Properties of Superpave Asphalt Concrete Subjected to Impact of Moisture Damage

Saad Issa Sarsam
Professor of transportation Engineering
College of engineering, Dept. of Civil Eng.
University of Baghdad
E-mail: saadisasarsam@coeng.uobaghdad.edu.iq

Ali Hussein Alwan
MSc. student
College of engineering, Dept. of Civil Eng.
University of Baghdad
E-mail: ali_h.alwan@yahoo.com

ABSTRACT

Moisture damage is a primary mode of distress occurring in hot mix asphalt (HMA) pavements in Iraq. Because of the loss of bond, or stripping, caused by the presence of moisture between the asphalt and aggregate, which is a problem in some areas and can be severe in some cases, it is requires to evaluate the design asphalt mixture to moisture susceptibility. Many factors such as aggregate characteristics, asphalt characteristics, environment, traffic, construction practices and drainage can contribute to stripping. Asphalt concrete mixes were prepared at their optimum asphalt content by superpave system and then tested to evaluate their engineering properties, which include tensile strength, resilient modulus, and permanent deformation, stiffness, and fatigue characteristics. These properties have been evaluated using indirect tensile strength, uniaxial repeated loading and repeated flexural beam. The experimental results, in general, showed that the mixes subjected to moisture damage give low resistance to indirect tensile strength, low resilient modulus at 40˚C, high permanent deformation at 40˚C, low stiffness, and low fatigue life, by (19%, 21%, 93%, 62% and 70%) respectively as compared with unconditioned mixture.

Key words: Asphalt concrete, Moisture Damage, Superpave System

خصائص الخرسانة الاسفلتية فائقة الاداء المعرضة لتأثير الضرر بالرطوبة

سعد عيسى سرسم
أستاذ
قسم الهندسة المدنية، كلية الهندسة، جامعة بغداد

علي حسين علوان
طالب ماجستير
قسم الهندسة المدنية، كلية الهندسة، جامعة بغداد

الخلاصة

الضرر بالرطوبة هو اسلوب رئيسي لحدوث الفشل في التبليط بالخلطة الساخنة الاسفلتية في العراق بسبب خسارة الربط، أو التقشر، والناتجة عن وجود الرطوبة بين الأسفلت والركام، والتي هي مشكلة في بعض المناطق ويمكن أن تكون شديدة في بعض الحالات، فانه من المطلوب تقييم الخلطة الاسفلتية المصممة الى حساسية الرطوبة. أن العديد من العوامل مثل خصائص الركام، وخصائص الأسفلت، والبيئة، والحجم المرور، وطريقه التنفيذ والصرف يمكن ان تساهم في التقشر. تم إعداد خلطات الخرسانة الإسفلتية في نسبة الاسفلت المثلى باستخدام النظام فائق الاداء ومن ثم اختبارها لتقييم الخواص الهندسية الخاصة والتي تشمل قوة الشد، ومعامل المرونة الحركي، تشوه دائم، والصلادة، وخصائص الكلال. وقد تم تقييم هذه الخصائص باستخدام قوة الشد غير المباشرة، الحمل احادي المحور المتكرر وكذلك فحص انحناء الكسر المتكرر. النتائج المختبرية وبشكل عام، أظهرت أن الخلطة المعرضة للضرر بالرطوبة تعطي مقاومة منخفضة لقوة الشد غير المباشرة، ومعامل مرونة حركي منخفض عند 40 درجة مئوية وتشوه دائم عالي في 40 درجة مئوية، صلادة منخفضة، عمر كلال منخفض، بمقدار (19٪، 21٪، 93٪، 62٪ و70٪) على التوالي مقارنة مع خليط غير معرض للرطوبة.

