Evaluation of Modified Local Asphalt Mixtures by Fatigue Distress Criteria

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ABSTRACT

A fatigue is the accumulation of the materials damage in asphalt concrete mixtures and growing of cracks, under increasing effect of repeated vehicular loading, aging and environment factors, in this research study the effect of temperature, asphalt content, mineral filler, applied Strain, and the polymer (SBS) as a modified asphalt to evaluate their effect on fatigue crack. To achieve the objective of this research, the Nottingham flexural fatigue test is considered and superpave mix design requirements are employed. Test specimens of 380 mm length by 60 mm width and 50 mm height were sawed from slabs of the prepared mixes by rolling wheel compaction. Using Controlled-strain procedure, the tests were conducted at temperatures of 10-20-30 ±1°C and at a frequency of loading of 5 Hz. The full factor design as well, three asphalt contents 4.72, 5.22 and 5.72%, mineral filler (Portland cement, limestone dust), applied strain (400-750µs), and (2-4%) percent of (SBS) polymer, Local material properties, stress level and environmental impacts are considered for this aspect. From the result, it is observed that 2% of SBS modified mixture given a best result due to increase the percent of fatigue life to (120%) as the average when compared with the control mixture, the fatigue life has a positive relationship with asphalt content and temperature when using control strain . The fatigue life of the mixture with limestone dust have result more than mixture with Portland cement, In the general, The fatigue life of mixture at 400µs has given result more than 750µs.

Keyword: fatigue life, superpave, Nottingham test, asphalt content, SBS –polymer

تقييم الخلطات الاسفلتية المحلية المحسنة بالاعتماد على معايير تشوهات الكلل

الخلاصة

الكلل هو تراكم ضرر المواد في الخلطة الاسفلتية ونمو الشقوق فيها ، حيث يتم ذلك تحت تأثير تكرار أحمال المركبات عليها ،التعتيق و العوامل البيئية ، في هذا البحث تم دراسة تأثير كل من (تغير درجة الحرارة ، محتوى الاسفلتي في الخلطة ، تغير نوع المادة المالئة، تغير مقدار الانفعال وإضافة مادة محسنة للإسفلت بوليمر (SBS ستايرين بيوتادين ستايرين) وتاثيره على عمر الكلل ، وحسب متطلبات تصميم المزيج الاسفلتي الفائق الاداء وتم قطع عتبات الاختبار بأبعاد (٣٨٠ ملم طول و ٦٣ ملم عرض و ٥٠ ملم ارتفاع) من بلاطات الخلطات الاسفلتية المحضرة بواسطة جهاز العجلة الضاغطة وحسب نسبة الفراغات المحددة .

أجريت اختبارات الانفعال-المحكم لشقــوق الكلل باستخدام معدات الاختبار بجهاز نوتنغهام والإجراءات الخاصة به . وأجريت الاختبارات في درجات الحرارة من ((١٠، ٢٠، ٣٠)± ١ م°) وعلى تردد تحميل ٥ هرتز و لثلاثة نسب للأسفلت (٤.٧٢، ٥.٢٢، ٥.٧٢٪)، ومادة مالئة (اسمنت بورتلاند، ومسحوق الحجر الجيري)، وتطبيق انفعال (٤٠٠-٧٥٠مايكروسترين)، وبإضافة بوليمر (SBS)بنسبة (2-4%) حيث جميع النتائج طابقة

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المواصفات القياسية المحلية ، وقد لوحظ أن الخلطة الحاوية على نسبة ٢% من بوليمرSBS تعطى نتيجة أفضل من حيث عمر الكلل ،قد تصل إلى (١٢٠٪) كمعدل من حيث مقارنتها بالخلطه المرجعية، وقد لوحظ ان عمر الكلل له علاقة طردية مع محتوى الإسفلت ودرجة الحرارة عند ثبوت الانفعال ، كما وقد تبين ان عمر الكلل للخلطة الاسفلتية الحاوية على مسحوق حجر الجيري تعطي عمر اكبر بالمقارنة مع الخلطة الحاوية على الاسمنت البورتلاندي ، وقد تبين ايضا ان عمر الكلل للخلطه الاسفلتية عند ٤٠٠µs تعطي نتيجة أكثر من ٧٥٠µs.

INTRODUCTION

Fatigue cracking is one of the three major types of distress (rutting, fatigue cracking, and low temperature cracking) for asphalt pavements, (Huang, 1993), the relation of fatigue life has directed various engineering properties of typical hot mix asphalt (HMA) 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, (Moghaddam et al, 2011). The main material property governing the fatigue failure mechanism is the tensile strain in the HMAC (Hot Mix Asphalt Concrete) layer. It is induced tensile strain due to the applied stresses exceeding the design tensile strain of the layer of pavement, fatigue-cracking initiates and eventually leads to failure of the structure, (Edward, 2007). Different properties of type, amount of asphalt binder and air voids in the mixture effect on the fatigue life of pavement, (NCHRP, 2004; SHRP, 1994). Also, the gradation of aggregate affects more than asphalt binder in the mixture on fatigue resistance, (Hafiang, 2001). The mechanism of fatigue cracking was divided in to three stages of asphalt concrete (Smith, B. J 2000) as shown in Figure (1):

- Crack initiation, which gets from the initiation and growth of microcracks.
- Crack propagation, which the microcracks development and extension to form macrocracks as a growth of stable crack
- Disintegration, which gets from the collapse and final failure of the material as a development of unstable crack.

Fatigue life usually consumes most of the old before wider phase, this phase can be described by using the Paris' law which related between the rate of cracks development to the fundamental properties of the material and investigational conditions, (Paris, 1963).

