Fatigue Cracking Performance of Local Superpave Asphalt Concrete Mixtures

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Received on: 27/3/2014 & Accepted on: 30/9/2014

ABSTRACT

In Iraq, fatigue cracking is considered to be the most important type of distress affecting the performance of asphalt concrete pavements on major state highways. This research describes the results of a laboratory study of the fatigue response of a typical Iraqi asphalt concrete mixes to define the effects of degree of compaction (as measured by air-void content), asphalt content, temperature and aging on this performance parameter. To achieve the objective of this research, the Nottingham flexural fatigue test is considered and Superpave mix design requirements are employed. Test specimens of (400 mm length by 63 mm width and 50 mm height) were sawed from slabs of the mixes prepared to the target air-void contents by rolling wheel compaction. Controlled - procedure. The tests were conducted at temperatures of 10±1°C (50±2°F), 20 ±1°C (68±2°F) and 30±1°C (86±2°F) and at a frequency of loading of 10 Hz. The long term aging experiment employed a full factorial design as well, with three asphalt contents, two aging periods, two air-void contents and three test temperatures for a nominal total of 36 tests were performed. Local material properties, stress level and environmental impacts were considered for this aspect. It was concluded that for strain – controlled testing, an increase in term aging results in a decrease in laboratory fatigue life and a decrease in mix stiffness, and an increase in test temperatures within the range tested results in an increase in laboratory fatigue life and a decrease in mix stiffness. Finally, a series of recommendations are presented for enhancing the fatigue performance of Iraqi pavements including changes to current construction quality assurance procedures.

Keywords: Asphalt concrete; Superpave; Fatigue performance; Nottingham test; Air void content; Degree of compaction;Asphalt content; Aging; Mix design and analysis.

تصرف تشققات الكلل للخلطات الاسفلتية المحلية عاليــة الأداء

الخلاصة:

في العراق ، تعتبر شقوق الكلل من اكثر انواع الفشل اهمية حيث تؤثر على أداء الرصف بالخرسانة الإسفلتية على الطرق الرئيسية السريعة .يصف هذا البحث نتائج الدراسة المختبرية لاستجابة شقوق الكلل لخلطات الاسفلت العراقية النموذجيــة لتحديــد تأثيرات درجة الدمك (مقاسا بمحتوى نسبة الفراغات) ، محتوى الإسفلت ودرجة الحرارة و التقادم على معاملات الأداء.

لتحقيق الهدف من هذا البحث ، تم استخدام اختبار نوتنغهام لفحص شقوق الكلل وحسب متطلبات تصميم المزيـج الاسفلتي الفائق الاداء وتم قطع عتبات الاختبار بأبعاد (400 ملم طول و 63 ملم عرض و 50 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 درجـــات الحـــرارة من 10 ± 1 درجة مئوية (50 ± 2 درجة فهرنهايت)، 20 ± 1 درجة مئوية (68± 2 درجة فهرنهايت) و 30 ± 1درجة مئوية (86± 2 درجة فهرنهايت) و على تردد التحميل 10 هرتز . طبقت تجربة التقادم ذو المدى الطويل تصميم مضروب كامل ؛كذلك؛مع ثلاثة محتويات الأسفلت ، واثنين من فترات التقادم، واثنين من محتويات الفراغات الهوائيــة و ثلاث درجــات حرارة للفحص ليصبــح المجموع الاسمي للاختبارات المنفذة 36فحص .مع الاخذ بنظر الاعتبار خصائص المواد المحلية، ومستوى الإجهاد و الآثار البيئية لهذا الجانب. تم الاستنتاج من خلال فحص الانفعال المحكم بأن زيادة فترة الاكسدة تنتج نقصان في عمر تشققات الكلل ونقصان متانة الخلطة الاسفلتية وزيادة درجات الحرارة الفحص ضمن حدود الدرجات الفحص تنتج زيادة عمر تشققات الكلل ونقصان متانة الخلطة الاسفلتية. أخيرا ، يتم عرض مجموعة من التوصيات لتعزيز أداء شقوق الكلل في للتبليط او الرصف العراقي بما في ذلك تغييرات على إجراءات ضمان جودة البناء الحالية.

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 fatigue resistance of asphalt mixes is generally defined as their ability to respond to repeated traffic loading under the prevailing environmental conditions without significant cracking or premature failure being induced. Damage in asphalt pavements due to repetitive stresses and strains caused by both traffic loading and environmental factors can manifest itself as fatigue cracking which is considered as a primary distress mechanism in asphalt pavements (Baburamani, 1999). This means that a good prediction of a pavement's fatigue life will help develop and improve pavement design procedures. Fatigue resistance and stiffness are two required parameters for pavement design necessary to dimension the pavement structure (layer thickness).

The mechanism of fatigue can be divided into two parts: the first one is the occurrence of tensile stress/strain in the bottom of asphalt layer; the second one is the repetitive occurrence of such tensile stress/strain under traffic repetitions. The repetition of the tensile stress/strain causes the accumulation of micro damage in the bottom of the base layer that, over time, results in the break between the aggregate and the binder, thus generating more or less deep cracks. In other words, if a beam is subjected to load, the beam would tend to assume a convex downward shape, with tensile stress/strain in the bottom part and compressive stress/strain in the top one. Since the asphalt pavement has viscoelastic behaviour, it recovers when the load is removed. At the end of the first cycle, there is part of the strain that is recovered and a small part that is permanent. Under the next load, the pavement undergoes the same cycle. Ultimately the pavement will fail due to damage accumulation (Rajib et al., 2009).