الكلمات الرئيسية: خرسانة اسفلتية، الضرر بالرطوبة، النظام فائق الاداء

1. INTRODUCTION

The asphalt paving mixture is normally subjected to various detrimental types of distresses during its service life. Moisture damage is the loss of strength and durability in asphalt mixtures due to the effect of water or moisture vapor. It tends to accelerate the presence of the distress types. **Alwan, 2013**.The types of distress that can be related to moisture or the other factors are bleeding, cracking, rutting, and raveling. In view of this , the primary objective of this study is to evaluate the mechanical properties of asphalt concrete mixtures after it was subjected to the impact of moisture damage based on the following tests, Indirect tensile test (Moisture susceptibility) , uniaxial repeated load test (Resilient Modulus and permanent deformation) and repeated flexural beam test (fatigue characteristics).

2. BACKGROUND

2.1 Mechanisms of Moisture Damage

It is generally agreed that moisture can degrade the integrity of bituminous mixtures in two ways:

- By causing a reduction in the cohesive strength and stiffness of the mixture, characterized by the softening of the mixture.
- By causing failure of the adhesion (or bond) between bitumen and aggregate, referred to as stripping, **Terrel and shute, 1989.**

The following are some of the major moisture damage mechanisms that cause stripping, **Kennedy, 1985:**

1- Pore pressure of water in the mixture voids due to wheel-loading repetitions, thermal expansion-construction differences produced by ice formation, temperature cycling above freezing, freeze-thaw, and chemical shock, or a combination of these factors,
2- Asphalt removal by water, in the mixture at moderate to higher temperatures,
3- Water-vapor interaction with the asphalt filler mastic and larger aggregate interfaces.

2.2 Consequences of Moisture Damage

Damage due to moisture occurs in various forms and degrees of severity. The primary consequence of moisture damage is that of stripping, characterized by failure of the bitumen-aggregate bond. Stripping is often initially manifested in localized areas where the bitumen has integrated to the surface of the bituminous layer, referred to as flushing or bleeding. This migration of bitumen results in an unstable matrix in the lower portions of the bituminous layer which can lead to permanent deformation in the form of rutting and/or shoving as well as the development of potholes and cracking under the action of traffic loading, **Scholz, 1995**.

The other major consequence of moisture damage is that of a reduction of stiffness and strength in the bituminous layer, which decreases the load spreading capabilities of the pavement. Under the action of traffic loading, a pavement with reduced stiffness due to water damage is prone to rutting because of increased stresses and strains in the underlying layers. Loss of strength in the bitumen-aggregate matrix may also encourage stripping, **Kennedy, 1985**.

2.3 Water Sensitivity Tests

The moisture effect on physical properties and mechanical behavior of asphalt paving mixtures has been known for many years. Numerous empirical or semi-empirical test methods, such as the Lottman Laboratory Test, Tunnicliff and Root Test, Boiling Water Test, and Hamburg Wheel

Tracing Device, have been developed to predict moisture damage on asphalt mixtures. These test methods attempted to simulate the moisture damage that would occur in the field. **Sarsam, 2010**.

Lottman, 1982 describes the method, commonly referred to as the Lottman procedure; developed for the prediction of moisture damage in dense-graded bituminous mixtures. The method consists of nine specimens (4" diameter and 2 1/2" high) are compacted to expected field air void content. Specimens are divided into 3 groups of 3 specimens each. Group I is treated as control without any conditioning. Group 2 specimens are vacuum saturated (26 inches Hg) with water for 30 minutes. Group 3 specimens are vacuum saturated like Group 2 and then subjected to a freeze (0°F for 15 hours) and a thaw (140°F for 24 hours) cycle. All 9 specimens are tested for resilient modulus (Mr) and/or indirect tensile strength (ITS) at 55°F or 73°F. A loading rate of 0.065 inch/minute is used for the ITS test. Group 2 reflects field performance up to 4 years. Group 3 reflects field performance from 4 to 12 years. Retained tensile strength (TSR) is calculated for Group 2 and Group 3 specimens. A minimum TSR of 0.70 is recommended by **Lottman and Maupin, 1982,** who reported values between 0.70 and 0.75 differentiated between stripping and non-stripping HMA mixtures. It has been argued that the Lottman procedure is too severe because the warm water soak of the vacuum saturated and frozen specimen can develop internal water pressure. However, **Stuart 1986** and **Parker and Gharaybeh, 1987** generally found a good correlation between the laboratory and field results. Oregon has successfully used this test with modulus ratio in lieu of tensile strength ratio (TSR).