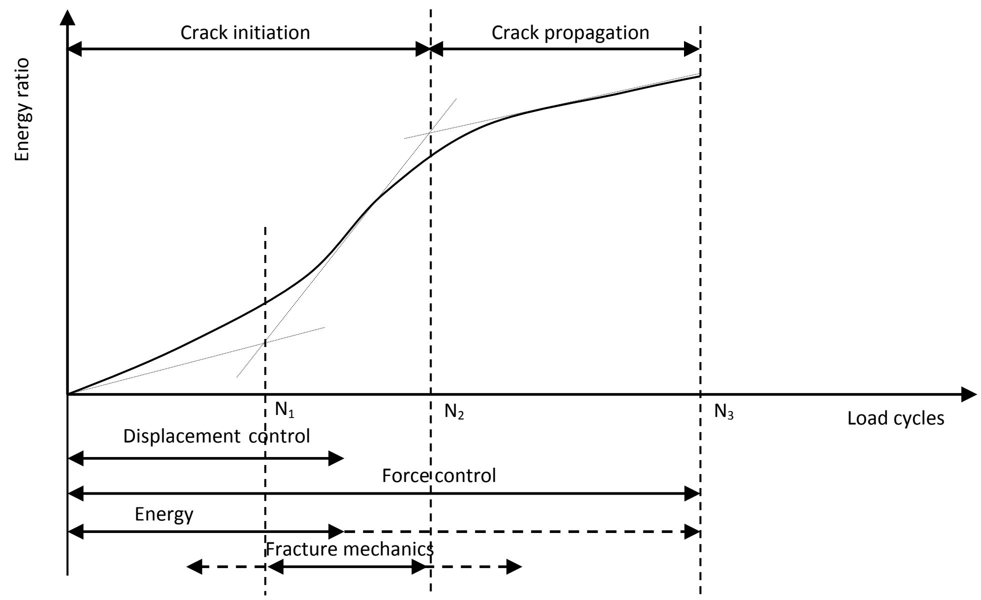


Figure (1): Fatigue Stages and Application Ranges of Different Fatigue Models,

(Hopman et. al., 1989)

In flexible pavement, there are two mechanisms of fatigue failure cracking. The articulated of the two mechanisms failure of fatigue cracking are shown in Figure (2) as below:
1- Bottom-Up Fatigue Cracking (BUC) – Alligator Cracks.
2- Top-Down Fatigue Cracking (TDC) – Longitudinal Cracks in Wheel Path.

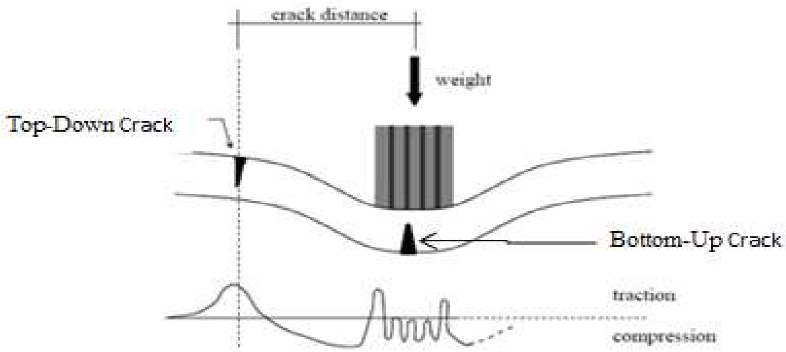


Figure (2): Mechanisms Failure of Fatigue Cracking

The purpose of this paper is to present and review the performance of fatigue life relationship with effecting factors and prediction of models though using Nottingham flexural fatigue 4-point Bending test, to accomplish these objectives; the program has been used to test of beams obtained from slabs prepared in the laboratory by rolling wheel compaction, laboratory -mixed, laboratory compacted specimens.

Laboratory Testing

Material

The asphalt mixture was included asphalt binder, fine and course aggregate in addition to additives. These material's properties were evaluated and the obtained results are compared with the SCRB (R/9, 2003) and ASTM specification requirements as presented in following sections. In this study asphalt grade AC (40-50) was obtained from AL-Daurah Refinery. The aggregate properties were played a key role in determining fatigue life, (Xiao et al., 2008). the crushed quartz aggregate was selected from al-Nibaie Quarry, it is widely used in the asphalt pavement, the properties of gravels were determined by laboratory experiments, the crushed lime stone from Ministry of Building and Construction Ashur company and Portland cement from Al-Mas company which obtained from the market were used as filler material.

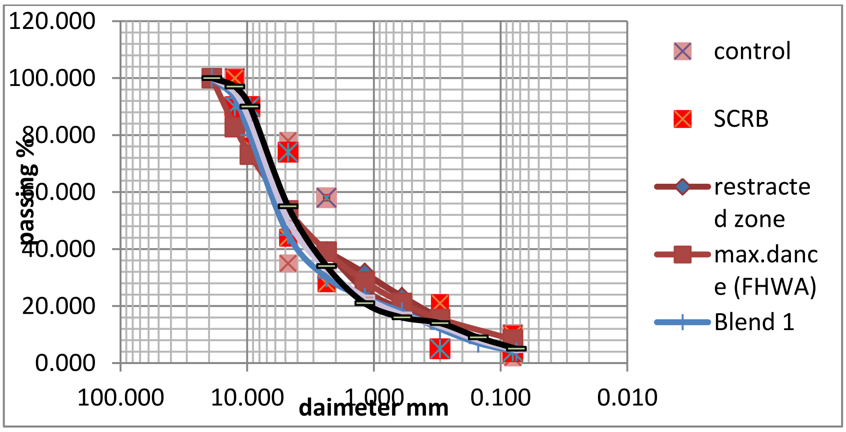
Additives

The additive is Styrene-butadiene-styrene known as SBS polymer brought from the Ministry of Industrial and Materials State Company for mining industries. SBS polymer is a white or yellowish porous particles of rod or wafer shape as shown in figure (3). It's the most widely accepted asphalt binder modification agent used by the many bitumen industry. SBS is based on two-phase block copolymers with hard and soft segments. The styrene end blocks provide the thermoplastic properties and the Butadiene mid-blocks provide the elastomeric properties, (Munteanu and Vasile, 2005). SBS is added by (2 and 4%) by weight of asphalt binder.

