaranteed to be available, and usually used for asphalt pavement construction.

ASPHALT CEMENT

Asphalt cement binder was obtained from AL-Nasiriya oil Refinery. It has a penetration grad 40-50. The physical properties of the asphalt binder are listed in Table 1.

FINE AND COARSE AGGREGATES

Coarse aggregates of crushed type, with a nominal maximum size of 19 mm, and fine aggregates consist of crushed and natural sand mixture were obtained from AL-Ukhaider quarry. The aggregates are washed, then dried, and sieved to different sizes. Table 2 present the physical properties of aggregates.

TABLE 1. Physical properties of asphalt cement binder

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

TABLE 2. The Physical Properties of Fine and Coarse Aggregates

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

MINERAL FILLER

The mineral filler implemented in this investigation is limestone dust. It was obtained from Karbala governorate. Table 3 present the physical properties of the mineral filler.

TABLE 3. The Physical Properties of Mineral Filler (Limestone dust)

Bulk specific gravity	% Passing Sieve No.200
2.617	94

FLY ASH

Fly ash of class F was implemented. Table 4 present the physical properties of fly ash, while the chemical composition of Fly Ash is listed in Table 5. It was obtained from local market.

TABLE 4. The Physical Properties of Fly Ash

Maximum Sieve size mm	% Passing	Specific gravity	Specific surface area (m2/ kg)
0.075	98	2.645	650

TABLE 5. Chemical Composition of Fly Ash

Chemical composition	Percent	ASTM C-618, 2015 Requirement (%)
SiO2	61.95	……….
Fe2O3	2.67	………...
Al2O3	28.82	…………
CaO	0.88	………….
MgO	0.34	5.0 max
Na2O	0.26	1.5 max
Loss on ignition	0.86	6.0 max

SILICA FUMES

Silica fumes was obtained as a fluffy powder. Table 6 presents the physical properties, while Table 7 shows its chemical composition of the Silica fumes. It was brought from local market.

TABLE 6. The Physical Properties of Silica Fumes

Maximum sieve size	PH value	Density (kg/m3)	Specific surface area (m2/ kg)
Passing sieve (0.075 mm)	4.5	2.6455	200000

TABLE 7. The Chemical Components of Silica Fumes

Chemical Composition	Percent
SiO2	99.1
Fe2O3	35.0 P.P.M
Al2O3	<o.o35
TiO2	<0.006
CaO2	0.03
MgO	52.0 P.P.M
SO3	<0.07
Loss on ignition	0.7

SELECTING THE GRADATION OF AGGREGATES FOR ASPHALT CONCRETE

The selected gradation of aggregates in the present investigation was as per (SCRB, 2003) specification and demonstrated in Figure 1.

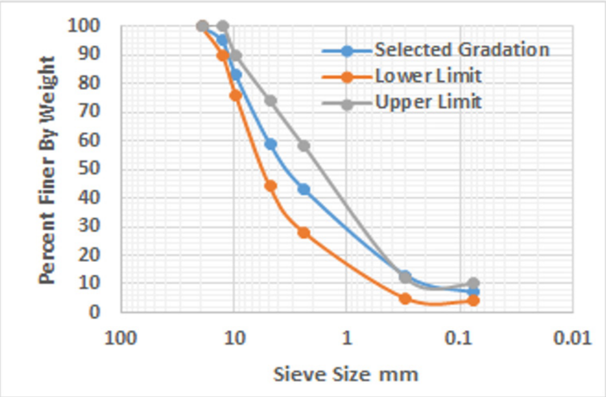

FIGURE 1. Aggregates Gradation as per SCRB, 2003.

It is usually implemented for wearing course pavement layer with dense gradation.

TESTING METHODS

PREPARING THE MODIFIED ASPHALT CEMENT

The modified asphalt cement binder is prepared by implementing the wet process. In such 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 1300 rpm of bleeding speed while the mixing temperatures of 160 °C was maintained for 20 minutes so that promoting the possible chemical and physical bonding of the components is achieved. 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 could be found in (Sarsam and Al-Lamy 2015).

