INFLUENCE OF AGEING ON FATIGUE LIFE OF ASPHALT CONCRETE

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ABSTRACT

The fatigue life of asphalt concrete is often related to environmental condition, loading condition, ageing, material composition and properties. This work investigates the influence of short- and long-term ageing of laboratory beam specimens, asphalt content, and testing temperature on fatigue life of asphalt concrete wearing course. Slab samples of (30 x 40x 6) cm have been prepared, beam specimens of (40x 5x 6) cm were cut from the asphalt concrete slab samples. Beam specimens were tested for fatigue life under the influence of three levels of micro strain (250, 400, and 750) at (5, 20, and 30) °C before and after practicing long-term aging. It was observed that the fatigue life decreases by (85 and 97) %, (87.5 and 97.4) %, (71.4 and 95.2) % after increasing the applied microstrain from (250 to 400 and 750) µƐ for control mixture and for mixtures subjected to short-and long-term ageing processes respectively. The fatigue life increases by (142.8 and 257.1) %, (34.4 and 57.8) % and (10 and 30) % when the asphalt content increases from (4.4 to 4.9 and 5.4) % for specimens practicing the applied microstrain of (250, 400 and 750) µƐ respectively. It was concluded that the fatigue life increases by a range of (two to fifteen) folds when the testing temperature increases from (5 to 20 and 30)°C respectively.

Key Words: Fatigue life, Asphalt concrete, Flexure strain, Ageing, Temperature, Strain level

1. Introduction

Fatigue life of the asphalt concrete mixture, which can be determined with cyclic fatigue tests in the laboratory, is an important design parameter for the structural design of asphalt pavements. Golchin and Mansourian, 2017 evaluated fatigue properties and fatigue life of asphalt mixtures by using the four-point bending beam. Analysis of the tests results showed that the mixtures tested at lower strains, had higher final stiffness while the fatigue life of specimens increased, when the level of test strains decreased. Song-tao et al., 2015 stated that the problems of asphalt aging have not been comprehensively considered when pavement is designed globally, so the effects of aging on the life of asphalt pavement have not been studied accurately. The study of fatigue performance in different degrees of aging plays a significant role in improving design parameters and asphalt mixtures, and preventing early damage, as well as improving road performance and extending the life of asphalt pavement. Aging of asphalt binders occurs in three stages, the first stage occures very fast during the production of asphalt mixtures. This stage is often referred to as short-term aging. The second stage of aging occurs at a slower rate while the mixtures are transported, laid down, and compacted. The third stage occures after construction while the asphalt concrete is in service and exposed to the surrounding environment as reported by Glover et al., 2009. Paul et al., 2016 stated that aging continues for about 2 to 3 years until the mixture approaches the maximum density, when no further densification occurs. Aging significantly affects the mechanical properties of asphalt mixture and hence the performance of the asphalt pavement. Therefore, it is required to characterize the aged asphalt mixtures properly for the successful design of asphalt pavements. A study by Al-Khateeb and Alqudahaims, 2018 investigated the influence of laboratory aging on the fatigue performance of asphalt mixtures. The mixtures were subjected to short and long term ageing then tested for fatigue using indirect tensile and various initial strain levels. It was found that the short term ageing led to an increase in fatigue life. Findings also showed that the fatigue life increased as the testing temperature increase. The evolution of resilient modulus, permanent strain and fatigue life of an asphaltic concrete mixture exposed under weather conditions was investigated by Quintana and Lizcano, 2012. It is concluded that resilient modulus of the mixture increases by an average of 2.17 times, during 48 months of exposure under environmental conditions. Such stiffness increase generates an increment of approximately 10 times in mixture fatigue-life because of asphaltic binder stiffening effect, due to its own ageing condition.The effect of ageing and temperature on the fatigue of asphalt concretes made with two types of binders, was studied by López-Montero and Miró, 2017. Specimens previously subjected to an accelerated laboratory ageing process were tested by a strain sweep test at different temperatures (-5ºC, 5ºC and 20°C). Results were compared with the obtained from the unaged specimens showing the relative importance of ageing and temperature on the parameters that determine the fatigue life of the mixture. The mixtures behaviour becomes more brittle with ageing and the decrease of temperature. However, ageing hardly has an effect on fatigue at lower temperatures. As reported by Sol-Sánchez et al., 2015, bituminous mixture should be designed and manufactured not only to withstand the traffic loads imposed, but also the action of the environment. It is necessary to carefully investigate all the variables that influence ageing. In fact, the ageing of asphalt mixtures depends on multiple factors, such as temperature, air and water, which therefore can have a great effect on the durability of asphalt mixtures. Sarsam, 2016 studied the impact of ageing on the stiffness of asphalt concrete through the fatigue process. It was concluded that the stiffness is susceptible to moisture damage and aging, the increase in Microstrain level leads into a remarkable decrease in initial and failure stiffness's. The stiffness is susceptible to the testing temperature and asphalt content, lower testing temperature of 5º C exhibits higher stiffness value, while higher binder content has a negative impact on the stiffness. The effects of aging on the fatigue property of polymer modified asphalt mixtures were investigated by Zhu et al., 2009. Two kinds of aging procedures are adopted, the short-time aging and natural aging with the original specimen exposed in the sunlight and subjected to the rain and temperature change for 3, 6 and 9 months. Four-Point Bending Test was conducted to evaluate fatigue properties of aged asphalt mixtures at 15°C compared with the original specimens. Test results indicate that the fatigue life of aged specimen is decreased significantly when compared with the original ones, especially of the natural aged specimens. Miró et al., 2015 examined the combined effect of the loss of volatiles and oxidation produced during ageing on the fatigue behaviour of the bitumen. Different temperatures have been used to evaluate the effect of visco-elastic phenomena on aged binder fatigue. The results showed that temperature plays an important role in the impact of ageing on the fatigue response of bituminous binders, and in the mechanical response of these materials. Sarsam and AL-Lamy, 2016 stated that fatigue is a process of cumulative damage and one of the major causes of cracking in asphalt concrete pavement. The traditional fatigue approach assumes that damage occurs in a specimen from dynamic repetitive loading that leads to fatigue failure of the specimen. The number of load repetitions to failure equal to the fatigue life, and can be calculated based on stress, or strain. The

