Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 5(5):326-332

Effect of Modifiers and Additives on Fatigue Behavior of Asphalt Concrete Mixes in the Gulf

Hamad I. Al-Abdul Wahhab[1+]

Abstract: The harsh environment in Gulf countries (GCs) raises the need to use Polymer Modified Asphalt Concrete in road construction to prevent rutting in the early life of the pavement. Once the stiffness of the asphalt concrete layer at high field temperatures, which may reach 72°C, is increased, it will not rut. This has worked well and drastically reduced pavement failure due to rutting. However, the high stiffness of the asphalt concrete makes it susceptible to cracking under repeated traffic loading. Fatigue cracking is observed in parts of the GC roads due to the use of polymer modified asphalt concrete, and it is considered one of the major distress mechanisms that affects asphalt pavement performance.

The objective of this study was to explore the effect of modifiers and additives on the fatigue behavior of asphalt concrete mixes in the Gulf Cooperation Council countries (GCC). Fatigue tests carried out in this study showed that certain polymers have the ability to improve the fatigue life of local mixes. Polymer modification has increased the resistance to the applied stress (load bearing) and strains (deflection) of local asphalt concrete mixes as compared to plain asphalt concrete mixes.

Key words: *Additives; Asphalt concrete; Fatigue; Polymer modification; Stress controlled test*.

Introduction

The actual enforcement of the use of modifiers in Saudi Arabia started seriously after a temperature zoning study in 1994 conducted by Al-Abdul Wahhab *et al* [1]. The Gulf countries (GCs) have a unique harsh environment that presents a real challenge to construction and material specialists, particularly when dealing with an asphalt concrete material. More than 50% of the pavements in the GCs experience a maximum pavement temperature of 76°C. The asphalt cements, as produced and used locally in the Gulf, are only suitable for about 40% of the GCs area. The Ministry of Transport (MOT) has adopted a temperature zoning for the Kingdom of Saudi Arabia, where up to 60% of the country's regions will need to use stiffer asphalt binders than those produced by local refineries [2]. They recommended the use of polymers to meet this performance grading (PG) requirement. Fatigue cracking is observed in parts of the GCs road network due to the use of polymer modified asphalt concrete mixes.

Fatigue cracking is one of the main distress modes in asphalt pavement. Fatigue damage to asphalt pavements is a complex phenomenon occurring from repeated bending that results in microdamage to the asphalt pavement. This microdamage is a competitive process between microcracking and healing, manifested as a reduction in stiffness of the asphalt pavement, degrading the load capacity and ability to resist further damage. Eventually, microcracks coalesce into macrocracks that appear in the wheel path. This type of distress occurs at intermediate temperatures under repetitive traffic loading. It occurs over the long term, but once initiated, it progresses rapidly and leads to a total structural collapse of the pavement. This distress is commonly referred to as alligator cracking. Traditionally, fatigue cracking was thought to occur at the bottom of asphalt layer when the damage accumulated by repeated loads is higher than the failure limit of asphalt concrete mixture. In addition to conventional fatigue cracking concept, several researchers have hypothesized that fatigue cracking could be propagated by tensile or shear stresses, or combinations of both occurring at the bottom or at the surface of asphalt concrete layer. Myers [3] found that the high tensile stresses underneath the ribs of radial truck tires could cause surface-initiated cracking. Thus, fatigue cracking can form and grow in any location of the pavement structure where sufficiently large tensile or shear stresses, or a combination of both, occur. Fatigue cracking is usually affected by a number of factors. Heavy wheel loads and thin pavements, or those with weak underlying layers, increase the tensile stresses and may result in fatigue cracking.

Accurate asphalt concrete characterization is essential and vital for realistic performance prediction of asphalt concrete pavements. To define the fatigue response of asphalt concrete layers, a variety of techniques, equipments, specimen configurations, types and modes of loading were used by various researchers as indicated in the literature. Generally, the most common testing methods are categorized as follows: Triaxial repeated tension and compression [4], diametral repeated load test [5, 6], repeated simple flexure test, repeated flexure test on elastic foundation [7, 8], fracture mechanics [9], and laboratory wheel tracking test [10].