PREPARING THE ASPHALT CONCRETE MIXTURE, SLAB SAMPLES, AND BEAM SPECIMENS

The mineral filler was combined with fine and coarse aggregates to meet the specified gradation. The combined aggregates were then heated to 160 ºC before it was mixed with asphalt cement. The asphalt binder or the modified asphalt binder was heated to 150 ºC to get a kinematic viscosity of (170±20) centistokes as recommended by (SCRB, 2003). Then, the binder was added to the heated aggregate in the desired percentage and mixed thoroughly by a spatula for two minutes so that the aggregate particles were covered with thin film of the asphalt binder. The mixture practiced the short-term ageing process in an oven for 4 hours at temperature of 135 ºC according to (AASHTO R-30, 2002). The optimum asphalt binder 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 short-term aged mixtures were casted in a slab mold of (400 x 300 x 60) mm and subjected to roller compaction to the target bulk density for each binder type according to (EN12697-33, 2007). The applied static load was 5 kN while the number of load passes depended on the asphalt 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 height, 63±2 mm width 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.

LONG-TERM AGEING OF BEAM SPECIMENS

A part of the beam specimens was subjected to oxidation ageing (long-term ageing), beams have been stored in an oven for five days (120 hours) at 85°C as per (AASHTO R-30, 2002) procedure. Specimens were then withdrawn from the oven and stored in the testing chamber for two hours at the required testing temperature of 20°C for the fatigue test.

CONDITIONING OF BEAM SPECIMENS FOR MOISTURE DAMAGE

A group of the beams was subjected to moisture damage by conditioning the beams in water bath at 25º C for two hours, the air in the voids was evacuated using a compressor with a vacuum of 3.74 kPa applied for 10 minutes to obtain 80 % saturation. The asphalt concrete beam specimens were then placed in a deep freeze at (-18°C) for 16 hours. The frozen beam specimens were then moved to a water bath and stored for 24 hours at (60ºC). Then they were dried and placed in the testing chamber for two hours at 20º C before testing for fatigue life. The only deviation of this procedure from that described in AASHTO, 2002 is that the tested specimen is a beam and not a cylindrical specimen.

REPEATED FLEXURAL BENDING BEAM TEST

The four-points repeated flexural bending beam test according to (AASHTO T321, 2010) was implemented to identify the influence of fine additives on the fatigue life of asphalt concrete beam specimens at intermediate pavement operating temperature of 20 °C and under constant strain level. Figure 2 demonstrates the four- points flexural bending test setup.

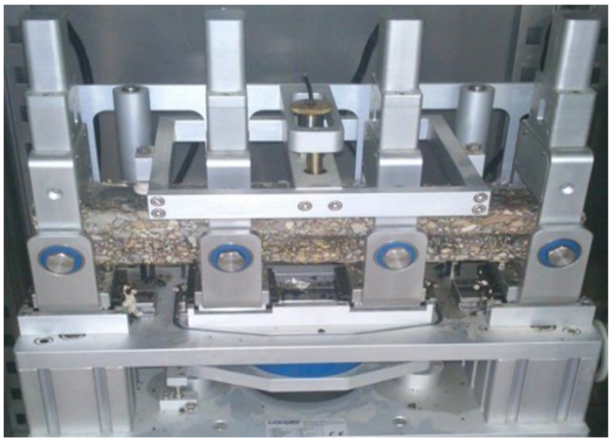

FIGURE 2. Four- points flexural bending beam test setup.

During the flexural fatigue test, the beams are subjected to repeated four-point loading. The load frequency is usually set to 5 Hz. A repeated sinusoidal (haversine) load is applied on the two inner clamps on the beam specimen with the outer clamps providing a reaction load. The setup creates a constant bending moment over the center portion of the asphalt concrete beam (between the two inside clamps). Beams were subjected to a repeated flexural bending load. Three different Microstrain levels of 250, 400, and 750 were tried to simulate various modes of loading in the field.

RESULTS AND DISCUSSIONS

INFLUENCE OF FINE ADDITIVES ON FATIGUE LIFE AFTER SHORT TERM AGEING OF ASPHALT CONCRETE

Figure 3 demonstrates the influence of fine additives on the fatigue life of asphalt concrete beam specimens in terms of number of flexural load cycles until failure of asphalt concrete specimen. It can be noted that implementation of additives exhibits positive influence on fatigue life regardless of the additive type for asphalt concrete mixtures after practicing short term ageing process. Such behavior agrees with Glover et al. 2009.