results of repeated four point flexural fatigue beam testing conducted by Sarsam and Alwan, 2014 have indicated that fatigue life decreases by 70 percent after subjecting asphalt concrete to moisture damage. For a Microstrain range from 250 to 400, the fatigue life decreases by 87 percent as compared to reference mixture. Karakas, 2018 stated that exposure of environmental conditions such as traffic and climate is one of the prominent reasons aging in asphalt. The most common mechanism of aging is the degradation in the chemical structure of the binder by oxidation. Asphalt aging could cause several serious issues on the pavement such as stiffening, stripping that accelerates fatigue cracking and different moisture-induced problems such as raveling
and potholes.

The aim of the present investigation is to assess the influence of short and long term ageing process, testing temperature, asphalt content, and strain levels on the fatigue life of asphalt concrete wearing course by implementing the repeated four point flexure test.

2. Materials and Methods

The materials used in the present assessment are economicaly available and usually used by roadway agencies for asphalt pavement construction in Iraq.

2.1. Asphalt Cement

Asphalt cement of (40-50) penetration graded was utilized in this assessment. It is obtained from AL-Naesria oil Refinery, south of Baghdad. The properties of asphalt cement comply with the specifications of State Commission for Roads and Bridges SCRB, 2003. The physical properties of this type of asphalt cement are presented in Table 1.

Table 1. Physical Properties of Asphalt Cement

Property	Test Conditions	ASTM, 2009 Designation	Value	SCRB, 2003 Specification
Penetration	25°c , 100gm, 5 sec.	D5-06	42	40-50
Softening Point	(ring &ball)	D36-895	49	-
Ductility	25°c ,5cm/mi	D113-99	136	>100
Specific Gravity	25°c	D70	1.04	-
Flash Point	Cleave land open cup	D92-05	256	>232
After thin film oven test properties D1754-97				
Penetration	25°c , 100gm, 5 sec.	D5-06	33	
Ductility of Residue	25°c, 5cm/minutes	D113-99	83	

2.2. Coarse and Fine Aggregates

Crushed coarse aggregate passing sieve size 19 mm and retained on sieve No.4 was obtained from AL-Ukhaider quarry. A mixture of Crushed and natural sand was used as Fine aggregate (particle passing sieve No.4 and retained on sieve No.200) according to SCRB specification (2003) was brought from the same source. The physical properties of fine aggregates are listed in Table 2.