The majority of fatigue test data have been developed by simple flexure tests in which the stress or strain was repeatedly applied until the specimen failed or exhibited changes in characteristics, which rendered the mixture unsuitable. Results of these tests have been expressed in the form of the following equations [11, 12]:

$$N_f = a\left(\frac{1}{\varepsilon_t}\right)^b \quad (1)$$

or

[1] Department of Civil Engineering, King Fahd University of Petroleum & Minerals, P.O. Box 1625, Dhahran 31261, Saudi Arabia.

[+] Corresponding Author: E-mail hawahab@kfupm.edu.sa
Note: Submitted November 3, 2011; Revised April 1, 2012; Accepted April 19, 2012.

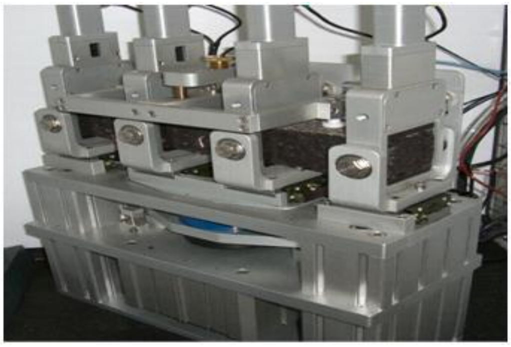

Fig. 1. Four-Point Bending Beam Machine.

$$N_f = c\left(\frac{1}{\sigma_t}\right)^d \quad (2)$$

where ε and σ are the magnitudes of tensile strain and stress respectively, *a*, *b*, *c* and *d* are material coefficients associated with the laboratory test methodology, and N_f is the number of load applications to failure. A number of different types of flexural equipment have been developed to study the fatigue characteristics of asphalt concrete mixtures including (but not limited to):

1. Flexure tests in which the loads are applied repeatedly or sinusoidally under center-point or four- point bending, as shown in Fig. 1,
2. Rotating cantilever beams subjected to sinusoidal loads, and
3. Trapezoidal cantilever beams subjected to sinusoidal loads or deformations.

Adhikari and You [13] have used four-point bending beam fatigue for a typical Michigan asphalt concrete mixture under various loading frequencies and test temperatures to evaluate Asphalt Institute and Shell fatigue prediction models over wide ranges of laboratory testing conditions. The results in this study showed that there is a strong linear correlation between the flexural stiffness and compression modulus, with the flexural stiffness about 30% lower than the compression modulus.

The objective of the research work was to evaluate the effect of different additives on fatigue properties of local asphalt concrete mixes. Moreover, it aims to identify and suggest the best modifiers that can provide an effective solution to mitigate fatigue without compromising other important engineering behavior of the local asphalt concrete mixes.

Experimental Work

The work was divided into four phases. The first phase was comprised of materials collection. This included obtaining fresh asphalt from Riyadh refinery, surveying available additives and selection of additives based on their performance in local asphalt concrete mixes, and collecting two major aggregates. The second phase consisted of characterization of collected materials and determining the required additive percentages that can improve the performance grade (PG) of the base (unmodified) asphalt to PG 76-10 (if applicable), based on Superpave binder performance grading procedure. Superpave Mix Design method was employed to design different wearing course (WC) mixes using selected additives for each of the two aggregate sources in the third phase. Aggregate gradation as used by MOT/SHRP (Strategic Highway Research Program) was used to determine the best aggregate skeleton and then the optimum asphalt content was determined based on the Superpave Mix Design specification adopted by MOT for WC layer. In the fourth phase, specimens were prepared using gyratory and slab compactors for different additives and aggregates as per the experimental design. These specimens were tested for fatigue and indirect tensile strength (ITS).

Table 1. Physical Properties of Collected Aggregates.

Physical Property	Limestone (E)	Basalt (W)
L.A. Abrasion, %	35.5	23.2
Soundness, %	10.3	8.22
SG_{bulk}, Coarse Aggr.	2.571	2.834
SG_{bulk}, Fine Aggr.	2.605	2.761
SG, Filler	2.682	2.776
Sand Equivalent, %	62	68
PI, %	NP	NP
pH	7.68	7.82
% P_2O_5	0.25	0.18
% SiO_2	54	74
% Al_2O_3	38	22
% Fe_2O_3	1.49	0.1
% (K_2O + Na_2O)	3.1	0.92

Materials needed in this study were collected from local sources, apart from fibers, which were obtained from an international supplier. Materials collected include aggregates, additives and modifiers, and asphalt cement.