Figure (3): photograph of the polymer SBS

Select the Design Aggregate Structure

The three specifications of superpave gradations were used to select best gradation blends, the specifications were the 0.45 power chart, restricted zone and control points, (Asphalt institute 2007), and the three trail blends were selected under the restricted zone as presented in Figure (4) and Table (1), the experimental work shown in figure (5).



Figure(4): Superpave Gradation Limits, (Christopher, 2004*)*

Table (1): Gradation of Three Blends under Restricted Zone

Sieve size		Superpave Specification , 2007		Iraqi Speci. SCRP R9		Blend (1)	Blend (2)	Blend (3)	Weight of Aggregate for sample of 4500 gm		
Standard Sieves	English Sieves	max	min	max	min				Blend (1)	Blend (2)	Blend (3)
19mm	3/4"	100	100	100	100	100	100	100	0	0	0
12.5mm	1/2"	100	90	100	90	93	97	95	315	135	225
9.5mm	3/8"	---	90	90	76	80	90	85	585	315	450
4.75mm	#4	---	---	74	44	45	55	50	1,575	1575	1,575
2.36 mm	#8	39.1	39.1	58	25	30	34	33	675	945	765
1.18mm	#16	31.6	25.6	---	---	23	21	23	315	585	450
0.6mm	#30	23.1	19.1	---	---	18	16	17	225	225	270
0.3mm	#50	15.5	15.5	21	5	12	14	13	270	90	180
0.15mm	#100	---	---	---	---	7	9	8	225	225	225
0.075mm	#200	10	2	10	4	4	5	4.5	135	180	157.5
Filler						0	0	0	180	225	202.5

Figure (5) show the experimental work.

Superpave gyratory compactor (SGC) was used to produce hot-mix asphalt (HMA) specimens in the laboratory to assess volumetric properties and predict pavement performance. The fabrication of a specimen is in accordance with standard specification ASTM D 6925. After compacted all specimens, the data are taken from SGC software archive, from these data the percent air void (V_A %), voids in mineral aggregate (VMA %), voids filled with asphalt (VFA %) and percent G_{mm} are calculated, and selected (blend 1) as the best blend according to the superpave specifications.

Select the Optimum Asphalt Content

Once the aggregate structure is selected, started to select design asphalt content, the specimens are compacted at varying asphalt binder contents (estimated asphalt binder content %, estimated asphalt binder content ±0.5%, and estimated asphalt binder content +1%).

After aging the HMA specimens, they were compacted. The data were taken from SGC and ($G_{mm,}$ G_{mb}, VMA, VFA, V_a%, DP) were calculated, the mixture properties are then evaluated to determine design of the asphalt binder content.

Finally, the optimum asphalt content which is (5.22%). The (VMA and VFA) which are (16.085% and 75%) respectively as shown in figure (6).

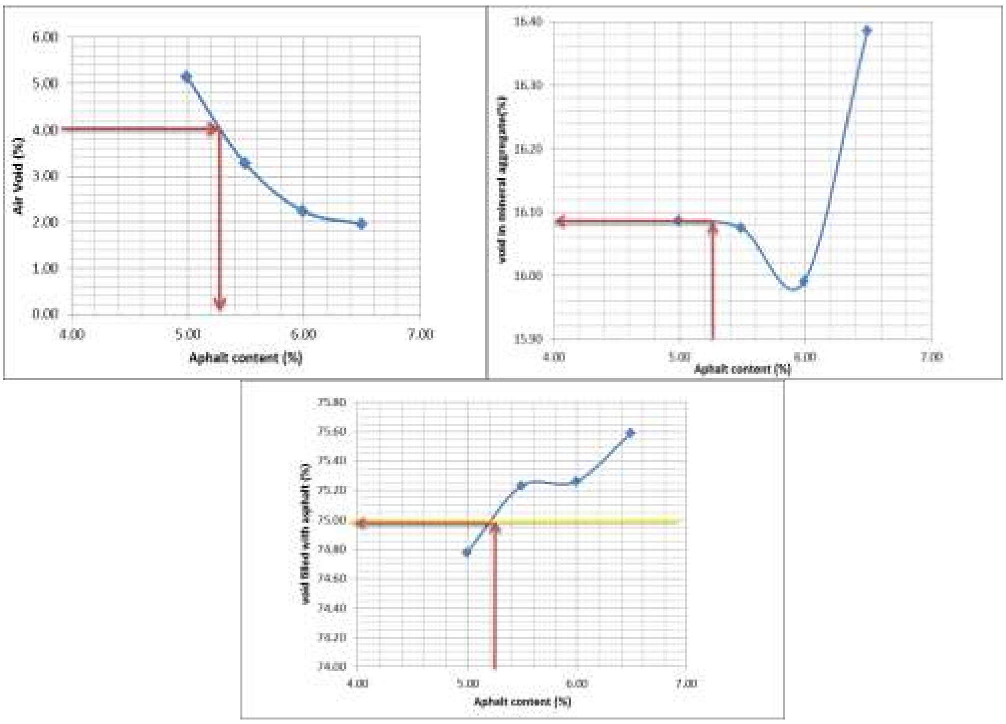


Figure (6): Relation that used to find AC, VMA and VFA.