Generally, the micro cracking originates at the bottom of an asphalt concrete layer caused by horizontal tensile strain; this compromises the contact between the aggregate skeleton and the binder (particle-to-particle contacts).

Furthermore, the water trapped in the cracks and the repeated loading leads to a decrease in the strength of the mixtures and micro cracking starting to propagate towards the layers above and leading to pavement collapse. This phenomenon is called Bottom-Up Cracking (Thom, 2008).

The purpose of this paper is to present and review the performance of fatigue cracking and develop fatigue life prediction models though using Nottingham Flexural Fatigue 4-point Bending test, to accomplish these objectives; the program has included: (1) testing of beams obtained from slabs prepared in the laboratory by rolling wheel compaction, laboratory - mixed, laboratory

compacted specimens; and (2) testing of beams (sawed from slabs) from the test sections, referred to as field-mixed, field compacted specimens

According to European standards, fatigue can be evaluated by means of bending tests or direct and indirect tests. This paper focuses on 4-Point Bending (4PB) test according to American Specifications (AASHTO – T321) for determining the fatigue life of compacted hot- mix asphalt subjected to repeated flexural bending, whereas a sinusoidal loading is applied to the specimen, and specimen of (380 mm length by 63 mm width and 50 mm height) is placed among four clamps and the fracture happens in the middle part of the beam characterized by a constant maximum value of bending moment as shown in Figure (1).

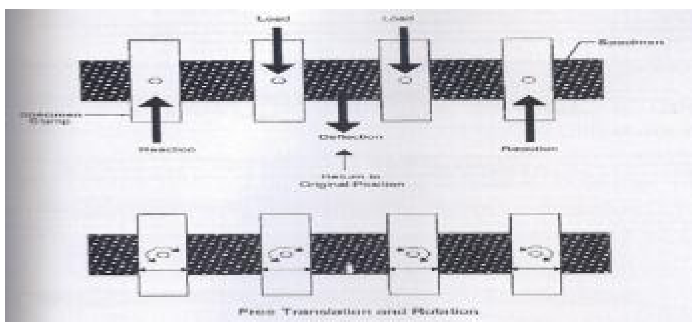

Figure (1): Load and Freedom Characteristics of Fatigue Test Apparatus, AASHTO T-321, (2010)

Four -Point Bending Test (4PB)

The 4 Point Bending test is the most used fatigue test in the world. The test was performed for the experimental work with requirement specified in AASHTO T-321 standard in the National Center for Construction Laboratories and Research NCCLR, as shown in Figure (2).

Prismatic beams were manufactured with dimensions of 380 mm in length, 50 mm in height and 63 mm in width. The specimen was restrained at four points by means of four clamps: the two outside remains static (they can only shift horizontally), the centrals deflect according to the strain applied. The test system included a close-loop, computer controlled loading component which during each load cycle in response to commands from the data processing and control component, adjusts and applies a load such that the specimen experiences a constant level of strain during each load cycle.

The loading device is capable of providing repeated sinusoidal loading at a frequency range of 5 to 10 Hz and subject specimens to 4-points bending with free rotation and horizontal translation at all load and reaction points. The deformation of the specimen was measured at the bottom between the two central clamps. This test simulates very well a pavement fatigue failure under traffic loading because repeated loading causes tension in the bottom zone of the specimen, cracking will initiate and after propagates to the top zone until failure; failure usually occurs in the area of uniform bending moment between the two inner clamps, as shown in Figure (3).

In the 4 point bending test, initial stiffness was chosen at the 50 load application. Conventionally, fatigue failure point is the moment of load cycle at which the specimen exhibits a 50 percent reduction in stiffness relative to the initial value of stiffness, (AASHTO T-321, Di Benedetto et al., 2004, and Shen and Carpenter, 2007).

Figure (2): Beam Fatigue Testing Machine at NCCLR

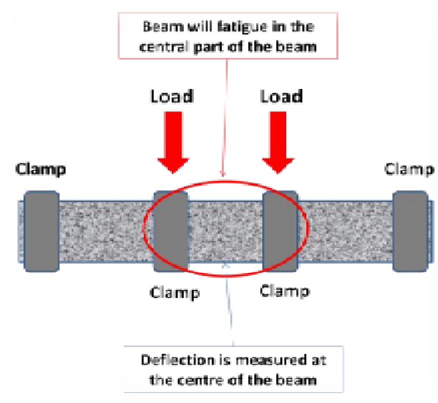

Figure (3): Configuration of 4-point Bending Test.

Many researchers have investigated the fatigue characteristics of asphalt mixtures using the dissipated energy concept. Pronk and Hopman (1991) suggested that the dissipated energy per cycle or period was responsible for the fatigue damage in the asphalt mixtures. Tayebali et al. (1992) introduced two terms (stiffness ratio and dissipated energy ratio) and found a unique relationship between the stiffness ratio and the dissipated energy ratio, but not necessarily between cumulative dissipated energy and fatigue life. Baburamani and Porter (1996) showed a strong correlation between initial dissipated energy and fatigue life of asphalt mixtures.

More recent studies suggested that more consistent results can be achieved through the ratio of dissipated energy change (RDEC) (Carpenter et al., 2003; Shen and Carpenter, 2007; Shu et al., 2008). This concept was first introduced by Carpenter and Jansen (1997), who suggested using the change in dissipated energy to characterize the damage accumulation and fatigue life. The change in dissipated energy represents the total effect of fatigue damage without the necessity of considering material type and loading modes. The application and study of cumulative dissipated energy was calculated according to AASHTO T- 321.