Tunnicliff and Root, 1984 report a method similar to the Lottman procedure. They proposed six specimens to be compacted to 6-8% air void content and divided into two groups of three specimens each. Group 1 was treated as control without any conditioning. Group 2 specimens are vacuum saturated (20 inches Hg for about 5 minutes) with water to attain a saturation level of 55 to 80 percent. Specimens saturated more than 80 percent are discarded. The saturated specimens are then soaked in water at 140°F for 24 hours. All specimens are tested for ITS at 77°F using a loading rate of 2 inches/minute. A minimum TSR of 0.7 to 0.8 is usually specified. Evidently, the use of a freeze-thaw cycle is not incorporated into **ASTM D4867-88**, which is based on this method. The freeze-thaw cycle is optional. The primary emphasis is on saturation of the specimen which for a short duration of about 24 hours has been reported to be insufficient to induce moisture related damage, **Coplantz and Newcomb 1988.**

AASHTO accepted the Modified Lottman Test **AASHTO T-283, 1985**. It is a combination of the Lottman and the Tunnicliff and Root Tests. Six specimens are produced with air voids between six percent and eight percent. The specimens are then split into two groups. The first group is the control group. The second group is saturated between 70 and 80 percent with water and is placed in the freezer (0°F or -18°C) for 16 to 18 hours. The frozen cores then are moved to a water bath at 140°F (60°C) for 24 hours. After conditioning, the resilient modulus test and/or the indirect tensile strength (ITS) tests are performed. The ITS test is performed at 77°F (25°C) with a loading rate of 2 in/min. The ratio of the average tensile strengths of the wet cores and the dry cores is known as the tensile strength ratio (TSR). The minimum acceptable TSR as per AASHTO is 70%, **Roberts et al. 1996.** Despite the recognized problems of AASHTO T 283, it was considered the best available method for evaluating the moisture sensitivity of asphalt concrete mixes. Since AASHTO T 283 was the recommended Superpave test, several researchers have investigated the parameters of this test method and compared it to the results of other methods.

3. MATERIAL CHARACTERAZATION

The materials used in this work, namely asphalt cement, aggregate, and fillers were characterized using routine type of tests and results were compared with superpave system.

3.1 Asphalt Cement

The asphalt cement used in this work is a 40-50 penetration grade. It was obtained from the Dora refinery, south-west of Baghdad. The asphalt properties are shown in **Table 1.**

3.2 Aggregate

The aggregate used in this work was crushed quartz obtained from Al-Nibaie quarry. This aggregate is widely used in Baghdad city for asphaltic mixes. The coarse and fine aggregates used in this work were sieved, and recombined in the proper proportions to meet the wearing course gradation as required by SP-2 specification. The gradation curve for the aggregate is shown in **Fig. 1**. Routine tests were performed on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the **SCRB, 2003** are summarized in **Table 2**.

3.3 Filler

Mineral filler used in this study is Portland cement obtained from Badoush factory; the physical properties are shown in **Table 3**.

4. EXPERIMENTAL WORK

The experimental work was started by determining the optimum asphalt content for the asphalt concrete mix using the Superpave mix design method. Asphalt concrete mixes were made at their optimum asphalt and tested to evaluate the engineering properties to mixture subjected to moisture damage which (Specimen is considered conditioned after it was subjected to vacuum saturation followed by a freeze cycle followed by a 24 hour thaw cycle, and accomplished by performing AASHTO T-283). These properties have been evaluated using indirect tensile strength, uniaxial repeated loading and repeated flexural beam tests.

4.1 Superpave Mix Design

Two specimens are prepared at the trial asphalt content. It was compacted using gyratory compaction, four asphalt binder contents, at ± 0.5 % of the estimated asphalt content, and at + 1.0 % of the estimated asphalt content. About 4.7 kilograms of the mix are used to prepare test specimens of 150 mm (5.9 in) in diameter and 115±5 mm (4.53±0.2 in) in height, and prepared accordance to method AASHTO TP4.

