Fatigue Behavior of Modified Asphalt Concrete Pavement

Saad Isaa Sarsam
Professor
Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
Email: saadisasarsam@coeng.uobaghdad.edu.iq

Ammar Khalaf Jabbar Allamy
M.SC Student
Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
Email:ammar_civil_allamy@ymail.com

ABSTRACT

Fatigue cracking is the most common distress in road pavement. It is mainly due to the increase in the number of load repetition of vehicles, particularly those with high axle loads, and to the environmental conditions. In this study, four-point bending beam fatigue testing has been used for control and modified mixture under various micro strain levels of (250 µƐ, 400 µƐ, and 750 µƐ) and 5*HZ*. The main objective of the study is to provide a comparative evaluation of pavement resistance to the phenomenon of fatigue cracking between modified asphalt concrete and conventional asphalt concrete mixes (under the influence of three percentage of Silica fumes 1%, 2%, 3% by the weight of asphalt content), and (changing in the percentage of asphalt content) by (0.5% ±) from the optimum. The results show that when Silica fumes content was 1%, the fatigue life increases by 17%, and it increases by 46% when Silica fumes content increases to 2%, and that fatigue life increases to 34 % when Silica fumes content increases to 3% as compared with control mixture at (250 µƐ, 20°C and optimum asphalt content). From the results above, we can conclude the optimum Silica fumes content was 2%. When the asphalt content was 4.4%, the fatigue life has increased with the use of silica fumes by (50%), when asphalt content was 5.4%, the additives had led to increasing the fatigue life by (69%), as compared with the conventional asphalt concrete pavement.

Key words: asphalt concrete, silica fumes, asphalt cement, fatigue life

تصرف الكلال في رصفة الخرسانه الاسفلتيه المحسنه

سعد عيسى سرسم
استاذ
جامعه بغداد, كليه
الهندسه,قسم الهندسه المدنيه

عمار خلف جبار اللامي
طالب ماجستير
جامعه بغداد,كليه
الهندسه, قسم الهندسه المدنيه

الخلاصه

تشققات الكلال تعتبر الاكثر شيوعا في الطرق الاسفلتيه. والسبب الاساسي في حدوث هذه المشكله هو الزياده الكبيرة في عدد المركبات وعدد مرات تكرار الحمال مصحوبه بزياده الاحمال المحورية ايضا, والضروف البيئيه. في هذه الدراسة، تم استخدام فحص four-point bending beam fatigue لتقييم خلطة الخرسانة الإسفلتية المعدلة والاعتيادية تحت تأثير مستوى انفعال متغير (250 µƐ, 400 µƐ, 750 µƐ) و5*HZ*. ان الهدف الرئيسي من الدراسة هو مقارنه تقييميه لمقاومة ظاهرة الكلال بين الرصفة المحسنة والرصفة الاعتيادية تحت تأثير ثلاث نسب من ابخرة السيليكا (%1,%2,%3) كنسبه من وزن الاسفلت الاسمنتي)، وتغير نسبه الاسفلت بمقدار (±0,5) عن النسبة المثلى. النتائج بينت انه عندما كانت نسبه ابخرة السيليكا 1% زاد عمر الرصفة بمقدار 17%, و زاد عمر الرصفة بمقدار46% عندما زادت نسبه ابخرة السيليكا بمقدار2%, وزاد عمر التبليط بمقدار 34% عندما زادت نسبه نسبه ابخرة السيليكا الى 3%,(250 µƐ, 20°C) عند نسبة الاسفلت المثالية. ومن النتائج اعلاه تبين ان النسبه المثاليه لاضافه ماده ابخرة السيلكا هو2%. وعندما كانت نسبه الاسفلت 4.4% قل عمر التبليط بمقدار 50%, وعنما زادت نسبه الاسفلت الى 5,4% قل عمر التبليط بمقدار69%, مقارنه مع الاسفلت الاعتيادي تحت تأثير نفس الضروف.

الكلمات الرئيسيه : الخرسانة الاسفلتية، ابخرة السيليكا, الاسفلت الاسمنتي, الكلال.