Aggregates

Two types of aggregate, limestone and basalt, were collected from dominant types of aggregate used in the GCs. Limestone aggregate is the dominant aggregate in the central (C) and eastern (E) parts of the Arabian Peninsula while basalt aggregate is the dominant aggregate in the western (W) part. Crushed aggregates were selected from MOT approved crushers that are currently supplying crushed aggregates to major road projects. Enough aggregates were collected to last for the project duration; they were sieved and processed according to the Superpave gradation requirements and stored in sealed plastic containers of 50 kg capacity for further use.

Aggregates were subjected to a comprehensive physical testing to evaluate:

1. Sand equivalent (ASTM D 2419)
2. Bulk specific gravity of coarse and fine aggregates and mineral filler (ASTM C 127, ASTM C 128 and ASTM D 854)
3. Soundness of aggregate by magnesium sulfate (ASTM C 88)
4. Los Angeles abrasion of coarse aggregates (ASTM C 131)
5. Atterberg limits (ASTM D 423 and ASTM D 424)
6. Chemical analysis

Results for the physical properties of the aggregates are given in Table 1. Sand equivalent test results for collected aggregates were 62% for the Limestone and 68% for the Basalt, which meet MOT construction specifications requirement of minimum sand equivalency of 45%.

Magnesium sulfate soundness test results were 8.22 for the Basalt and 10.3 for the Limestone. The general MOT specification requires aggregates for wearing course mixes to have a soundness loss of

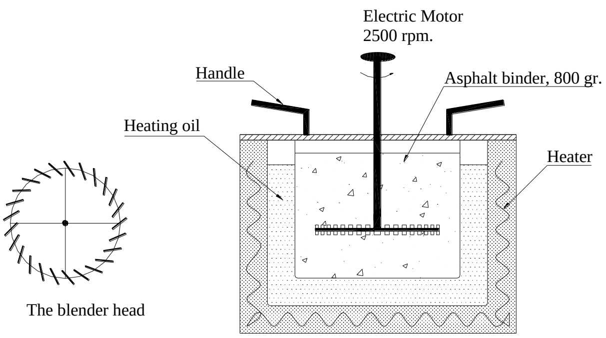

Fig. 2. Schematic Diagram for the Blending Machine.

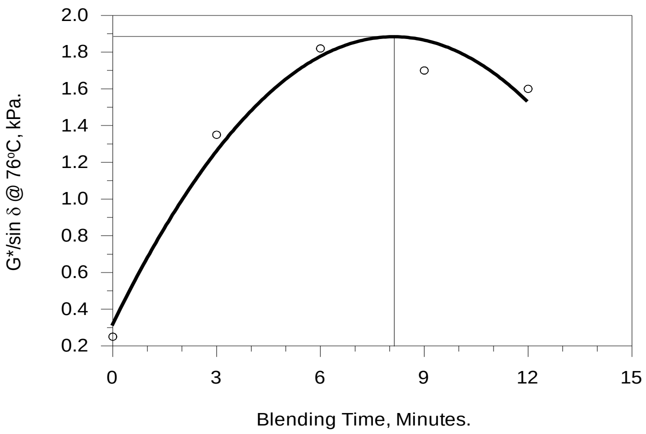

Fig. 3. Determination of Optimum Blending Time Using G*/sin δ @ 76°C.

less than 12%.

In performing the chemical analysis of the aggregates, each test sample was prepared from a representative portion of the same aggregate by grinding and crushing so as to pass a 300 μm sieve (ASTM C 289-1995). An aliquot from each sample was analyzed after treatment with boiling dilute hydrochloric acid and sodium hydroxide. To find the total mineral constituents of the aggregate, the samples were digested. The method employed was extraction with hydrochloric acid. The filtrate from the insoluble residue was analyzed to determine parameters such as SiO_2, Fe_2O_3, Al_2O_3, Na_2O, and K_2O. Reagent grade chemicals were used in all tests. The results of the chemical analysis are given in Table 1. Identification of the constituents of a sample is usually a necessary step towards recognition of the properties that may be expected to influence the behavior of the material in its intended use, but identification is not an end in itself. From the table, it is evident that almost all aggregate samples have quite a good percentage of siliceous material and aluminum oxides.