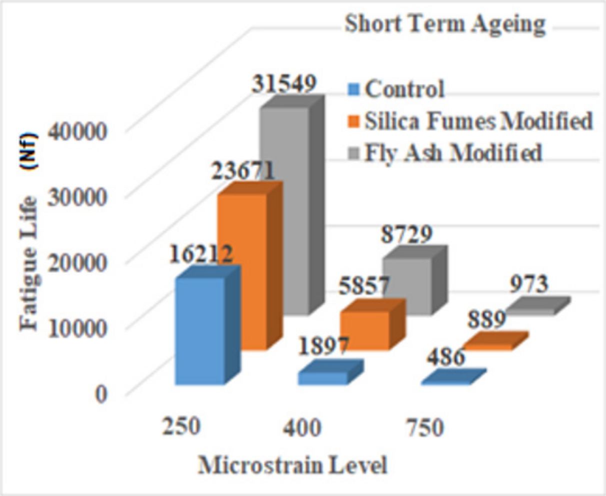

FIGURE 3. Fatigue Life After Short Term Ageing

At lower microstrain level of 250, which represent the deformation under low traffic load, the fatigue life increased by (94.6 and 46) % after implementation of fly ash and silica fumes respectively as compared with the control mixture without additives. At medium microstrain level of 400, which represent the deformation under medium traffic load, the fatigue life increased by (360 and 208) % after implementation of fly ash and silica fumes respectively. However, at higher microstrain level of 750, which represent the deformation under high traffic load, the fatigue life increased by (100 and 83) % after implementation of fly ash and silica fumes respectively. Similar behavior was reported by (Golchin and Mansourian 2017). On the other hand, the increment in the microstrain level has significantly decreases the fatigue life regardless of the additives type. It can be noticed that the fatigue life declines after increasing the microstrain level from 250 to 400 and 750 by (88.3 and 97) %, (75.2 and 96.2) %, (72.3 and 97) % for control, silica fumes modified, and fly ash modified mixtures respectively. It can be stated that the additives were able to resist the deformation at moderate loading as compared with the control mixture.

INFLUENCE OF ADDITIVES ON FATIGUE LIFE AFTER LONG-TERM AGEING OF ASPHALT CONCRETE

As demonstrated in Figure 4, implication of additives for modification of asphalt binder exhibits positive impact on fatigue life of asphalt concrete after practicing long term ageing process.

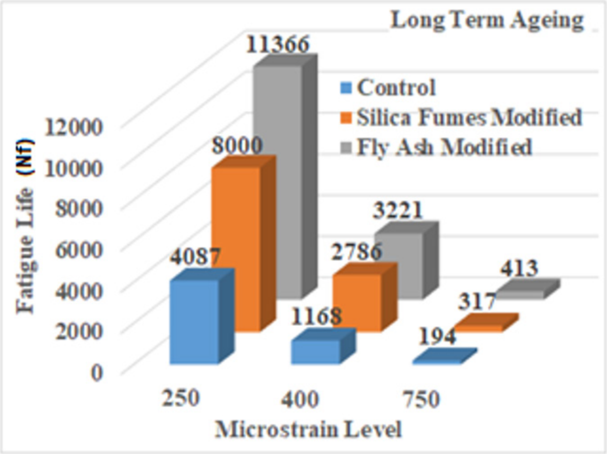

FIGURE 4. Fatigue Life After Long Term Ageing

At microstrain level of 250, the fatigue life increases by (178 and 95.7) % after implementation of fly ash and silica fumes respectively when compared to the control mixture without additives. At microstrain level of 400, the fatigue life increases by (72.5 and 138.5) % after implementation of fly ash and silica fumes respectively. However, at higher microstrain level of 750, the fatigue life increases by (158.6 and 116) % after implementation of silica fumes and fly ash respectively. However, the increment in the microstrain level has significantly decreases the fatigue life regardless of the additives type. It can be observed that the fatigue life decreases after increasing the microstrain level from 250 to 400 and 750 by (71.4 and 95.2) %, (65.1 and 96) %, (71.6 and 96.3) % for control, silica fumes modified, and fly ash modified mixtures respectively. Such behavior agrees well with (Al-Khateeb and Alqudahaims 2018). However, the fatigue life of asphalt concrete declines after long term ageing when compared with that after short term ageing. This could be attributed to the stiffening of the mixture and reduction in the flexibility after the loss of volatiles from the binder through the long-term ageing. The decline in fatigue life after long-term ageing as compared to the fatigue life after short term ageing for control, silica fumes modified, and fly ash modified mixtures was (74.7, 38.4, and 60) %, (66.2, 52.4, and 64.3) %, (63.9, 63.1, and 57.5) % under 250, 400, and 750 microstrain levels respectively. It can be stated that the fly ash modified mixture exhibit lower susceptibility to long-term ageing process as compared to other mixtures.