The moisture sensitivity on the mixture design

Moisture sensitivity was measured accordance to standard specifications ASTM D 4867 and AASHTO T 283; it was the final step in the procedure of superpave. The ratio of tensile strength of the conditioned subset to that of the unconditioned subset as shown in Table (2)

$$. F_r(kPa) \quad \frac{P(kpa)}{_i(mm)} \qquad (Psi) \quad \frac{2P(psi)}{D(in)} \qquad ...(1)$$

Where:
F_r = tensile strength, kPa (psi)
P = maximum load, N (lbf)
t = specimen height immediately before tensile test, mm (in.), and
D = specimen diameter, mm (in.).
Then the tensile strength ratio “TSR” is calculated as follows:

$$\frac{r(\,con \qquad ples)}{r(\,con \qquad ples)} \qquad ...(2)$$

Table (2): Results of the Moisture Sensitivity

Name sample		Height	Load (P)	Tensile Strength *(F_r)*	TSR	Standard limit
Control samples	1	112	27	26.8	91%	More than 80%
	2	111.5	28			
	3	113	28.5			
Condition samples	1	112	26	24.3		
	2	112	25.5			
	3	113	24.4			

Samples Preparation

The roller compactor is used for mixtures compaction, the mold has dimensions of (380 length *300 width *120 height) mm is used to prepare beam samples with then cut to dimensions of (380±6 length, 60±6 width, 50±6 height) mm according to the standard specification AASHTO T-321 as shown in figure (7). 108 samples are prepared to study many factors; these factors are presented in Table (3).

The weight of samples depended on its density. Generally, two specimens are prepared in laboratory by standard mix (at approximately 4% air voids), after the specimens are compacted, the results are checked with standard specification requirements, the density at N_{design} (100 cycles) is depended to calculate the sample weight as (density multiple volume equal weight), the weight approximately equal to 13.73 kg.

Table (3): Depended factors for Repeated Flexural Beam Fatigue Testing

Factor	value		
Temperature	10°C	20°C	30°C
Strain	400µs	750µs	-
Asphalt content	4.72%	5.22%	5.75%
Filler type	Lime stone dust	Portland cement	-
Asphalt types	origin asphalt	Modified asphalt 2% SBS	Modified asphalt 4% SBS

The modified asphalt prepared in the laboratory by many steps as follows:

1. Firstly, the asphalt binder is heated to required temperature approximately about 180°C.

2. Weight the amount of asphalt that is needed to modify which it approximately (5 kg).
3. Weight the amount of SBS polymer that need for adding to asphalt, (for 2% SBS equal (100gm) is added to (5kg) and 4% SBS equal (200gm).
4. SBS was added to the asphalt with Continuous motion and save the temperature about 180°C.
5. After melting and mixing, modified asphalt is used to prepare the asphalt mixture.

Figure (7): Samples Preparation in Rolling Compacter

Repeated Flexural Beam Fatigue Testing

The procedure of repeated flexural beam fatigue testing is accomplished according to standard specification (AASHTO T- 321), all conditions and testing method are explained for determining the fatigue life of compacted (HMA), the repeated flexural Bending this test was conducted at NCCLR laboratory as shown in figure (8).

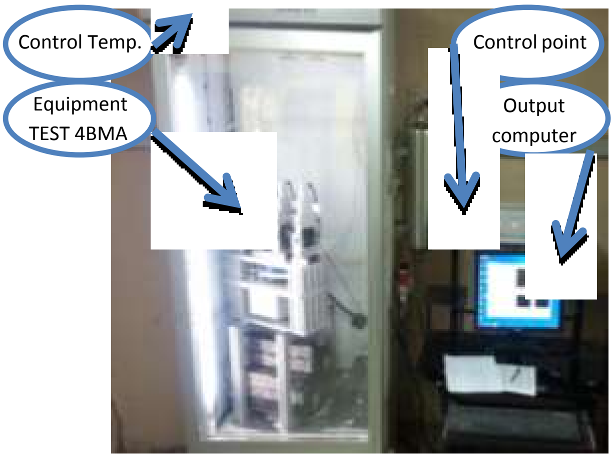


Figure (8): 4-point Repeated Flexural Beam Testing

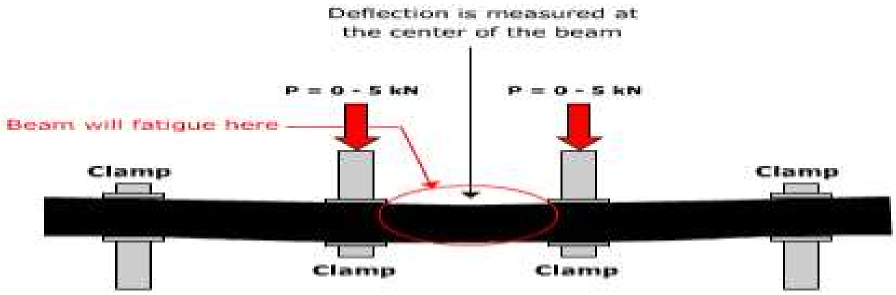
Flexural Fatigue Test Principles

The repeated flexural beam test measures the fatigue life of a HMA beams when placed among four loading points at a specified strain level. During the test, the beam is grasped 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 as observed in Figure (9). The maximum bending moment is done by weight of beam in addition the sinusoidal motion of this setup machine it was done in the middle of beam between two inner clamps. The maximum deflection caused by maximum bending moment position. Three important points were studied as follows:-

1- Stiffness of the asphalt mixtures.

2- The number of loading cycles to failure can then give an estimate of a particular HMA mixture's fatigue life.

3- Dissipated energy that indicates the energy that is lost or altered in material through mechanical work, heat generation, or damage of the sample.