Table 2. Physical Properties of Coarse and Fine Aggregates

Property	Value	ASTM, 2009 Designation No.
Coarse Aggregates		
Bulk specific gravity	2.542	C127-01
Water absorption %	1.07%	C127-01
Wear % (Los Angeles abrasion)	18%	C131-03
Fine Aggregates		
Bulk specific gravity	2.558	C128-01
Water absorption %	1.83%	C128-01

2.3. Mineral Filler

The mineral filler used in this work is limestone dust, mostly passing sieve No.200. It was obtained from Karbala governorate. The physical properties of the filler are presented in Table 3.

Table 3. Physical Properties of Filler (Limestone Dust)

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

2.4. Selection of Aggregates Gradation

The selected aggregates gradation in this assessment follows the SCRB, 2003 specification for wearing course with 12.5 mm nominal maximum size. Table 4 shows the implemented aggregates gradation.

Table 4. Implemented Gradation for Aggregates

Sieve size (mm)	**%Passing by weight**	
	Selected Gradation	**SCRB, 2003 Specification**
19	100	100
12.5	95	90-100
9.5	83	76-90
4.75	59	44-74
2.36	43	25-58
0.3	13	5-21
0.075	7	4-10

2.5. Preparation of Asphalt Concrete Mixture

The aggregates were dried to a constant weight at 110ºC, and then sieved to different sizes. Coarse and fine aggregates were combined with mineral filler to meet the specified gradation. The combined aggregate was then heated to 160º C, while the asphalt cement was heated to a temperature of 150º C. Asphalt cement was added to the heated aggregates to achieve the desired amount, and mixed thoroughly using a mechanical mixer for three minutes until all aggregate particles were coated with asphalt cement. The asphalt concrete mixture was subjected to short term oven aging for 4hrs at temperature of 135 ºC as per (AASHTO, 2013). Asphalt concrete mixtures were prepared at optimum asphalt content of 4.9% and at asphalt contents of 0.5 percent above and below the optimum, (4.4 and 5.4) %. The process of finding the optimum asphalt content was based on Marshall Properties as per (AASHTO, 2013), the details could be found at (Sarsam and Alwan, 2014). Slab samples of (40 x 30 x 6) cm was prepared using roller compaction to the target bulk density according to (EN12697-33, 2007). Beam specimens of (5 x 6 x 40) cm sizes were extruded from the slab using the diamond saw.

Beam specimens were conditioned to long term aging as per AASHTO, 2002 procedure. Figure 1 exhibit the long-term ageing process.

2.6. Determination of Fatigue Life with the aid of Repeated Flexural Beam Fatigue Test

The repeated flexural beam fatigue Test was implemented on the beam specimens as per AASHTO T 321, 2010. Asphalt concrete beams were placed in the four-point loading apparatus. Three testing temperatures of (30, 20, and 5) °C have been implemented. On the other hand, three different Microstrain levels of 250, 400, and 750 were tried to simulate various modes of loading in the field. The flexural fatigue test is performed by placing a beam of asphalt concrete in the repetitive four points loading chamber at a specified strain level and testing temperature. During the test, the beam was held in place by four clamps and a repeated sinusoidal load is applied to the two inner clamps 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). The number of loading cycles to failure was then recorded which gave an estimation of a particular mixture's fatigue life. Figure 2 exhibit the four-point bending beam test setup.