1. INTRODUCTION

Several distresses hamper the performance of flexible pavements in Iraq and result in premature failure. In flexible pavements, the primary forms of distress are fatigue cracking, rutting, and thermal cracking. These distresses manifest themselves most of the time due to construction, material quality, bad maintenance, and incongruous design. Fatigue cracking, called alligator cracking and associated with repetitive traffic loading, is considered to be one of the most significant distress modes in flexible pavements. The fatigue life of an asphalt pavement is directly related to various engineering properties of typical hot mix asphalt (HMA). It is mainly due to the increase in the number of load repetition of vehicle particularly those with high axle loads, and to the environmental conditions. The construction practice and design short comings may also results in shortening of pavement's life and increase maintenance cost as well as road user cost. It is vital to find out ways to delay the asphalt pavement deterioration and increase its service life, **Moghaddam et al., 2011. Miller and Bellinger, 2003,** presented pavement distresses and failure mechanisms in Highway Pavement in their Distress Identification Manual (HPDIM), it was stated that to minimize asphalt concrete pavements distress there are several ways, which could extent pavement service life:

- Produce a new binder type with better physical, chemical and rheological Properties.
- Improve the pavements and mix design.
- Improve the construction methods and maintenance techniques.

Modified asphalt is assumed to be one of the most important solutions for pavement distress. To produce modified asphalt there are several methods and different materials at different modification level. To reduce the cost of highway construction and maintenance, asphalt researchers look for alternative additives materials such as silica fumes, fly ash, and lime. The effect of different types of modifiers to improve fatigue resistance of asphalt pavement is a field of interest for many asphalt researchers, but efforts concentrated on the fatigue resistance for asphalt concrete mixtures are scarce. Silica fume is a good alternative of the most new important commercial materials that are used to improve the properties of asphalt mixtures and asphalt, **Sarsam and AL-Lamy, 2015.** Silica fume is one of the materials which is easy to use and mix with asphalt materials for being too fine; have positive effect on asphalt cement by reducing its temperature susceptibility, silica fumes exhibit lower, reduction in the stiffness modulus., **Sarsam, 2008 and AL-Zubaidi, 2014.**

2. MATERIALS CHARACTERISTICS

2.1 Asphalt Cement

Asphalt cement was obtained from Nasiriya oil refinery; the physical properties are listed in

Table 1.

2.2 Aggregate

Crushed coarse aggregate (retained on sieve No.4) was obtained from AL-Ukhaydir- at Karbala quarry. Crushed sand and natural sand used as Fine aggregate (particle size distribution between sieve No.4 and sieve No.200), was brought from the same source. It consists of hard, tough grains, free from loam and other deleterious substances. The physical properties are listed in **Table 2.**

2.3 Mineral Filler

The mineral filler is a non-plastic material, mostly passing sieve No.200 (0.075mm). The filler used in this work is limestone dust obtained from factory in Holly Karbala governorate. The phy**sical** properties of the used filler are presented in **Table 3.**

2.4 Silica Fumes

It was manufactured by Wacker Silicon Company in Germany as fluffy powder, and obtained from local market, **Table 4** Shows its physical properties. **Plate 1** Shows the sample of Silica fumes used. It was decided to use silica fumes based on previous work, **Sarsam, 2008.**

3. TESTING PROGRAM

3.1 Preparation of Modified Asphalt Cement

Modified asphalt was prepared by using the wet process. In the wet process, asphalt cement has been heated to a 150 °C and then blended with a Silica Fume modifier with different content (1%, 2 % and 3%by weight of asphalt cement). Such percentages were based on **Sarsam, 2013** work, it was prepared in the laboratory using special manufactured mixer at a blending speed of about 1300 rpm and elevated temperatures (177-190°C) for 20 minutes to promote the chemical and physical bonding of the components. During the blending process, the asphalt cement swells and softens as an indication of possible reacts with Silica fumes**. Plate 2** Shows the blending apparatus.