Additives and Modifiers

Six well-known commercial additives/modifiers available on the local and international markets were collected to be used in this study, which include:

1. One elastomer and two plastomer polymers that were selected based on MOT recommendations and were collected from a local supplier. One linear low density polyethelyne (LLDPE) grade polymer was collected from SABIC Industries, Riyadh. The polymer has a narrow molecular weight distribution that has been designed to have excellent low temperature toughness and stress crack resistance. Eastman EE-2 polymer, a functionally modified olefin, which is designed to be used as a high temperature modifier for road asphalt, was also selected as a plastomer polymer. SBS elastomer, a linear copolymer synthesized with butadiene and styrene monomer, was also selected for this study.
2. Crumb rubber was collected from Saudi Rubber Products Co. It was provided in both coarse and fine grain powdered form.
3. Cement dust was collected from local cement factories, KSA.
4. Polyacrylonitrile fiber was purchased from an international supplier.

Asphalt Cement

The asphalt cement of grade 60/70 pen being used in this study was obtained from Saudi Aramco Riyadh Refinery. The main reason for using this grade is its widespread use in road projects throughout the Kingdom.

Asphalt Modification and PG Grading

A special blender composed of high shear blade was used to blend the polymer with the asphalt; the blending speed was controlled with a DC motor capable of producing up to 2,500 rpm. The temperature was controlled through a heating oil bath. The blending machine and its components are shown in Fig. 2. Dynamic shear modulus (G*/sin δ) at 76°C was used as a measure to monitor the consistency of asphalt-polymer blend during blending. The shear modulus at 76°C was selected since it represents the highest performance grade (PG) temperature required in the GCs. The shear modulus was monitored during the blending at 5, 10, 15, 30, and 45 minutes of the blending time. The optimum blending time is determined at the peak of G*/sin δ, as shown in Fig. 3. Moreover, the minimum polymer content can be determined from the blending graphs of polymer concentration versus G*/sin δ (at 76°C). The target G*/sin δ must be greater than 1.00 kPa.

Storage stability of the prepared blends was evaluated; in addition, the SHRP PG binder specification was implemented to find the PG of the modified binders. The SHRP binder characterization test procedures include Dynamic Shear Rheometer (DSR), Bending Beam Rheometer (BBR), and Direct Tension Test (DTT).

The percentage of polymers required to achieve PG 76-10 are shown in Table 2. It is noted that only the three polymers, namely EE-2, SBS and LLDPE, were graded since SHRP PG grading cannot be applied to crumb rubber modified asphalt.

Mix Design and Samples Preparation

Superpave mix design method was used to design asphalt concrete mixes following the MOT/SHRP specifications for 12.5 mm top size Superpave wearing course (WC) layer (Table 3) and modified asphalt binder. The optimum asphalt content obtained through Superpave mix design for different additive-asphalt combinations was used to prepare compacted beam and cylindrical asphalt concrete specimens utilizing the slab and gyratory compactors.

Table 2. Modified Asphalts Performance Grades Properties.

Code	Binder	% Additives	DSR kPa	DSR after RTFO, kPa	DSR after PAV, MPa	Flexure Creep (BBR) S-value	Flexure Creep (BBR) m-value	PG Grade	Storage Stability
1	Plain Asphalt	0	1.995	3.64	121.3	0.306	2.96	PG 64-16	N.A.
2	EE-2	5	1.924	4.01	42.6	0.309	3.82	PG 76-10	96.2
3	SBS	4	1.780	3.55	57.2	0.305	2.73	PG 76-10	88.1
4	LLDPE	3	1.612	3.92	83.7	0.311	2.86	PG 76-10	81.6
5	Crumb Rubber	20 ± 2% of the Total Binder Mass	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
6	Fiber	3 kg / Metric Ton of Asphalt Concrete Mix	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
7	Cement Dust	2	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

N.A. = not applicable.

Table 3. Asphalt Concrete Aggregate Gradation.