Laboratory Testing
Material

To meet the objectives of this research, available local materials were used including asphalt binder, aggregates and mineral filler. Asphalt binders (40-50 or PG 64-16) was obtained from Al-Daurah refinery in Baghdad and the aggregate from Al-Nibaie quarry in north of Baghdad whereas the mineral filler was brought from lime factory in Karbala. The aggregates are sieved and recombined in the proper proportions to meet the wearing course gradation as required by SCRB specifications (2003). A 19 mm aggregate maximum size gradation is used in this research. The fractions of aggregate are separated into 9 sizes, as retained on each of the following sieves, 3/4", 1/2", 3/8", No.4, No.8, No.16, No.30, No.50, and No. 200) using dry sieve analysis. Mineral filler (Limestone) has been added according to the desired gradations requirements. The gradation curve for the aggregate is shown in Figure (4); four lines are presented: the upper , the lower curves of the Iraqi specifications of SCRB in addition to the controls points of Superpave system, as shown in Table (1).

In this research, the Superpave mix design system was adopted with varying volumetric composition. The Superpave Gyratory Compactor was used at the NCCLR lab. to prepare 14 asphalt concrete cylindrical specimens of (150 mm diameter × 132 mm height) for carrying out volumetric design according to Superpave system (AASHTO Designation: T 312-2010). The optimum asphalt content was 5.0% for the selected gradation and asphalt binder shown in Table (1).

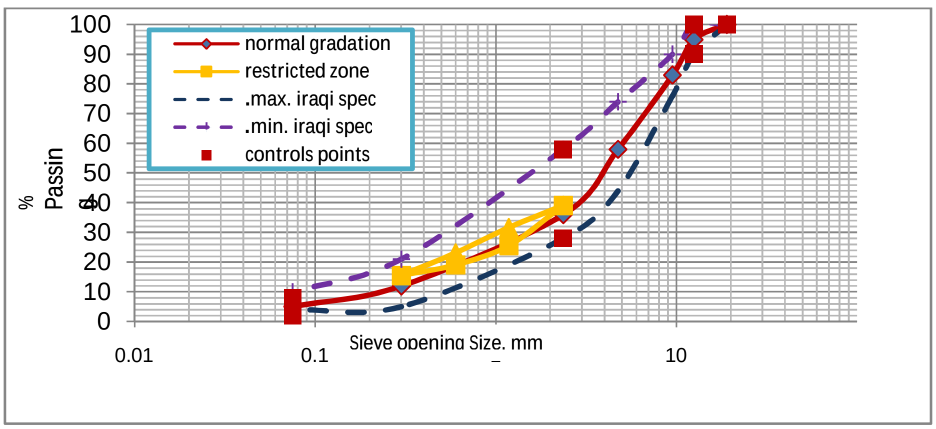

Figure (4): Selected Gradation for Used Aggregate

Sample Preparation

The dimensions of the beam specimen used were 50±6 mm high, 63±6 mm wide and 380±6 mm long according to AASHTO T 321, (2007). The bulk density was determined for every specimen according to AASHTO T166, (2010). The aggregate and asphalt were mixed in mixing bowl for three to ten minutes until asphalt sufficiently coated the surface of the aggregates to the mixing temperatures corresponding to the asphalt binder, as shown in (Figure 5). The asphalt-aggregate mixture was then subjected to short term oven aging for 4 hrs at temperature of 5° C according to AASHTO PP-2. 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 (Asphalt Institute, 2007), then the asphalt concrete mix was casted as a beam. Tests were conducted at optimum asphalt content and at asphalt contents of 0.5 percent above, and 0.5 percent below optimum. In this research, specimens for flexural fatigue testing were prepared using Roller Compactor Device at NCCRL according to EN12697-33 (2005), because this method of compaction simulates field compaction in a progressive way, as shown in Figure (6). A slab sample of (400 mm by 300 mm by 50±6 mm) was prepared with a static load of (5-10 kN) and variable number of passes depending on the asphalt content in the mix and degree of compaction (air voids ratio) by trial and error method, Figure (7). After compaction, the slabs were cut into fatigue beams using a wet saw. Fatigue beam dimensions were 380 mm length, 63 mm width, and 50 mm height (15 in., 2.5 in., and 2.0 in., respectively) using diamond cutter , and saw at least 6 mm from both sides of each test specimen to provide smooth, parallel surfaces for mounting the measurement gages as shown in (Figure 8) . The total number of specimens was (36 beams).

Repeated Flexural Beam Fatigue Testing

The standard beam fatigue procedure is found in (AASHTO T- 321) "Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending". This test was conducted at NCCLR laboratories (as shown in Fig. 9). The flexural fatigue test was performed by placing a beam of hot mix asphalt (HMA) in repetitive four points loading at a specified strain level. During the test, the beam is held in place by four clamps and a repeated haversine (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 deflection caused by the loading is measured at the center of the beam. The number of loading cycles to failure can then give an estimate of a particular HMA mixture's fatigue life. Another important value that can be obtained from the beam fatigue test is the dissipated energy of the specimen. Dissipated energy is a measure of the energy that is lost to the material or altered through mechanical work, heat generation, or damage to the sample as shown in equation (5).