3.2 Preparation of (Flexural Fatigue Beam Test) Specimens

The dimensions of the beam specimen used were 50±6 mm high, 63±6 mm wide and 400 mm (15.75 in) long according to AASHTO T 321, (2007). The bulk density was 2.2826 Kg/m^3 for every specimen as presented in AASHTO T166, (2010). The aggregate and asphalt were mixed in mixing bowel on hot plate for three minutes until asphalt sufficiently coated the surface of the aggregates. The asphalt-aggregate mixture was then subjected to short term oven aged for 4hrs at temperature of 135 C according to AASHTO PP2. The mix was stirred every 30 minutes during the short term aging process to prevent the outside of the mixture from aging more than the inner side because of increased air exposure, then the asphalt concrete mix was casted slab mold. Tests were conducted at optimum asphalt content and at asphalt contents of 0.5 percent above, and 0.5 percent below optimum. Specimens for flexural fatigue testing were prepared using Roller Compactor Device at NCCLR according to, **EN12697-33 ,2003**, because this method of compaction simulates field compaction in a progressive way. A slabs specimen of (400 mm by 300 mm by 50±6 mm) was prepared using the hot aged asphalt concrete loose mix. The dimensions of the compacted slabs used are 400 mm (15.75 inch) in length and 300 mm (11.8 inch) in width and 60 mm (2.36 inch) in height. with astatic load was (5 kN) and number of variable passes depended on the asphalt content in mix (where 20 number use of passes for 5.4% asphalt content, 30 number of passes for 4.9% asphalt content(optimum),and 60passes for 4.4%asphalt content, by trial and error).12 slab samples were prepared, then cut by the Diamond-cutter into dimension previously mentioned, **Plates 3, 4 and 5** give an illustration of compacted and cut samples of slab and beam. The total number in all test was (24 beams).control mixture (9 beams), and Modified mixture by using silica fume (15 beams). A total of 36 beam specimens were tested for fatigue behavior.

4. DISCUSSION OF TEST RESULTS

4.1 The Effect of Silica Fumes Content on Fatigue Life

Fig.1 depicts the effect of Silica fumes content on fatigue life. From the analysis of the results, it can be seen that when Silica fumes content was 1% that fatigue life increases by 17%, and it increases by 46%when Fly ash content increases to 2%, and that fatigue life increases to 34 % when Silica fumes content increases to 3% as compared with control mixture (250 μƐ, 20°C and optimum asphalt content). Because the mixture became more flexibility .it may be related to increasing viscosity and stiffness of mixture**.**

Based on the data shown in **Table 5**. It appears that the fatigue life increases by 20%, 115%, and 80% at Silica fumes content 1%, 2%, and 3% respectively, as compared with control mixture (400 μƐ, 20°C and optimum asphalt content), and that the fatigue life increases by 7%, 57%, and 33% at Silica fumes content 1%, 2%, and 3% respectively as compared with control mixture (750 μƐ, 20°C and optimum asphalt content).

Generally, increases in micro strain level lead to reduces in the fatigue life value in the same mixture. For example at modified mix by using 2% Silica fume it can be noted that fatigue life reduced by 75% when micro strain level change from 250 μƐ to 400 μƐ, decreases to 84% when micro strain level increases from 400μƐ to 750μ.

Also we noted that the Silica fume has a significant effect on the fatigue life. The analysis of the data shown in **Table 5.** Depicts when Silica fume content change from 1% to 2% that fatigue life increases by 24% but when Silica fumes content change from 2% to 3% that fatigue life reduced by 8%. Finally, from the results above, it can be concluded that optimum Silica fumes content was 2% from fatigue life point of view.

4.1.2 The effect of asphalt content on fatigue life

The effect of asphalt content on modified and unmodified mixture was depicted in **Fig.2**. K1 and K2 parameters can be concluded from the data shown in **Fig. 2 and Table 6**. Failure criteria implemented was that when the reduction in beam stiffness will reach 50% of its initial stiffness, the number of loading cycles is considered as fatigue life.

It can be seen that fatigue life increases significantly, because increasing thickness of asphalt film between aggregate leads to decreases tensile strain at the bottom of layer, **Alwan, 2012 and Al-kashaab, (2009)**

The analysis of this figure shows when asphalt content decreasing from 4.9 to 4.4 percent the fatigue life decreases 55% at control mix, it decreases 53% at modified mixture by using Silica fume, (at 250 μƐ). While when asphalt content increases from 4.9 to 5.4 percent the fatigue life increases 53% at control mix, 60% at Silica fume.

Fig. 3 shows the impact of silica fumes on fatigue life of asphalt concrete, when micro strain level increases the fatigue life decreases significantly. So fatigue life reduces 30% at control mix, 64% at S.F, when asphalt content increases from 4.9 to 4.4. When micro strain level change from 250 μƐ to 400 μƐ, and increases by (16%, 8%) at Control mix, S.F, respectively, when asphalt content increases from 4.9 to 5.4 percent.