Figure 1. The long-term ageing process

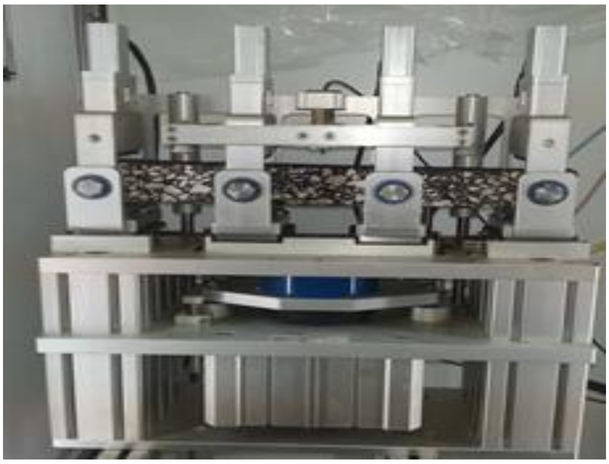

Figure 2. four-point bending beam test setup

3. Results and Discussions

3.1. Evaluation of Fatigue Life

Fatigue life measurements were conducted at microstrain levels of 750, 400, and 250, a frequency level of 5Hz, testing temperature of (5, 20, and 30) °C, and three percentages of asphalt contents. Log-log Plots were established between the fatigue life (Nf) and the above-mentioned variables. The most important parameters for fatigue life test are the intercept and slope of the fatigue life curve. The prepared asphalt concrete mixture was separated to three lots, the first lot was denoted as the control mixtures. The control mixture was compacted in the roller compactor and a slab sample was obtained. Beam specimens were extracted from the slabs and tested for fatigue life. The second lot was subjected to short term ageing as per AASHTO, 2002 procedure, then it was compacted to slab samples. Beam specimens were extracted from the slabs of the second lot and tested for fatigue life. The third lot was subjected to short term ageing, then it was compacted to slab samples. Beam specimens were extracted from the slabs of the third lot and subjected to long term ageing as per AASHTO, 2002, then tested for fatigue life.

3.2. Influence of Ageing on Fatigue Life for Asphalt Concrete

The fatigue life of asphalt concrete was evaluated by implementing the repeated flexural beam fatigue test on the beam specimens as per AASHTO T 321, 2010. Figure 3 demonstrate the influence of ageing process on the fatigue life. It can be observed that the fatigue life decreases for asphalt concrete after practicing the ageing process regardless of the ageing technique implemented. When the applied microstrain level was low (250 µƐ), the fatigue life decreases by (16.4 and 77.5) % after practicing short- and long-term ageing respectively. When the applied microstrain level was moderate (400 µƐ), the fatigue life decreases by (30.3 and 57) % after practicing short- and long-term ageing respectively. However, after application of high level of microstrain (750 µƐ), the reduction in fatigue life was (31.4 and 65.5) % after practicing short- and long-term ageing respectively.

On the other hand, the fatigue life decreases by (85 and 97) %, (87.5 and 97.4) %, (71.4 and 95.2) % after increasing the applied microstrain from (250 to 400 and 750) µƐ for control mixture and for mixtures subjected to short-and long-term ageing processes respectively. similar findings were addressed by Zhu et al., 2009.

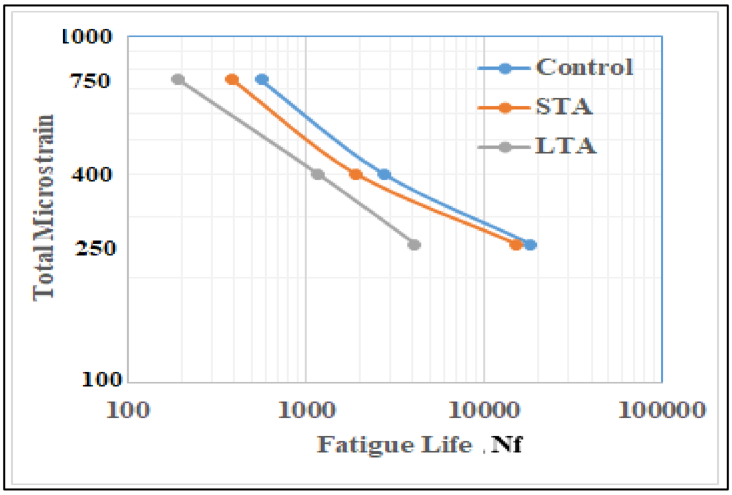

Figure 3. Influence of ageing process on the fatigue life

Table 5 exhibit the fatigue parameters of asphalt concrete, the ageing process was able to decrease both of the intercept which represent the total microstrain after the first load repetition (N =1), and the slope which represent the rate of deformation throughout the fatigue life. Such observation indicates the stiffening of asphalt concrete after the ageing process. The power models relating the microstrain (µƐ) with the fatigue life (Nf) exhibit a strong coefficient of determination (R2). Similar findings were reported by Sarsam and Alwan, 2014.