Sieve Size, mm	% Passing	Control Points Max.	Control Points Min.	Tolerance %
12.5	95.2	100	100	± 4
9.5	81.8	90	-	-
4.75	44	-	-	± 5
2.360	31.5	58	28	± 4
2.000	28.5	-	-	-
1.180	22.1	-	-	-
0.600	16.1	-	-	-
0.425	12.4	-	-	-
0.300	11.3	-	-	-
0.180	9	-	-	-
0.150	7.9	-	-	± 2
0.075	5.2	10	2	± 1.5

Polymers were blended with asphalt cement binder using the high shear blender. Crumb rubber was added to asphalt at a rate of 20 ± 2% of the total binder mass and blended with asphalt cement at 180°C for at least one hour. Plain and modified asphalts were mixed with aggregate at a mixing temperature in which the binder viscosity was 0.170 ± 0.02 pa.s in large temperature controlled mixer, and compacted in a 6-in. mold using a gyratory compactor following MOT/SHRP specifications for high traffic level greater than 30 million ESAL (high volume expressways). The compaction temperature was set where the binder had viscosity of 0.280 ± 0.03 pa.s. Fiber was added to aggregate at a rate of 3 kg/metric ton of asphalt concrete mix and blended with aggregate for at least 10 seconds before adding asphalt. Table 4 shows the coding for the different asphalt concrete mixes, optimum asphalt contents, and volumetric parameters for designed mixes.

Indirect Tensile Strength and Fatigue Testing

Compacted samples were evaluated to determine optimum asphalt content based on Superpave volumetric mix design procedure (AASHTO MP2-00), moisture sensitivity test (AASHTO T-283), and Indirect Tensile Strength (ITS) test (AASHTO T-245). ITS test results for all mixes are shown in Table 5.

Asphalt concrete slabs (38 cm × 30 cm × 6.6 cm) were compacted to the optimum density using slab compactor as shown in Fig. 4.

Slabs were cut into beam samples (38 cm × 6.6 cm × 5.0 cm) using a masonry saw as shown in Fig. 5. Beam samples were conditioned at the test temperature and tested with the Flexural Beam Fatigue test, following AASHTO T-321 (TP8-94). Samples were tested in a stress controlled mode to simulate asphalt pavement

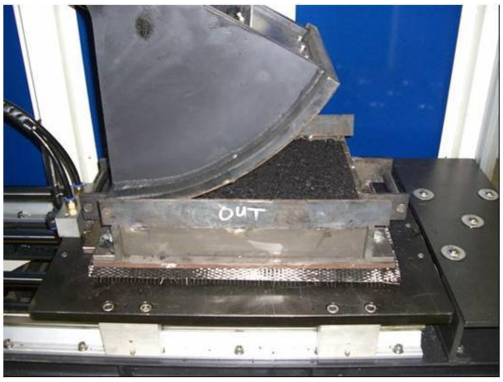

Fig. 4. Preparation of Slab Samples.

Table 4. Optimum Asphalt Contents and Volumetric Parameters for Designed Mixes.

Mix Type	Limestone Aggregate (E) Code	OAC	Av	VMA	VFA	DP	Basalt Aggregate (W) Code	OAC	Av	VMA	VFA	DP
Plain Asphalt	E-1	4.7	4.1	14.3	71.1	1.16	W-1	4.2	4	14.7	70.2	0.97
Plastomer	E-2	4.7	4.1	14.4	72.2	1.14	W-2	4.3	4.1	14.9	69.9	1.01
Elastomer	E-3	4.8	4.1	14.5	70.6	1.1	W-3	4.4	4	15.1	69.3	0.95
LLDPE	E-4	4.7	4.1	14.4	72	1.12	W-4	4.3	4	14.8	70.1	0.98
Crumb Rubber	E-5	5.7	4.2	14.7	73.3	1.18	W-5	5.2	4.1	15.5	70.5	1.12
Fiber	E-6	5.3	4	14.4	69.8	1.2	W-6	4.7	4	14.9	70.2	1.12
Cement Dust	E-7	5	4	14.2	69.1	1.18	W-7	4.3	4	14.5	70	1.1

Table 5. Optimum Asphalt Contents and ITS Test Results for Prepared Mixes.

Asphalt Concrete Mix	Limestone Aggregate (E)			Basalt Aggregate (W)		
	Mix Code	Optimum Asphalt Content, %	Mean ITS, kPa	Mix Code	Optimum Asphalt Content, %	Mean ITS, kPa
Plain Asphalt	E-1	4.7	1449	W-1	4.2	1134
Plastomer	E-2	4.7	1587	W-2	4.3	1576
Elastomer	E-3	4.8	1599	W-3	4.4	1225
LLDPE	E-4	4.7	1532	W-4	4.3	1326
Crumb Rubber	E-5	5.7	980	W-5	5.2	908
Fiber	E-6	5.3	1237	W-6	4.7	1043
Cement Dust	E-7	5.0	1452	W-7	4.3	1469

Fig. 5. Beam Samples.