INFLUENCE OF ADDITIVES ON FATIGUE LIFE AFTER MOISTURE DAMAGE OF ASPHALT CONCRETE

Figure 5 exhibit the fatigue life of asphalt concrete mixtures after practicing moisture damage, it can be noticed that implication of additives to modify the asphalt binder has enhance the fatigue life especially the silica fumes modifier. The fatigue life after implementing silica fumes and fly ash exhibits higher values than that of control mixture by (219 and 96.1) %, (168 and 72.5) %, (158.6 and 116) % when the specimens are tested under 250, 400, and 750 microstrain levels respectively. It can be observed that the fatigue life decreases after increasing the microstrain level from 250 to 400 and 750 by (83.5 and 93.4) %, (86.2 and 94.6) %, (85.5 and 92.7) % for control, silica fumes modified, and fly ash modified mixtures respectively. However, the fatigue life of asphalt concrete declines after practicing moisture damage when compared with that before such process.

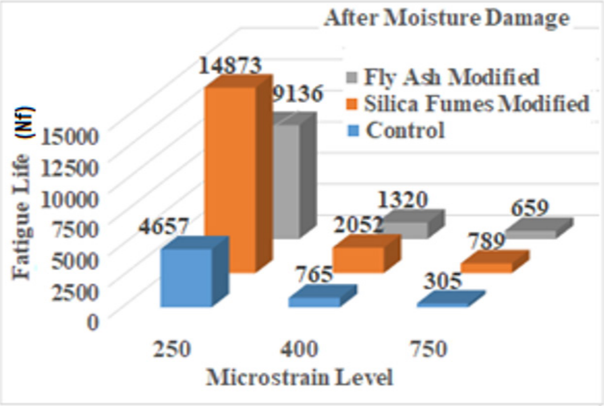

FIGURE 5. Fatigue Life After Moisture Damage

This could be attributed to the stripping after freezing and thawing of the mixture which decline the flexibility of the mixture. The reduction in fatigue life after practicing moisture damage as compared to the fatigue life before such process for control, silica fumes modified, and fly ash modified mixtures was (71.2, 59.6, and 37.2) %, (37.1, 64.9, and 11.2) %, (71, 84.8, and 32.2) % under 250, 400, and 750 microstrain levels respectively. It can be stated that silica fumes modified mixture exhibit lower susceptibility to moisture damage as compared with other mixtures. Such behavior agrees with Almeida et al. 2018.

CONCLUSION

Based on the testing program and limitations of the materials implemented, the following conclusions can be addressed.

1. The fatigue life decreases after increasing the microstrain level from 250 to 400 and 750 by (88.3 and 97) %, (75.2 and 96.2) %, (72.3 and 97) % for control, silica fumes modified, and fly ash modified mixtures respectively.
2. The fatigue life of asphalt concrete mixtures increased by (46 and 94.6) %, (208 and 360) %, (83 and 100) % after implementation of silica fumes and fly ash at 250, 400, and 750 microstrain levels respectively when compared to the control mixture without additives.
3. The reduction in fatigue life after long-term ageing for control, silica fumes modified, and fly ash modified mixtures was (74.7, 38.4, and 60) %, (66.2, 52.4, and 64.3) %, (63.9, 63.1, and 57.5) % under 250, 400, and 750 microstrain levels respectively.
4. The fatigue life of asphalt concrete after long-term ageing increases by (95.7 and 178) %, (138.5 and 72.5) %, (158.6 and 116) % after implementation of silica fumes and fly ash respectively when compared with the control mixture without additives at microstrain level of 250, 400, and 750 respectively.
5. The fatigue life after moisture damage and after implementing silica fumes and fly ash exhibits higher values than that of control mixture by (219 and 96.1) %, (168 and 72.5) %, (158.6 and 116) % when the specimens are tested under 250, 400, and 750 microstrain levels respectively.
6. The reduction in fatigue life after practicing moisture damage as compared to the fatigue life before such process for control, silica fumes modified, and fly ash modified mixtures was (71.2, 59.6, and 37.2) %, (37.1, 64.9, and 11.2) %, (71, 84.8, and 32.2) % under 250, 400, and 750 microstrain levels respectively.
7. Fly ash modified mixture exhibit lower susceptibility to long-term ageing process as compared to other mixtures, while silica fumes modified mixture exhibit lower susceptibility to moisture damage as compared with other asphalt concrete mixtures.

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DECLARATION OF COMPETING INTEREST

None

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