Table 5. Fatigue Parameters and Models for Asphalt Concrete Under Ageing

AC%	State	Fatigue Parameter		Models	Coefficient of Determination R^2
		Slope	Intercept		
4.9 %	Control mix	0.314	5214.3	$\mu\varepsilon = 5214.3\ Nf^{-0.314}$	0.981
	Short term Ageing	0.295	4113	$\mu\varepsilon = 4113\ Nf^{-0.295}$	0.974
	Long term Ageing	0.360	5015.3	$\mu\varepsilon = 5015.3\ Nf^{-0.36}$	0.998

3.3. Influence of Asphalt Content on Fatigue Life for Asphalt Concrete

Figure 4 depicts the influence of asphalt cement content on fatigue life of asphalt concrete. It can be observed that the fatigue life increases significantly as the binder content increases regardless of the applied microstrain. This may be attributed to the increase in asphalt cement film thickness which can possess a more durable mixture. It can be detected that at low microstrain level of (250 µℇ), the fatigue life increases by (142.8, 257.1) % when the asphalt content increases from (4.4 to 4.9 and 5.4) %. When the applied microstrain level was moderate (400 µℇ), the fatigue life increases by (34.4 and 57.8) % when the asphalt content increases from (4.4 to 4.9 and 5.4) %. However, after application of high level of microstrain (750 µℇ), the improvement in fatigue life was minimal in a range of (10-30) % as the asphalt content increases.

Table 6 exhibit the fatigue parameters of asphalt concrete at various asphalt content, increment of asphalt content was able to decrease both intercept and the slope, thus improving the flexibility of asphalt concrete. The power models relating the microstrain (µℇ) with the fatigue life (Nf) at various binder content exhibit a strong coefficient of determination (R2). Similar findings were reported by Sarsam and AL- Lamy, 2016.

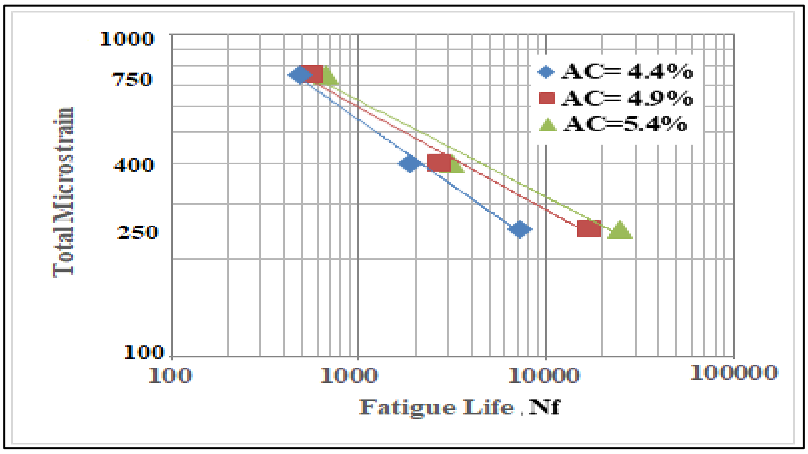

Figure 4. Influence of Asphalt Content on the fatigue life

Table 6. Fatigue Parameters and Models for Asphalt Concrete at Various Binder Content

Asphalt Content %	Intercept	Slope	Models	R^2
4.4	9065.3	0.407	$\mu\mathcal{E} = 9065.3\ (Nf)^{-0.407}$	0.993
4.9	5424.7	0.319	$\mu\mathcal{E} = 5424.7\ (Nf)^{-0.319}$	0.983
5.4	4984	0.300	$\mu\mathcal{E} = 4984\ (Nf)^{-0.3}$	0.973