Beam specimens were tested in repeated flexure in the controlled-strain mode of loading at a frequency of 10 Hz. While the majority of the tests were performed at 10°C, 20°C and 30°C to define the influence of temperature on fatigue behavior and because fatigue cracking is thought to be a primary HMA distress at these intermediate temperatures. At higher in - service temperatures (above about 38°C (100°F)) rutting is usually the HMA distress of greatest concern, while at lower temperatures (below about 4°C (40 °F)) thermal cracking is usually the HMA distress of greatest concern.

A strain level of approximately 300 microstrains was used such that the specimen underwent minimum of 10,000 load cycles. During each load cycle, beam deflections were measured at the center of the beam to calculate maximum tensile stress, maximum tensile strain, phase angle, stiffness, dissipated energy, and cumulative dissipated energy. The data were recorded automatically by a data acquisition system, as shown in Figure (10).

Failure is assumed to occur when the stiffness reaches half of its initial value, taken at the 50th cycle. The initial stiffness is determined from the load at approximately 50 repetitions; the test is terminated manually when this load has diminished by 50 percent. Maximum stress, strain, and stiffness are determined as follows, (AASHTO, T 321):

$$\sigma_t = \frac{0.357\,P}{bh^2} \qquad \text{... (1)}$$

Where:

σ_t: Maximum tensile stress (Pa),
P: load applied by actuator, N
b: average specimen width, in meters; and
h: average specimen height, in meters.

Figure (5): Mixing of asphalt binder and aggregate

Figure (6): Slab preparation in Roller Compactor machine

Figure (7): Slab under compaction effort

Figure (8): Beam fatigue test (specimen after test)

Figure (9): Beam fatigue Test: testing device

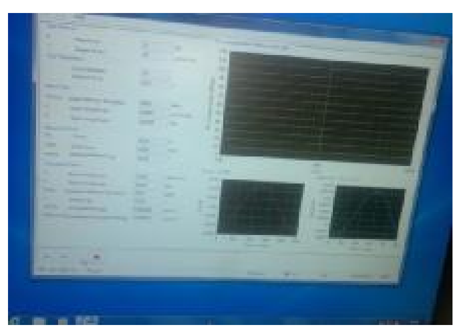

Figure (10): Raw data from the test

$$\in_t = \frac{12\delta h}{(3L^2 - 4a^2)} \quad \ldots(2)$$

Where:

$\in_t$: Maximum tensile strain (m/m),

δ : Maximum deflection at center of beam, in meters

a: space between inside clamps, 0.357/3 m, (0.119 m); and

L: Length of beam between outside clamps, 0.357 m.

$$Flexural\ Stiffness\ (S) = \frac{\sigma_t}{\epsilon_t} \quad \ldots(3)$$

Where:

S: $Flexural\ Stiffness\ , in\ (Pa)$

$$Phase\ angle\ (j) = 360fs \quad \ldots.(4)$$

Where:

J: Phase angle in (deg.)

f: load frequency, in Hz; and

s: time lag between $P_{max.}$ and σ_{max}

$$Dissipated\ Energy\ (D) = \pi\sigma_t \in_{t^2} \sin(j) \quad \ldots(5)$$

Where:

D: Dissipated energy in (j/m^3) per cycle

$$Cumulative\ Dissipated\ Energy\ , \left(\frac{J}{m^3}\right): \sum_{i=1}^{i=n} D_i \quad \ldots.(6)$$

Where:

D_i: D for the i^{th} load cycle.

$$Initial\ \ Stiffness\ (A): S = A\ e^{bn} \quad ..(7)$$

Where:

A: initial stiffness in (Pa), a constant from plotting stiffness (S) against load cycles (n) and best – fitting the data.

e: natural logarithm to the base e,

b: constant.

$$Cycles\ to\ failure\ \left(n_{f.50}\right) = \frac{\ln(S_{f.50})/A}{b} \quad \ldots.(8)$$

Where:

S_{f50}: stiffness, 50 percent of initial stiffness, in Pa; and

$S_{\ f50/A}$: 0.5, by definition.

$$Cumulative\ Dissipated\ Energy\ to\ Failure\ ,\left(\frac{J}{m^3}\right):\ \sum_{i=1}^{i=N_{f.50}} D_i \qquad ....(9)$$

Results and Analysis

Fatigue life and stiffness were measured at strain level of 300 με, and frequency level 10 Hz, and three test temperatures of 10 °C, 20 °C and 30 °C and two air voids contents are used. Tables (2) and (3) show the result of flexural fatigue test, the data include fatigue life (N_f), flexural Stiffness (Pa), Cumulative dissipated energy (j/m^3) for each specimen and test condition.

In this study, the commonly used 50% stiffness reduction method was adopted to determine the fatigue life of an asphalt mixture. This method defines the fatigue life of an asphalt mixture as the number of loading cycles when the stiffness decreases to 50% of its initial value measured at the 50th load cycle, (AASHTO, T-321).

Stiffness Approach

In this study, results are plotted on a graph displaying number of 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 (11). In phase I, a rapid decreases in stiffness can be observed, followed by Phase II, which corresponds to a linear decrease in stiffness. In Phase III, fracture cracking occurs as a result of the damage acceleration of micro cracks ultimately turn to observable macro cracks, which cause the failure of the specimen, as shown in Figure (12).