Figure(9): Mechanism of 4-RFBT Work

The HMA beams of dimensions (380 * 50 * 63 mm) are obtained from the slab sample and placed in a 4-point loading machine, and then the beams are subjected to a repeated load. Tests can be run at a constant strain level or a constant stress level, in this research, the constant strain level is selected. The control strain means that the displacement amplitude was kept constant and the force required maintaining, the initial strain level decreases gradually after crack initiation during the test, as the flexural stiffness of the mix are effectively decreased. The failure or termination point is arbitrarily selected as a certain reduction in the initial stiffness from that at beginning of the test, generally 50%, as there is no well-defined fracture of the specimen. The controlled displacement mode of loading simulates conditions in thinner (<100 mm thick) asphalt pavements. The mix stiffness control stress level, which in turn controls the rate of crack propagation, and the measured fatigue life, includes the number of cycles to crack propagation (Pell, 1973). And the test procedure have been contained many steps as shown in AASHTO T321. Figure (10, 11) and table (4) shown the conditions of the case examination

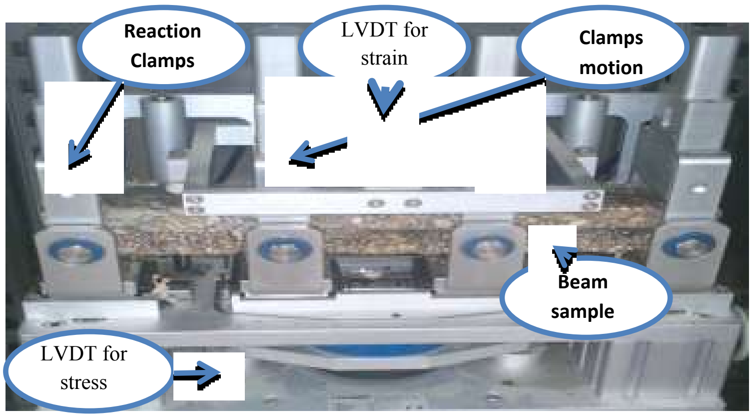


Figure (10): Beam Testing in 4-RFBT

Table (4): Data Inter to Machine

According AASHTO T321

Item	Value	Limitation
Strain	400 & 750 µs	250-750µs
Frequency	5 Hz	5-10Hz
Test End Value %	50 % from initial stiffness	---
Initial stiffness	50^{th} cycle	---

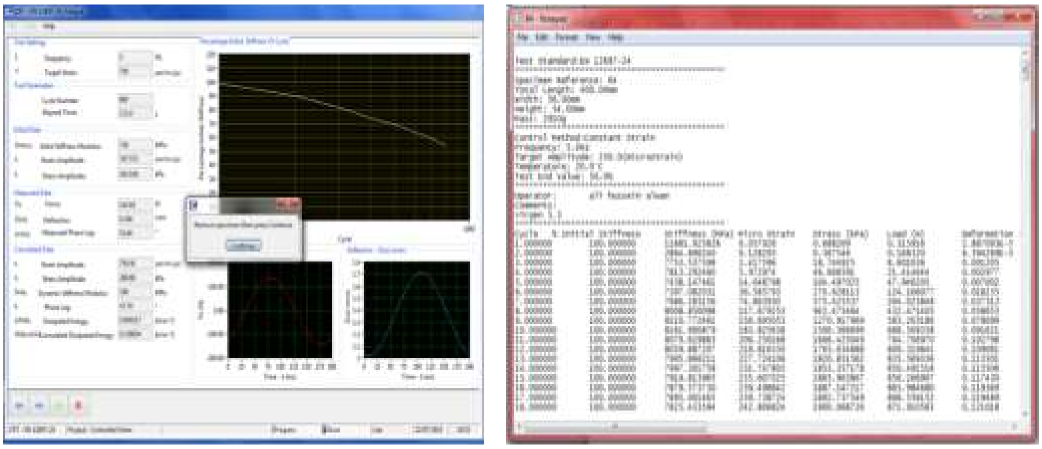


Figure (11): Microsoft Access database application which reports the result

Result and Discussion

Effect of Load Repetition on Stiffness

In this paper, results are plotted on a graph displaying number of load repetitions (N) versus the stiffness for each test. A curve is plotted for the loaded beam during test running. The stiffness of asphalt mixtures decreases throughout the crack developing process in pavements. Generally, the stiffness versus loading cycle plot of an asphalt mixture during fatigue testing exhibits are shown in Figure (12).

The relations were conducted for two strain levels (400 and 750 µs) with load frequency equal to (5 Hz) and three testing temperatures (10°C, 20°C and 30°C), the principle work of the 4 Point Bending test included the repeated loads applied on beams at constant condition (temperature, strain level , and load frequency) that reduce the stiffness to reach 50% of the initial stiffness (considered as the failure point), the data sheet presents some parameters as number of load repetition, fatigue life , stiffness of material and dissipated energy are most necessary, Figure (12) shows the relation between stiffness and number of repeated load at constants (temperature 30°C and strain 750 µs), it can observed that a rapid decreases in stiffness, followed by a linear decrease in stiffness, fracture cracking occurs as a result of the damage acceleration of microcracks ultimately turn to observable macrocracks, which cause the failure of the specimen.