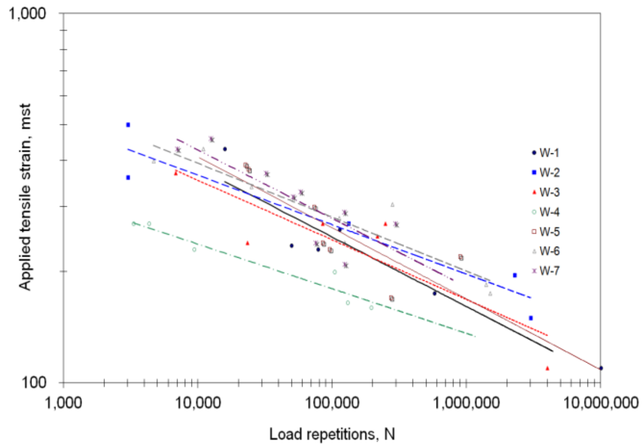

Fig. 6. Relation between Load Repetition (N) and Applied Strain (ε) for Basalt Mixes.

thick layer construction used by MOT. At least six samples were tested under different bending peaks to peak stress (kPa). The software calculated corresponding stiffness (MPa), peak to peak strain $\times 10^{-6}$, peak to peak load (kN), deflection (mm), dissipated energy (Mj/m^3), and phase angle (°).

As the asphalt concrete beam sample was subjected to load repetitions, stiffness reduced rapidly at the start then reached a constant slope till failure of the beam, which was defined in this study as 40% of the initial stiffness. Collected data were analyzed to determine relations between load repetition to failure (N) and applied peak to peak stress (σ), or initial peak to peak strain (ε).

Results

Basalt Aggregate

Fig. 6 shows the relation between load repetition (N) and initial strain (ε) for Basalt aggregate mixes while Fig. 7 shows the relation between load repetition (N) and applied stress (σ). Both figures show good correlation between applied stress and strain and load repetitions at failure.

At strain levels less than 300 micro-strain (mst), W-6 and W-2 mixes have the best performance. Mixes W-3 and W-5 gave the third and fourth best fatigue performance. Mix W-7 gave fatigue behavior less than that of plain asphalt for strain levels less than 200 mst. Mix W-4 gave the worst fatigue life under a given strain level.

At a given stress level, W-2 gave the highest fatigue life followed by W-3 and W-4 mixes. Mixes W-1 and W-6 have comparable behavior. This indicates that fiber mixes tend to behave similarly to plain mixes under similar stress levels, but outperformed plain mixes under similar strain levels. W-3 ranked as the second best performance, while W-5 ranked as the fourth best performance. Mix W-7 exhibited the worst fatigue behavior. Under the same stress level, it gave fatigue behavior less than that of plain asphalt. Mix W-4 exhibited fatigue behavior similar to that of W-3.

Plastomer modified mix (W-2) outperformed plain asphalt concrete mix under both strain and stress levels. It can endure higher strain or stress levels as compared to plain asphalt concrete mixes.

Limestone Aggregate

Fig. 8 shows the relation between load repetition (N) and initial strain (ε) for the Limestone aggregate, while Fig. 9 shows the relation between load repetition (N) and applied stress (σ). Both figures show good correlation between applied stress and strain and load repetitions at failure.

At strain level greater than 300 mst, E-6 has the best performance followed by E-3 mix. At strain levels less than 300 mst, E-3 and E-6 mixes have the best performance followed by E-2 mix. E-1, E-4, and E-7 mixes came next with performance similar to that of plain asphalt concrete mix. E-5 mix gave the least fatigue performance.

At a given stress level, E-3 gave the best performance, followed by E-2. E-4, E-1 and E-6 mixes came next with performance similar to the plain asphalt followed by E-7, while E-7 gave the least fatigue performance. Mixes E-1 and E-6 have comparable behavior. This indicates that fiber mixes tend to behave similar to plain mixes under similar stress levels, but outperformed plain mixes under similar strain levels.