Also when micro strain level change from 400 to 750. Fatigue life reduces 13% at control mix, 22% at S.F, when asphalt content increases from 4.9 to 4.4 percent, and increases by (19%, 6%) at Control mix, S.F, respectively, when asphalt content increases from 4.9 to 5.4 percent. **Table 6** depicts the effect of asphalt content on modified and unmodified mixture in relation to the fatigue life cycle at different micro strain level. It depicts that when using Silica fumes, fatigue life increases 50%, as compared with conventional mix (at 250 μƐ, at 4.4% asphalt content), the fatigue life increases by 9% when using Silica fume as compared with control mix (at 400 µƐ, at 4.4% asphalt content).also it increases by 25 using Silica fume (at 750 µƐ, at 4.4% asphalt content). It shows that the difference in the ratios of the fatigue life at optimum asphalt content 4.9%. The analysis of the figure shows the percentage of change varying significantly, it can be seen the fatigue life increases 46% when using Silica Fumes (at 250 µƐ), it increases by 115% (at 400 µƐ), at 750 µƐ the fatigue life increases by 40% (All of these ratios were compared with control mix).

Table 6 shows comparative between modified and unmodified mixture toward the fatigue life at (optimum asphalt content +0.5%, 5.4%). It can be seen the fatigue life increases 53% at Silica Fumes (at 250 µƐ), it increases by 100% at S.F (at 400 µƐ), at 750 µƐ the fatigue life increases by 33% at Silica Fumes (All of these ratios were compared with control mix). K1 and K2 can be concluded from the data shown in **Tables 7**. It was noted at 4.4% AC that K2 increases nearly by 6.9% and increases by 1.3% at 4.9%AC, and increases by 1.5% at 5.4% AC (at modified mixture by using Silica fumes respectively), as compared with control mix. K1 has the smallest values and decreases it was decreases slightly when using additives.

5. CONCLUSIONS

1-Accorcing to the results obtained from "Flexural Fatigue beam Test", it turns out that the perfect percentage of Silica fumes addition is (2%).

2- Decrease in Asphalt percentage by (0.5%) from the optimum asphalt content would result in a decrease in fatigue life by (55%) for control mixture and (45%) for the mixture modified by using Silica fumes. On the other hand, the effect of the additives was obvious in increasing the fatigue life by (50%) for Silica fume, as compared to the control mixture (at 250µε, 20°C, 4.4%AC).

3-Increase in Asphalt percentage by (0.5%) from the optimum asphalt content would increase the value of fatigue life by (53%) for the control mixture and by (48%) percent for the Silica fumes. Also the additives have Effect in an increase of the fatigue life value, as compared to control mixture by (41%) for the Silica.

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Table 1. Physical properties of asphalt cement.

Property	Unite	Test result	SCRB Specifications
Penetration 25˚c , 100gm5 sec(ASTM D-5)	0.1 mm	42	40-50
Softening point, Ring and ball (ASTM D-36)	°C	49	………….
Ductility, 25°C, 5 cm/min (ASTM D-113)	cm	136	>100
After thin film oven test (ASTM D-1754)			
penetration, 25°C, 100gm, 5 se	%	73	>55%
Ductility, 25°C, 5 cm/min	%	83	>25%

Table 2. Physical properties of coarse and fine aggregate.

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

Table 3. Physical properties of filler (Lime stone).

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

Table 4. Physical properties of silica fumes.

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

Table 5. Effect of additives type and content on fatigue life.

Mix. Type	Additives%	Micro strain level		
		250 µƐ	400 µƐ	750 µƐ
Control mix	0%	16212	2722	563
Modified mixture	1% S.F	19065	3280	604
	2% S.F	23671	5857	889
	3% S.F	21740	4881	751

Table 6. Fatigue life for control and modified mixture.