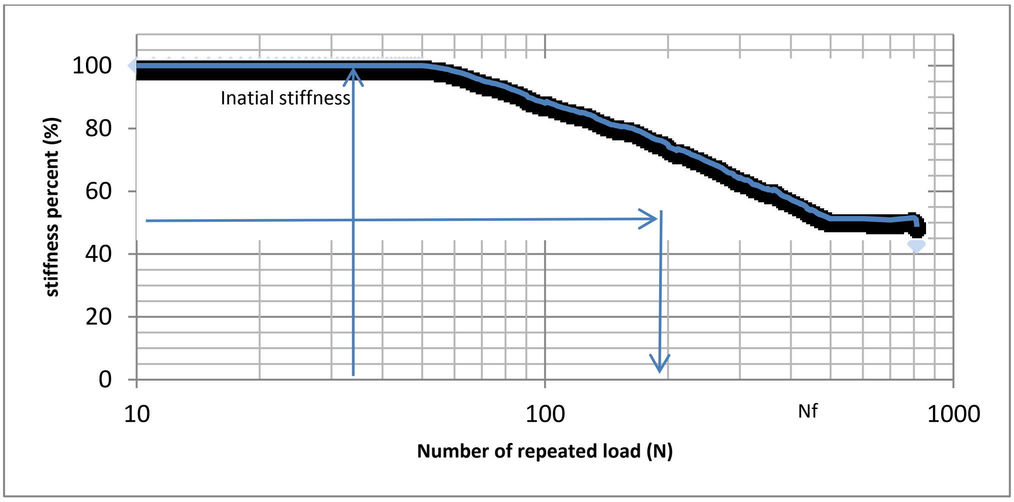


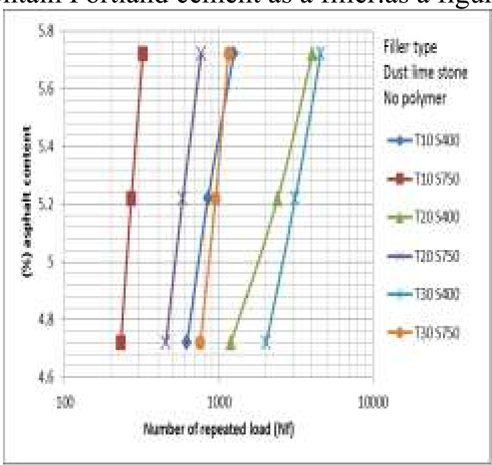
Figure (12): Relationship between stiffness and number of repeated load, at constant (temperature 30^0 C and 750 µs).

Variables Influencing on Fatigue Life

The number of repeated load (N_f) was used to predict fatigue life, the fatigue life measured under the some factor as (asphalt content in mixture, added additive, change temperatures, and micro strain level).

Effect of Asphalt Content.

Figure (13) shows that fatigue life of asphalt mixture contain a limestone dust as a filler increased by (37%) as asphalt content increased from (4.72% to 5.22%) and it was increased by (47%) when the asphalt content increased from (5.22% to 5.72%) at temperature of 10^{0}C and micro strain level of 400 µs) . The fatigue life increased (16%) when increased asphalt content from 4.72% to 5.22% and the fatigue life increased to (18%) when asphalt content increased from 5.22% to 5.72% at similar condition but with micro strain level of 750 µs. But at temperature is 20^{0}C, and the asphalt content increased from (4.72% to 5.22%), the fatigue life was increased by (100%), and it was increased by (68%) when asphalt content increased from (5.22% to 5.72%) at strain level of 400 µs. while at constant micro strain level of 750 µs and temperature of 20^{0}C, increasing asphalt content from (4.72% to 5.22% and 5.22% to 5.72%), the fatigue life increased by (29% and 32%) respectively. The asphalt content effects on the fatigue life, the life of fatigue increased with asphalt content increase, because that asphalt content increases thickness of asphalt film between aggregate and lead to reduce the tensile stress in the bottom of the layer. This is similar for the mixture contain polymer and also by the mix contain Portland cement as a filler.as a figure (14, 15).



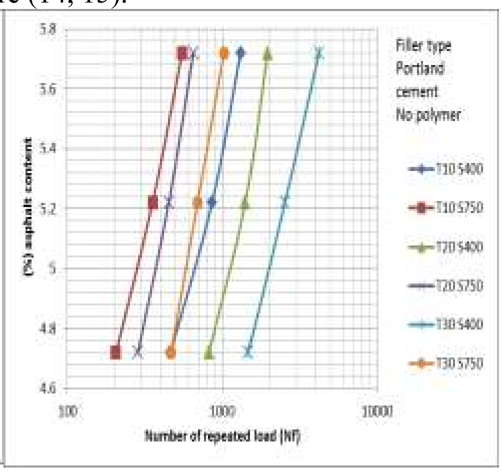


Figure (13): Relationship between the asphalt content and fatigue life for control mix

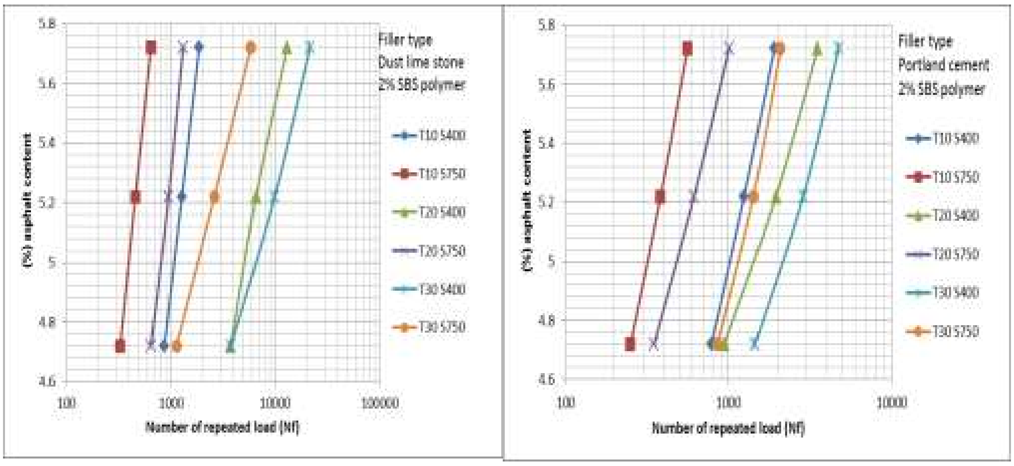


Figure (14) Relationship between the asphalt content and fatigue life for Modified mix with 4%SBS polymer