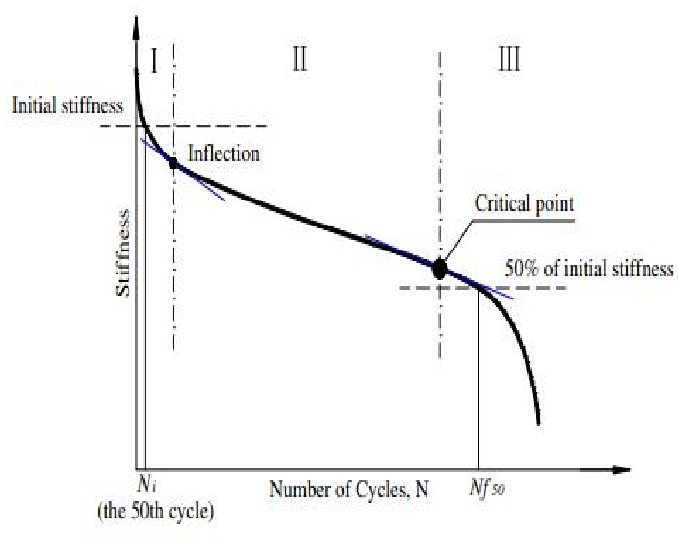

Figure (11): Typical stiffness versus loading cycle plot in Fatigue test, Baburamani, P., (1999)

Dissipated Energy Approach

With the stress and strain measurements, a hysteresis loop can be constructed for an asphalt mixture subjected to fatigue testing . The area of a hysteresis loop represents the energy absorbed by the mixture. During the fatigue test, the change of the area of hysteresis loops indicates that part of the energy in the system has been dissipated, and some plastic strain or damage has occurred to the asphalt mixture. As loading cycles increase and cracks initiate and propagate, the dissipated energy changes continuously throughout the fatigue process as shown in Figure (13). Therefore, the concept of dissipated energy (D) generated by an external work can be used as a direct and visualized way to describe the development of damage in asphalt mixtures. Dissipated energy per cycle can be calculated by equation (5).

Effect of Aging

In this study the long - term aging experiment investigated mixes with three asphalt contents ranging from 4.5 to 5.5 percent and air-void contents 4 to 7 percent. Each mix was subjected to long-term oven aging 6 days duration and tested at nominal strain level 300 microstrains. Average test results are summarized in Table (3) and Figures (14) to (17). These figures show that the basic effects of asphalt contents, air void contents and temperatures on laboratory fatigue life and initial stiffness by short and long-term aging. Clearly, fatigue test showed the effect of aging on stiffness, fatigue life and dissipated energy (D). The analysis of the figures show that stiffness and fatigue life after impact of long term aging decreases by 63.7 % and 36.9% respectively compared with short time aging (at 300 $\mu\varepsilon$, and selected binder asphalt).

Effect of Air Voids

Air voids is an important parameter which has a pivot role of the performance of asphalt pavement. Flexural stiffness of asphalt mixture at two levels of air voids is evaluated: (a) 4% air voids level and (b) 7% air voids level with PG (64-16) and temperatures of 10º C, 20º C and 30º C. The results are shown in Figures (18) and (19).

It is found that increasing of air voids from 4% to 7% will decrease stiffness and fatigue life (Nf) by 25 % and 69% respectively, and increase dissipated energy (D) by 5% while cumulative dissipated energy has decreased by 69% for asphalt (300$\mu\varepsilon$ and selected asphalt binder), that is may be due to the lack of bond between asphalt and aggregates, moreover smaller air-void content has an effects that contribute to longer fatigue life because air transmits little or no stress, so replacing some of its volume with asphalt and aggregate reduces the stress level in these components. In addition to a smaller air-void content creates a more homogenous asphalt-aggregate structure with uniformly distributed voids which results in less stress concentration at critical solid-air interfaces.

Effect of Asphalt content

Asphalt binder content is an essential component of asphaltic mixtures. The effect of asphalt content on fatigue life and stiffness were evaluated; as shown in Figures (20) and (21) for three different of asphalt content. It is observed that a change of asphalt content from 4.5 to 5.0 % causes 61 % and 28% increase in flexural stiffness and Fatigue life respectively , while a change of asphalt content from 5.0 % to 5.5 % causes 58 % and 20% increase in flexural stiffness and fatigue life respectively, as shown in Table (3). Also it is noted that the dissipated energy decrease as asphalt content increase. It is considered that increased asphalt content means increased thickness of the binder film between aggregate particles and an increased proportion of asphalt over a cross-section normal to the direction of tensile stress and the binder is much more compliant than the stiffer aggregate particles so bending strains are concentrated in the asphalt binder, so thicker films result in smaller binder strain if the overall mixture strain is not altered by the added asphalt. More asphalt means more asphalt area in cross-section and, hence, less stress in the asphalt because tensile stresses must ultimately be transferred through the asphalt, but the dissipated energy began to increase at high asphalt content when microstrains level is constant.

Effect of Temperature

Asphalt is a viscoelastic material; temperature has an important effect on its stiffness properties. The fatigue damage, or cracking of an asphalt pavement caused by traffic loads is influenced by the stiffness properties of the mix. As shown in Figures (22) and (23), the initial stiffness is affected by temperature variation. The stiffness at 30°C is less than the stiffness at 20°C. It is clear that the temperature effect significantly affects not only the initial stiffness but also on the fatigue life (N_f). The 10°C curve has a sharper inclination than do other temperatures, the 30°C curve has the flattest slope, and the test at 30°C seems to introduce much temperature variation.