3.4. Influence of Testing Temperature on Fatigue Life for Asphalt Concrete

Figure 5 exhibits the influence of testing temperature on fatigue life of asphalt concrete. It can be observed that the mixture exhibits low fatigue life when tested at cold environment of 5°C as compared to warmer environment. This may be attributed to the stiffer condition of the mixture and higher viscosity of the binder. A steep shape of the fatigue life-microstrain relationship could be detected indicating lower fatigue life and possible brittle and fracture type of failure. On the other hand, the fatigue life increases significantly as the testing temperature increases regardless of the applied microstrain. For specimens practicing high microstrain level of (750 µƐ), the fatigue life increases by (112.4, and 253.2) % when the testing temperature rises from (5 to 20 and 30) °C respectively. When the asphalt concrete beam specimens were practicing moderate level of microstrain of (400 µƐ), the fatigue life increases by (480.3, and 1370.5) % when the testing temperature rises from (5 to 20 and 30) °C respectively. However, specimens subjected to low microstrain level of (250 µƐ) exhibit an increment in fatigue life of (1316, and 1588.3) % when the testing temperature rises from (5 to 20 and 30) °C respectively. Such behavior agrees with López-Montero and Miró, 2017.

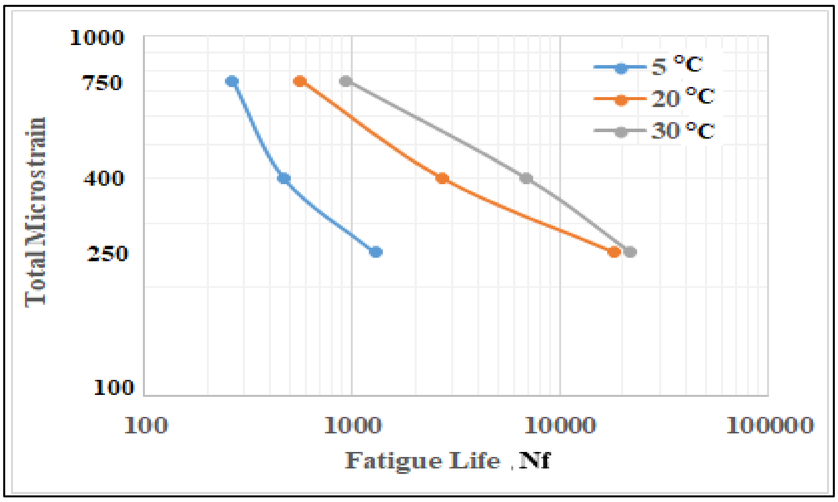

Figure 5. Influence of Testing Temperature on the fatigue life

Table 7 exhibit the fatigue parameters of asphalt concrete at various testing temperature, it can be noted that increment of testing temperature was able to increase the intercept and decreases the slope, thus exhibiting more flexibility of asphalt concrete. The power models relating the microstrain (µƐ) with the fatigue life (Nf) at various testing temperatures exhibit a strong coefficient of determination (R^2). Similar findings were reported by Quintana and Lizcano, 2012.

Table 7. Fatigue Parameters and Models for Asphalt Concrete at Various Testing Temperature

Testing Temperature °C	Intercept	Slope	Models	R^2
5	28492	0.669	$\mu\varepsilon = 28492\ (Nf)^{-0.669}$	0.942
20	5214.3	0.314	$\mu\varepsilon = 5214.3\ (Nf)^{-0.314}$	0.981
30	8108.4	0.346	$\mu\varepsilon = 8108.4\ (Nf)^{-0.346}$	0.994

4. Conclusion

Based on the limitations of materials and testing program, the following conclusions may be drawn.

a) The fatigue life decreases by (85 and 97) %, (87.5 and 97.4) %, and (71.4 and 95.2) % after increasing the applied microstrain from (250 to 400 and 750) µƐ for control mixture and for mixtures subjected to short-and long-term ageing processes respectively.

b) The fatigue life increases by (142.8 and 257.1) %, (34.4 and 57.8) % and (10 and 30) %when the asphalt content increases from (4.4 to 4.9 and 5.4) % for specimens practicing the applied microstrain of (250, 400 and 750) µƐ respectively.

c) The fatigue life increases by a range of (two to fifteen) folds when the testing temperature increases from (5 to 20 and 30)°C respectively.

d) The developed models could be implemented for the prediction of fatigue life of asphalt concrete under the assessed conditions.

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