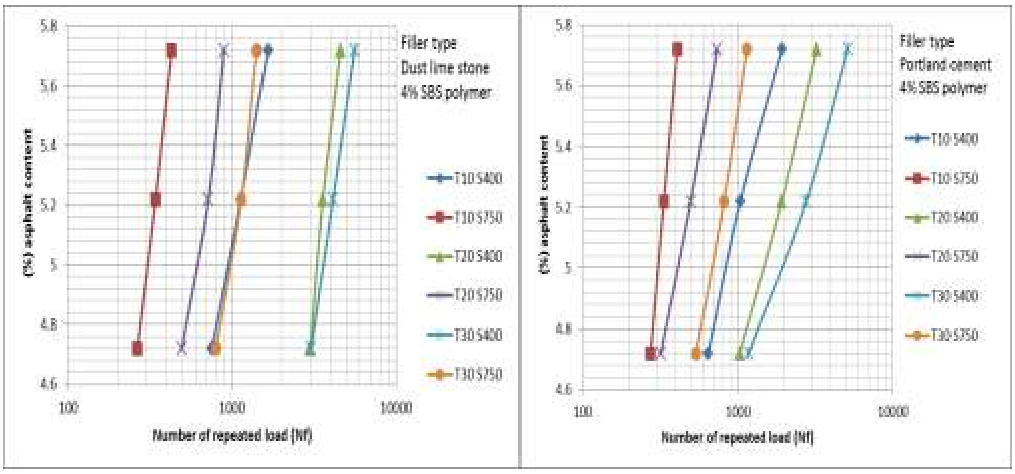


Figure (15) Relationship between the asphalt content and fatigue life for Modified mix with 4%SBS polymer

Effect of Temperatures

The temperature effect on the viscosity of asphalt binder, wherever the temperature increased in the mixture the viscosity of asphalt decreased too, so that the mixture was became flexibility, but the mixture became brittle with decreased temperature, (Mohiuddin, et, al 2015).

The fatigue life of control mixture was gradually increased (65%, 30%) with temperatures increased from (10^{o}C to 20^{o}C and 20^{o}C to 30 ^{o}C) respectively at constant micro strain 400 µs, and it was raised (54%, 64%) at 750 µs micro strain.

For the modified mixture asphalt with 2% SBS-polymer the fatigue life of asphalt increased (80%, 51%) for increased temperatures from (10^{o}C to 20^{o}C and 20^{o}C to 30^{o}C) respectively at micro strain 400 µs, but for 750 µs micro strain the fatigue life increased (52%,175%) with increased temperatures from (10^{o}C to 20^{o}C and 20^{o}C to 30^{o}C) respectively .

For the modified mixture with 4% SBS-polymer the fatigue life increased by (68%, 16%) for increased of temperatures from (10^{o}C to 20^{o}C) and from (20^{o}C to 30^{o}C) at micro strain 400µs , and for 750µs micro strain the fatigue life increased by (53%,59%) with increased temperatures from (10 ^{o}C to 20 ^{o}C and 20 ^{o}C to 30 ^{o}C), these results are shown in Figure (16). This is similar for the mixture contain polymer and also by the mix contain Portland cement as filler.

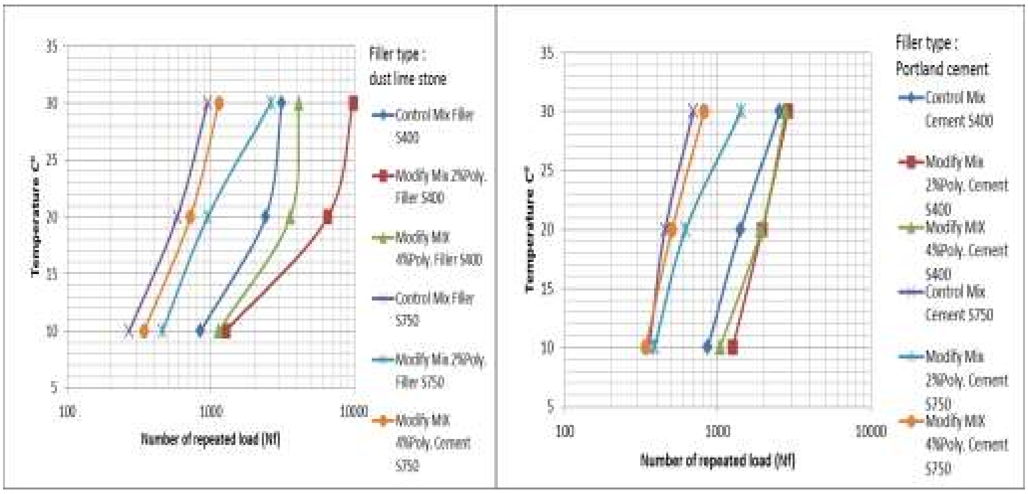


Figure (16) Relationship between the temperature and number of repeated load.

Effect of SBS Polymer Percentage

The SBS-Polymer was increased the viscosity of asphalt binder, it was increased the resistant fatigue crack by increase the tensile shear strength of material , the tensile shear strength increased with viscosity increased, because the adhesion and cohesion between the asphalt binder and aggregate increased.

From the experimental work, it is shown the fatigue life increased (50%, 172%, and 32%) When the comparison is made between the modified mixture with 2% SBS polymer and control mixture, the fatigue life increased (34%, 49%, 32%) when comparing between with the modified mixture with 4% SBS polymer and control mixture , the reduction in fatigue life was (11%,45%,58%) when comparison is made between modified mixture with 2% and 4% SBS polymer at constant 400 µs micro strain, limestone dust as filler and temperatures (10^oC, 20^oC, 30^oC) respectively.

The 2% the batter than 4% due to elasticity increased in the mixture, increased rate of temperature and low swelling.