An increase in temperature generally from 10°C to 20° C and from 20°C to 30°C result an increase in fatigue life per 28.9% and 17.9 % respectively for constant binder type and strain level. Temperature is highly positive-correlated with phase angle and accumulative dissipated energy through an increase in temperature generally results in an increase in phase angle and accumulative dissipated energy per binder type and strain level. Finally, An increase in temperature from 10°C to 20° C and from 20°C to 30°C result an decrease in flexural stiffness per 44.4% and 35.7 % respectively. In summarizing the bending beam fatigue test results, it was found that the aging effect on the stiffness and the compaction level effect on the fatigue life are two effects that are more prominent than those caused by the other material variables. The test results are shown in Table (3); the effect of various variables on either the stiffness or the fatigue life is presented.

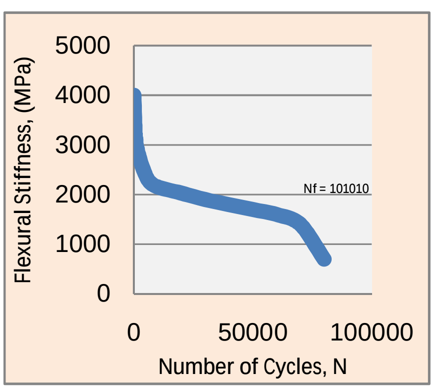

Figure (12): Stiffness evolution during a fatigue test

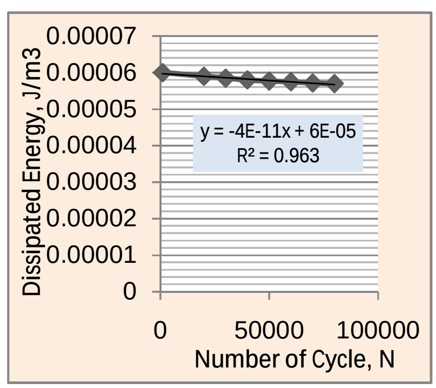

Figure (13): Dissipated energy versus number of cycle during a fatigue test

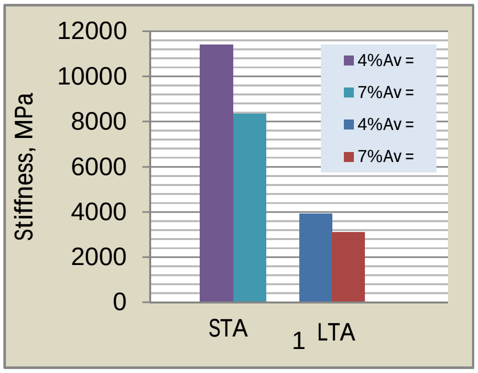

Figure (14): Stiffness results of STA & LTA fatigue test for different air voids

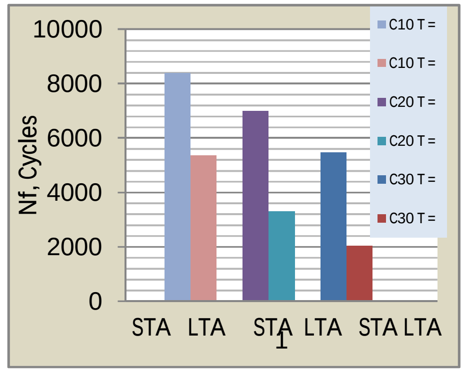

Figure (15): Nf results of STA & LTA fatigue test for different test temperature

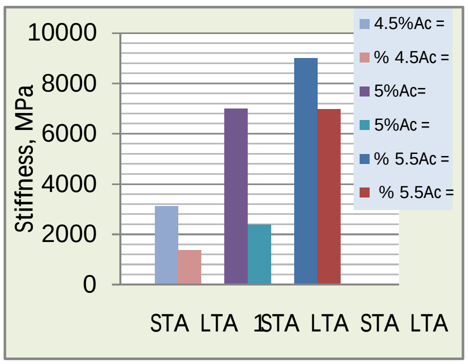

Figure (16): Stiffness results of STA & LTA fatigue test for different asphalt content