AC%	State	Fatigue Life, Nf		
		250 µƐ	400 µƐ	750 µƐ
4.4 %	Control mix	7421	1897	486
	S.F	10931	2070	609
4.9 %	Control mix	16212	2722	563
	S.F	23671	5857	789
5.4%	Control mix	24879	3182	670
	S.F	35084	6381	892

Table 7. Fatigue parameters K1, K2 and equations for fatigue life under effect of asphalt content

AC%	State	K1	K2	Equations
4.4 %	Control mix	1.07E-05	2.450	Nf=1.07E-05$(Ɛ)^{-2.450}$
	S.A	3.96E-06	2.620	Nf=3.96E-06$(Ɛ)^{-2.620}$
4.9 %	Control mix	1.65E-07	3.050	Nf=1.65E-07$(Ɛ)^{-3.050}$
	S.F	1.74E-07	3.090	Nf=1.74E-07$(Ɛ)^{-3.090}$
5.4%	Control mix	3.57E-08	3.290	Nf=3.57E-08$(Ɛ)^{-3.290}$
	S.F	3.25E-08	3.340	Nf=3.25E-08$(Ɛ)^{-3.340}$

Plate 1. Silica fume sample.

Plate 2. Manufactured blending apparatus and its components.

Plate 3. Slab specimens.

Plate 4. preparation for obtaining beams.

Plate 5. Four points bending beam device and testing equipment at NCCLR.

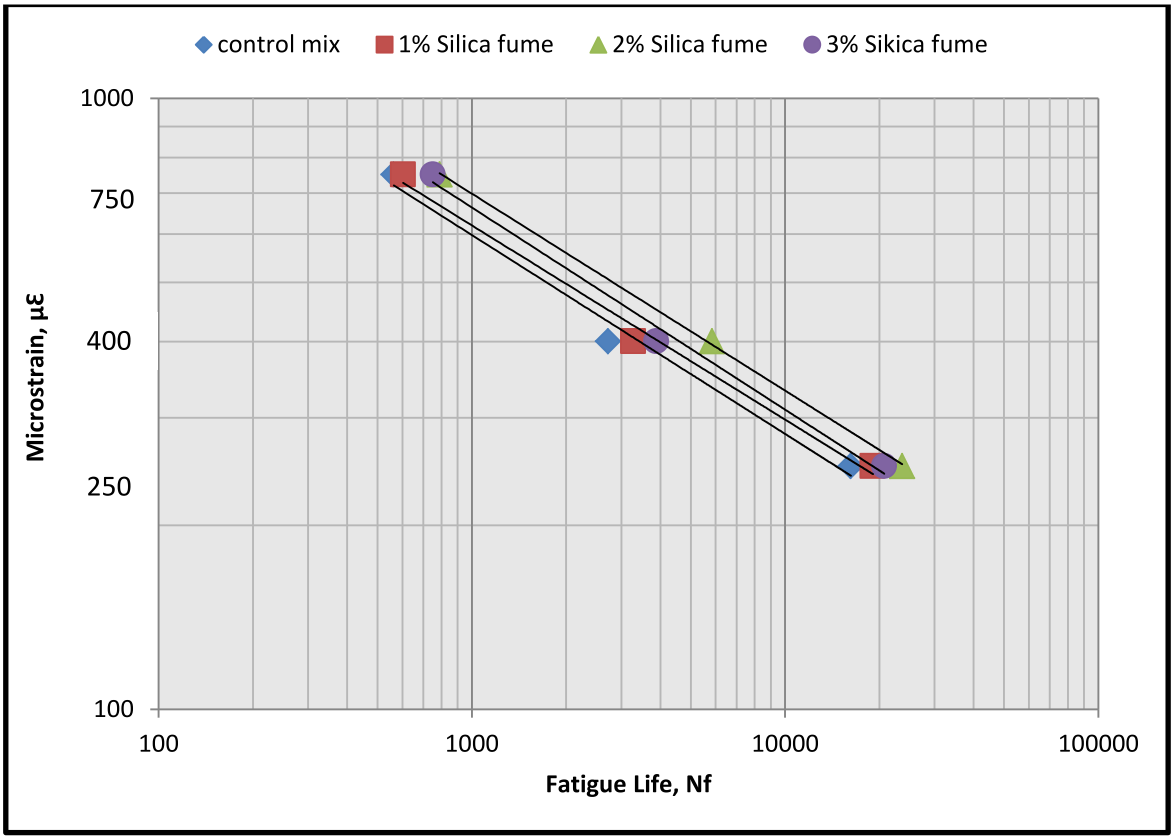

Figure1. Effect of different percent of silica fume on fatigue life to select the best percent, T=20°C