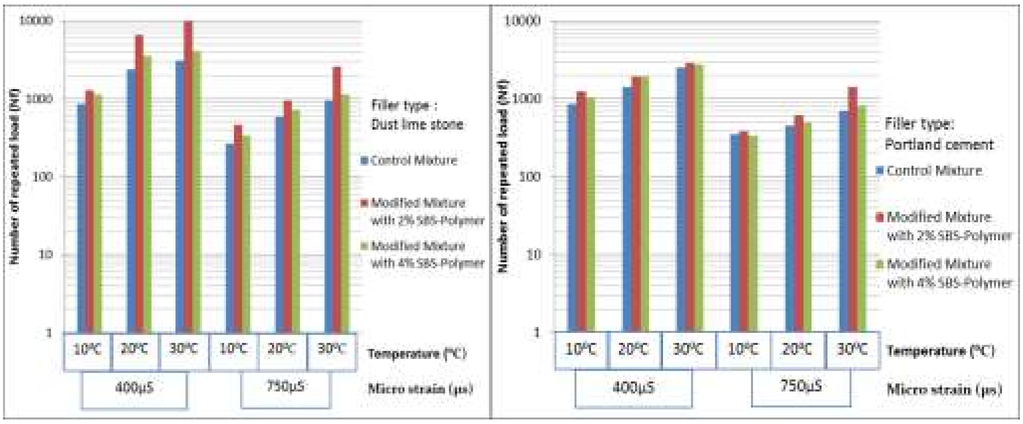


Figure (17) Relationship among the temperature, percent polymer and number of repeated load

Effect of Filler Types

Two types of filler are used are limestone dust and Portland cement, the two types of filler increased the durability of mixture, but Portland cement given stability and hardness more than limestone dust, when the hardness increased in the mixture that mean the fatigue life decreased and the elastic of mixture low, also said in the previous paragraphs.

Figures (18) represents the phenomena that fatigue life of control mixture decreased by (1% and 24%) when the comparison between the control mixture with limestone dust and Portland cement at temperature of 10^{0}C and for two constant micro strain 400 and 750µs respectively.

Also in temperature 20^{0}C and constant micro strain 400, 750µs the fatigue life raised to reach (70%, 29%) and fatigue life increased (23%, 37%) at temperature 30^{0}C, when the comparison between the control mixture with limestone dust and Portland cement.

For the modified mixture with (2%) SBS polymer when comparison between the modified mixture contain limestone dust and Portland cement as a filler, the fatigue life increased (12%, 83%, 139%) at 400µs micro strain and temperature (10^{0}C, 20^{0}C, 30^{0}C) respectively,

Effect of Strain

Asphalt lost the elasticity with repeated load, and with increasing load, the elasticity is reduced and fatigue life is reduced too. For example the fatigue life is reduced approximately (68%, 75%, 70%) when replaced strain from 400 µs to 750µs for control mixture with limestone dust at temperature (10^{0}C, 20^{0}C, 30^{0}C) respectively, and fatigue life is decreased (59%, 68%, 73%) when replaced strain from 400 µs to 750µs for control mixture with Portland cement at temperature (10^{0}C, 20^{0}C, 30^{0}C) respectively,

The fatigue life decreased (64%, 85%, 73%) and (68%, 80%, 72%) for limestone dust when compared between 400µs and 750µs micro strain for (2%, 4%) modified SBS polymer mixture and temperatures (10^{0}C, 20^{0}C, 30^{0}C) respectively. The fatigue life decreased (69%, 68%, 50%) and (67%, 74%, 71%) at Portland cement when compared between 400 and 750 micro strain for (2%, 4%) modified SBS polymer mixture and temperatures (10^{0}C, 20^{0}C, 30^{0}C) respectively, that show in the previously figures (18).

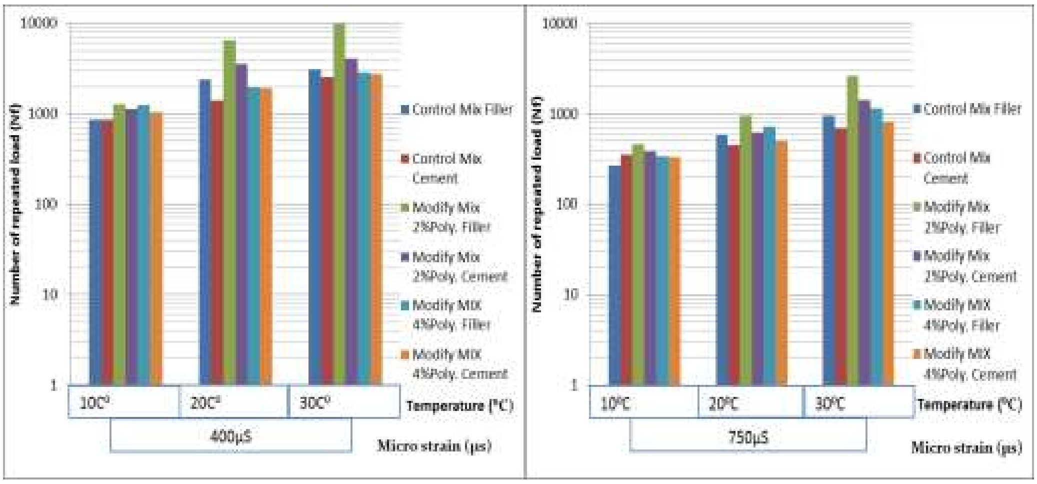


Figure (18): relation between the mixture with limestone dust and Portland cement Model of fatigue life

CONCLUTION

1- The result from two percent of SBS polymer (2% and 4%) for modified mixture and control mixture that used in this research, that 2% of SBS modified mixture gave the best result due to increasing the percent of fatigue life to (120%) when compared with the control mixture.

2- The repeated load caused decrease in the stiffness percent with increasing number of repeated load.

3- A fatigue life reduced when the asphalt content (decreased 0.5% from the optimum asphalt content), but it was increased when the asphalt content (increased 0.5% from the optimum); the relation between them and asphalt content is positive relationship.

4- The fatigue life decreased with temperature reduced from $20C^0$, but they increased when temperature raised from $20C^0$, they have positive relationship when using control strain.
5- The fatigue life of mixture with limestone dust gave result more than mixture with Portland cement, these consider positively relationship.
6- Generally, the fatigue life of mixture at 400µs gave result more than 750µs.

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