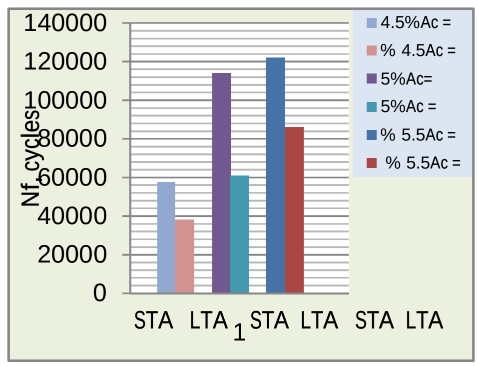

Figure (17): Nf results of STA & LTA fatigue test for different asphalt content

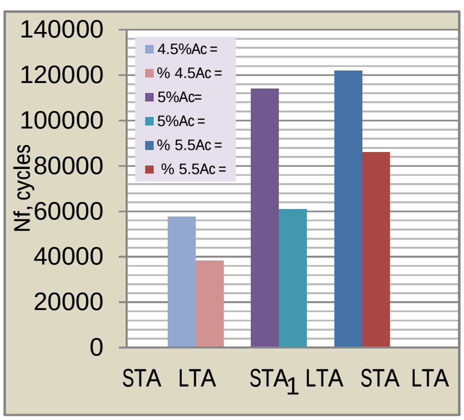

Figure (18): Effect of air voids on fatigue life for different mixtures

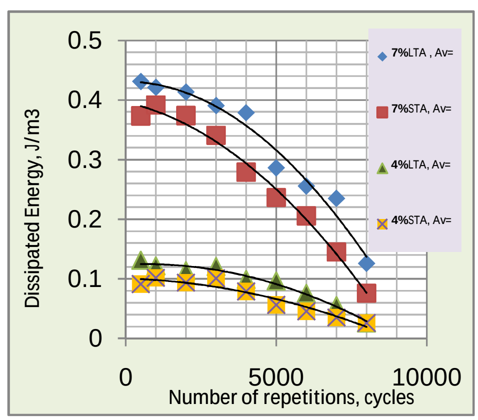

Figure (19): Effect of air voids on dissipated energy for different mixtures

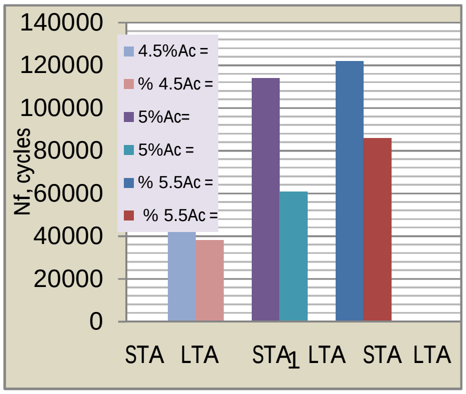

Figure (20): Effect of asphalt contents on fatigue life for different mixtures

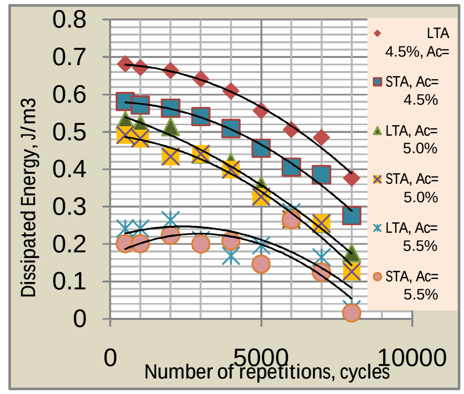

Figure (21): Effect of asphalt contents on dissipated energy for different mixtures

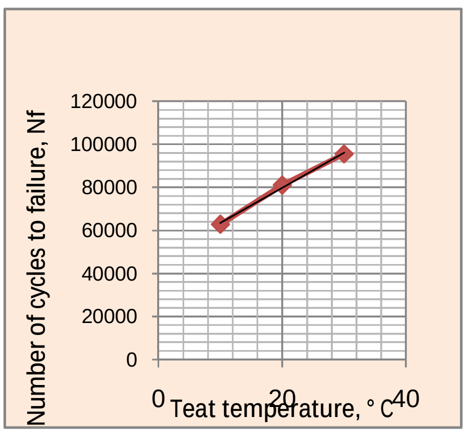

Figure (22): Effect of Temperature on fatigue life for different mixtures

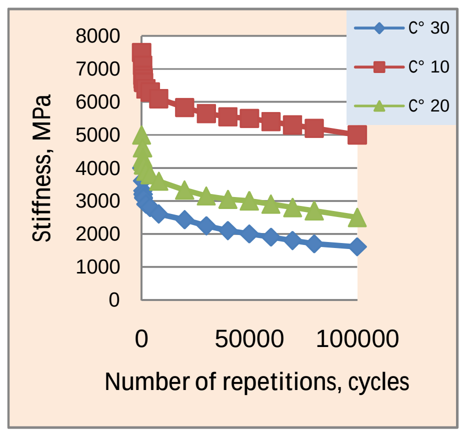

Figure (23): Effect of temperature on flexural Stiffness for different mixtures

Conclusions and Recommendations:

Conclusions based on the data and analyses presented herein are as follows:

1. Based on fatigue bending beam test results, and for strain- controlled testing, an increase in asphalt content within the range tested results in an increase in laboratory fatigue life and mix stiffness.

2. For strain- controlled testing, an increase in air-void content within the range tested results in a decrease in laboratory fatigue life and a decrease in mix stiffness.

An important consideration in mix design is construction control. With respect to fatigue performance, the data presented herein indicate that accurate control of air-void content is more important than accurate control of asphalt content.

3. For strain –controlled testing, an increase in term aging results in a decrease in laboratory fatigue life and a decrease in mix stiffness.
4. For strain - controlled testing, an increase in test temperatures within the range tested results in an increase in laboratory fatigue life and a decrease in mix stiffness.

Recommendations:

More research is needed to further explore the importance of other factors in pavement design. It is recommended to investigate the possibility of predicting fatigue performance from simple tests such as indirect tensile test. This may provide a rapid determination of fatigue coefficients for design purposes. Furthermore, it is recommended to investigate more the effect of mixture properties and test pa rameters on pavement performance, which in turn it may provide a relation between the fatigue coefficients and mixture properties.

Acknowledgements

The authors would like to acknowledge the National Centre for Construction Laboratories and Researches (NCCLR) in Iraq for their support during the preparation of this research.