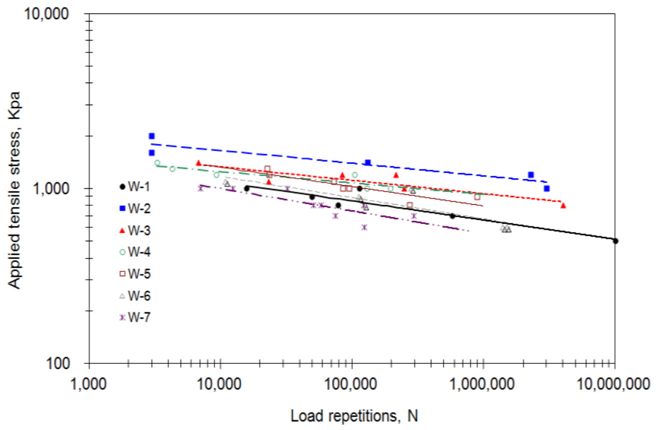

Fig. 7. Relation between Load Repetition (N) and Applied Stress (σ) for Basalt Mixes.

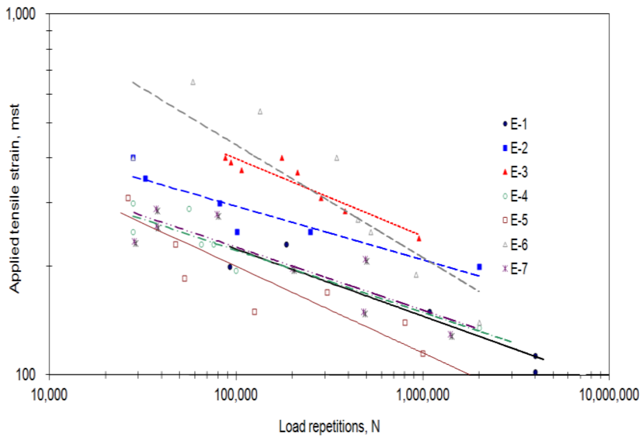

Fig. 8. Relation between Load Repetition (N) and Applied Strain (ε) for Limestone Mixes.

Table 6. Fatigue Relations as a Function of Applied Strain and Stress for Basalt and Limestone.

Mix Type	Basalt		Limestone	
	Function of Applied Strain	Function of Applied Stress	Function of Applied Strain	Function of Applied Stress
Plain	3E+16(ε–4.8053)	5E+28(σ–8.0687)	6E+16(ε–4.9864)	3E+25(σ–6.7517)
Asphalt	√ MSE = 50,645	√ MSE = 59,107	√ MSE = 768,284	√ MSE = 1,027,720
	% SER = 3	% SER = 3	% SER = 23	% SER = 30
	3E+21(ε–6.7772)	2E+42(σ–11.863)	2E+19(ε–5.7922)	2E+27(σ–7.0155)
Plastomer	√ MSE = 675,782	√ MSE = 690,741	√ MSE = 64,334	√ MSE = 99,183
	% SER = 62	% SER = 64	% SER = 15	% SER = 24
	3E+16(ε–4.7949)	7E+35(σ–10.107)	4E+15(ε–4.0796)	2E+20(σ–4.8113)
Elastomer	√ MSE = 97,094	√ MSE = 87,300	√ MSE = 39,440	√ MSE = 94,760
	% SER = 13	% SER = 11	% SER = 14	% SER = 33
	2E+22(ε–7.6923)	1E+41(σ–11.942)	4E+16(ε–4.9698)	2E+19(σ–4.8092)
LLDPE	√ MSE = 21,552	√ MSE = 20,514	√ MSE = 29,392	√ MSE = 53,599
	% SER = 29	% SER = 28	% SER = 9	% SER = 16
Crumb	3E+13(ε–3.5325)	4E+25(σ–6.825)	2E+13(ε–3.6394)	6E+25(σ–7.4422)
Rubber	√ MSE = 55,315	√ MSE = 26,406	√ MSE = 158,300	√ MSE = 290,451
	% SER = 26	% SER = 13	% SER = 47	% SER = 86
	4E+19(ε–5.9814)	3E+23(σ–6.2584)	2E+11(ε–2.3148)	1E+21(σ–5.407)
Fiber	√ MSE = 103,221	√ MSE = 146,411	√ MSE = 101,170	√ MSE = 267,641
	% SER = 24	% SER = 34	% SER = 16	% SER = 42
	3E+14(ε–3.9338)	8E+19(σ–5.2745)	2E+15(ε–4.3921)	1E+23(σ–6.1484)
Cement Dust	√ MSE = 78,945	√ MSE = 98,134	√ MSE =156,941	√ MSE =192,488
	% SER = 57	% SER = 71	% SER = 40	% SER = 49