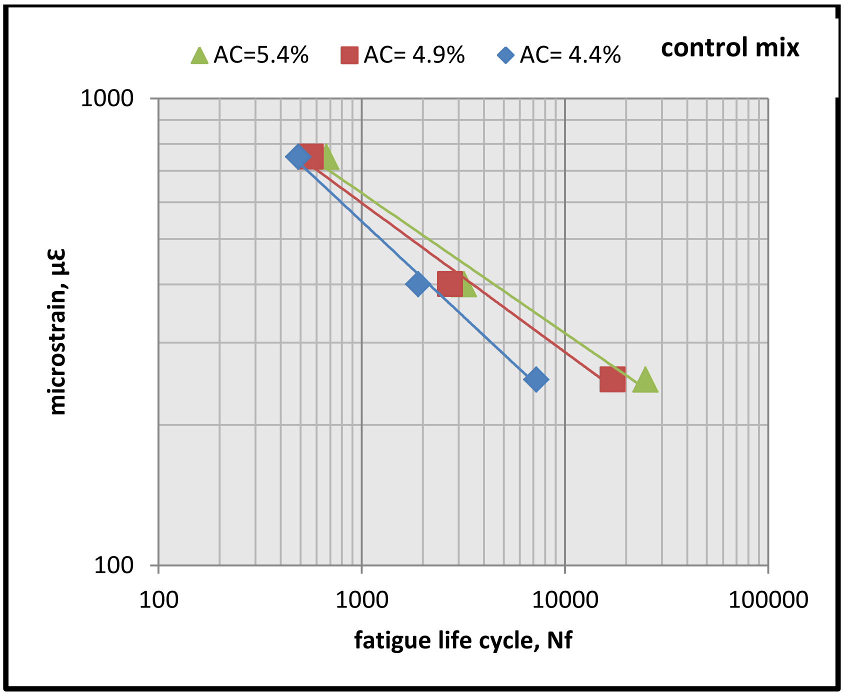

Figure 2. Effect of asphalt content on fatigue life for control mix, T=20°C.

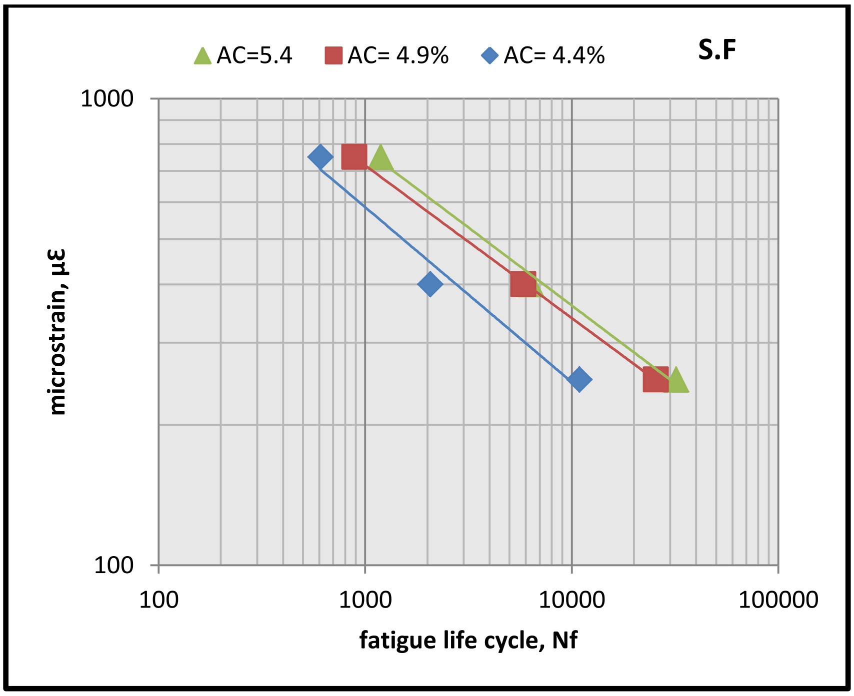

Figure 3. Effect of asphalt content on fatigue life for modified mix, T=20°C.