Table (1): Percent Passing by Weight of Selected Aggregate Gradation (12.5 mm Nominal Maximum Size, Wearing Course)

Sieve size		Gradation passing, %	Iraqi specifications SCRP, R9, 2004 wearing course		Superpave specifications, 2007			
Standard sieves (mm)	English sieves		Min.	Max.	Restricted zone		Control points	
19	3/4"	100	100	100	-	-	100	100
12.5	1/2"	95	90	100	-	-	90	100
9.5	3/8"	87	76	90	-	-	-	-
4.75	# 4	57	44	74	-	-	-	-
2.36	# 8	34	28	58	39.1	39.1	28	58
1.18	# 16	23	-	-	25.6	31.6	-	-
0.6	# 30	15	-	-	19.1	23.1	-	-
0.3	# 50	10	5	21	15.5	15.5	-	-
0.075	# 200	5	4	10	-	-	2	8

Table (2): Test Results of Repeated Flexural Beam Fatigue Testing continued

Sample No.	Air voids	Asphalt content	Aging	Test Temp.	Load Applied	Tensile Stress	Tensile Strain	Flexural Stiffness	Cumulative Dissipated Energy	Fatigue life
	%	%	Days	°C	N	Pa	m/m	Pa	J/m3	N_f
1	4	4.5	STA	10	600	1360000	0.000261	5.199E+09	72334.22	
2	4	4.5	STA	20	544	1233066.6	0.00037686	3.272E+09	95341.52	95340
3	4	4.5	STA	30	423	958800	0.00047107	2.035E+09	101011.66	101010
4	4	4.5	LTA	10	456	1033600	0.00046686	2.214E+09	38401.55	38400
5	4	4.5	LTA	20	375	850000	0.00052476	1.62E+09	63901.69	63900
6	4	4.5	LTA	30	225	510000	0.00061739	826058333	77701.60	77700
7	4	5	STA	10	1127	2554533.3	0.00016211	1.576E+10	148201.16	148200
8	4	5	STA	20	1067	2418533.3	0.00024422	9.903E+09	180541.43	180540
9	4	5	STA	30	867	1965200	0.00035422	5.548E+09	193591.77	193590
10	4	5	LTA	10	743	1684133.3	0.00041949	4.015E+09	64501.72	64500
11	4	5	LTA	20	534	1210400	0.00052476	2.307E+09	91291.99	91290
12	4	5	LTA	30	378	856800	0.00055634	1.54E+09	127051.83	127050
13	4	5.5	STA	10	1243	2817466.6	8.1582E-05	3.454E+10	163501.04	163500
14	4	5.5	STA	20	1067	2418533.3	0.00016053	1.507E+10	182401.18	182400
15	4	5.5	STA	30	957	2169200	0.00020316	1.068E+10	212551.28	212550
16	4	5.5	LTA	10	965	2187333.3	0.0001858	1.177E+10	96901.18	96900
17	4	5.5	LTA	20	786	1781600	0.00024948	7.141E+09	134551.33	134550
18	4	5.5	LTA	30	567	1285200	0.00027896	4.607E+09	165301.31	165300
19	7	4.5	STA	10	530	1201333.3	0.00029843	4.025E+09	20101.26	20100
20	7	4.5	STA	20	474	1074400	0.0004137	2.597E+09	27091.54	27090
21	7	4.5	STA	30	353	800133.33	0.00050791	1.575E+09	29891.64	29890
22	7	4.5	LTA	10	386	874933.33	0.0005037	1.737E+09	8841.546	8840
23	7	4.5	LTA	20	305	691333.33	0.0005616	1.231E+09	17341.65	17340
24	7	4.5	LTA	30	155	351333.33	0.00065423	537015450	22541.47	22540
25	7	5	STA	10	1057	2395866.6	0.00019895	1.204E+10	45211.23	45210
26	7	5	STA	20	997	2259866.6	0.00028106	8.04E+09	56431.5337	56430
27	7	5	STA	30	797	1806533.3	0.00039107	4.62E+09	60231.86	60230
28	7	5	LTA	10	673	1525466.6	0.00045633	3.343E+09	17531.78	17530
29	7	5	LTA	20	464	1051733.3	0.0005616	1.873E+09	26401.99	26400
30	7	5	LTA	30	308	698133.33	0.00059318	1.177E+09	38761.77	38760
31	7	5.5	STA	10	1173	2658800	0.00011843	2.245E+10	50421.09	50420
32	7	5.5	STA	20	997	2259866.6	0.00019738	1.145E+10	56741.26	56740
33	7	5.5	STA	30	887	2010533.3	0.00024001	8.377E+09	66871.36	66870
34	7	5.5	LTA	10	895	2028666.6	0.00022264	9.112E+09	28301.24	28300
35	7	5.5	LTA	20	716	1622933.3	0.00028633	5.668E+09	40411.39	40410
36	7	5.5	LTA	30	497	1126533.3	0.0003158	3.567E+09	51231.35	51230

Table (3): Influence of Temperature, Binder content, Aging and Air voids (degree of compaction)

Variable	Effect of Aging	Effect of Air Voids Content	Effect of Asphalt Content		Effect of Temperature	
	STA to LTA (%)	4.0 to 7.0 (%)	4.5 to 5.0 (%)	5.0 to 5.5 (%)	10º to 20 ºC	20º to 30 ºC
Flexural Stiffness, MPa	-63.7	-25	61	58	-44.4	-35.7
Dissipated Energy , J/m3	47.04	5.4	-26	-62	61	59
Cumulative Dissipated Energy , J/m3	-36.9	-69	28	20	28.9	17.9
Fatigue Life (Cycles to Failure), Nf	-36.9	-69	28	20	28.9	17.9

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