MSE = Mean square error; √ MSE = Mean error; % SER = Percent standard error

Statistical Analysis

Table 6 presents a summary for all developed regression equations for the two aggregate additive types as a function of stress or strain. It should be noted that the test mode was a controlled stress. The basic regression parameters such as slope and intercept can be depicted from the regression equations. Table 6 also presents the mean error of the function (√ MSE), which is the square root of mean square error (MSE). In addition, the table shows the mean error as a percent ratio of the group fatigue test data average (percent standard error), which can be used to judge variation of the fatigue function.

Percent standard error (% SER) varies between 3 and 86. Fatigue prediction is known to have high scatter and, therefore, standard error of up to 30% can be considered acceptable, and up to 40% to be marginal. Functions with percent standard error greater than 40% should be used with caution.

Results indicate that for Basalt aggregate, Plastomer (W-2) and cement dust mixes have % SER greater than 40. Fiber stress function has % SER of 34. All other equations can be considered reliable.

For Limestone aggregate, crumb rubber, fiber and cement dust mixes stress functions and crumb rubber strain functions have % SER greater than 40. Cement dust strain function and Elastomer (E-3) stress function have % SER of 40 and 33, respectively. All other equations can be considered reliable.

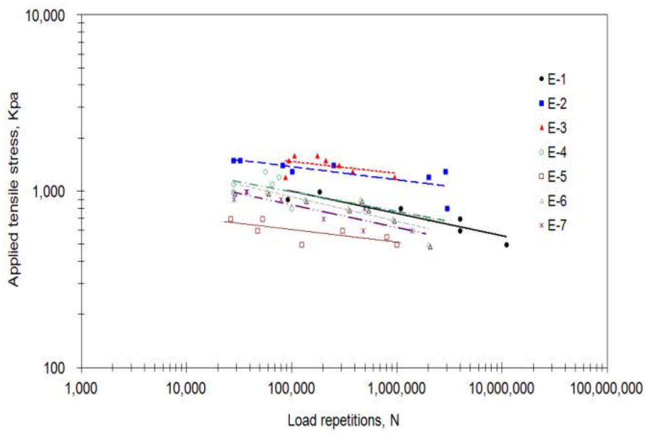

Fig. 9. Relation between Load Repetition (*N*) and Applied Stress (σ) for Limestone Mixes.

Conclusions

This study aimed to investigate and identify the effect of modifiers, especially polymers, on fatigue resistance of local asphalt concrete mixes. The study was designed to evaluate the effectiveness of different modifiers when used with local materials to resist fatigue cracking. Moreover, it aimed to identify and suggest the best modifier(s) to boost fatigue without compromising other important engineering properties of the local asphalt concrete mixes.

Based on the limited fatigue tests carried out in this study, certain polymers have the ability to improve the fatigue life of local mixes. Polymer modification has increased the resistance to the applied stress (load bearing) and strains (deflection) of local asphalt concrete mixes as compared to plain asphalt concrete mixes. Test results indicated that:

1. At a given stress level, Plastomer and Elastomer polymers gave the best fatigue behavior for all aggregates.
2. At a given strain level, fiber gave the best fatigue behavior for strain level greater than 250-300 mst, followed by Elastomer and Plastomer polymers for Limestone aggregate, and cement dust and Plastomer for Basalt aggregate.
3. At strain level less than 250-300 mst, Elastomer and Plastomer polymers for Limestone aggregate and cement dust and Plastomer for Basalt aggregate gave the highest fatigue life.
4. Crumb rubber was not effective in increasing the fatigue life of the studied mixes due to the dense grading of the aggregate used.
5. Performance grading (PG) of modified asphalt binder does not guarantee fatigue performance of asphalt concrete mixes. Plastomer, Elastomer, and LLDPE polymers having performance grade of PG 76-10 were used in this study. The fatigue performance for these polymers were ranked 3rd, 4th and 7th, respectively, when used with the Basalt aggregate; and 2nd, 3rd, and 7th, respectively, when used with the Limestone aggregate.

Acknowledgments

The author would like to acknowledge the support provided by King Fahd University of Petroleum & Minerals and King Abdulaziz City for Science and Technology in carrying out this study.

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