4.2 Indirect Tensile Test

The moisture susceptibility of the asphalt concrete mixtures was evaluated using AASHTO T-283. The result of this test is the indirect tensile strength (ITS) and tensile strength ratio (TSR). In this test, a set of specimens were prepared for each mix according to Superpave procedure and compacted to 7±1 % air voids. The set consists of six specimens and divided into two subsets, one set (unconditioned) was tested at 25°C and the other set (conditioned) was subjected to one cycle of freezing and thawing then tested at 25°C. The test shown in **Fig. 2** involved loading the specimens with compressive load at a rate of (50.8mm/min) acting parallel to and along the vertical diametrical plane through 0.5 in. wide steel strips which are curved at the interface with specimens. These specimens failed by splitting along the vertical diameter. The indirect tensile strength which is calculated according to **Eq 1** of the conditioned specimens (ITSc) is divided by the control specimens (ITSd), which gives the tensile strength ratio (TSR) as the following **Eq 2. Alwan, 2013.**

$$\text{ITS} = \frac{2P}{\pi D} \quad (1)$$

$$\text{TSR} = \frac{ITS\ (Conditioned)}{ITS\ (Unconditioned)} \quad (2)$$

Where:
ITS= Indirect tensile strength
P = Ultimate applied load
t = Thickness of specimen
D = Diameter of specimen
Other parameters are defined previously

4.3 Uniaxial repeated loading test

The uniaxial repeated loading tests were conducted for cylindrical specimens, 101.6 mm (4 inch) in diameter and 203.2 mm (8 inch) in height, using the pneumatic repeated load system shown below in **Fig. 3**. In these tests, repetitive compressive loading with a stress level of 20 psi was applied in the form of rectangular wave with a constant loading frequency of 1 Hz (0.1 sec. load duration and 0.9 sec. rest period) and the axial permanent deformation was measured under the different loading repetitions. All the uniaxial repeated loading tests were conducted at 40°C (104°F). The specimen preparation method for this test can be found elsewhere, **Albayati,, 2006**. The permanent strain (εp) is calculated by applying **Eq. 3**.

$$\text{Ep} = \frac{Pd}{h} x\ 10000 \quad (3)$$

Where
Ep = axial permanent microstrain
P d = axial permanent deformation
h= specimen height
Also, throughout this test the resilient deflection is measured at the load repetition of 50 to 100, and the resilient strain (εr) and resilient modulus (Mr) are calculated as follows:

$$\varepsilon\ \text{r} = \frac{rd}{h}\ 10000000 \quad (4)$$

$$\text{Mr} = \frac{\sigma}{\varepsilon\ \text{r}} \quad (5)$$

where
ε r = axial resilient microstrain

rd= axial resilient deflection (mm)
h= specimen height (mm)
Mr= Resilient modulus
σ = repeated axial stress (KPa)
εr= axial resilient strain (mm)

The permanent deformation test results for this study are represented by the linear log-log relationship between the number of load repetitions and the permanent microstrain with the form shown in **Eq.6** below which is originally suggested by **Monismith et. al., 1975** and **Barksdale 1972.**

$$Ep = a\,N^{b} \qquad \textbf{(6)}$$

Where
Ep = permanent strain
N=number of stress applications
a= intercept coefficient
b= slope coefficient

4.4 Flexural Beam Fatigue Test

Within this study, four-point flexural fatigue bending test was adopted to evaluate the fatigue performance of asphalt concrete mixtures using the flexural fatigue testing equipment shown in **Fig. 4,** this test was performed in strain controlled mode with flexural stress level 250μƐ,400μƐand 750μƐ applied at the frequency of 5 Hz and a repeated haversine (sinusoidal). All tests were conducted as specified in **AASHTO T 321** standards at 20°C (68°F) on beam specimens 50 mm x 63 mm x 400 mm prepared using Roller Compactor Device at NCCLR (National Center for Construction Laboratories and research) according to, **EN12697-33 2003**, because this method of compaction simulates field compaction in a progressive way. A slab sample of (400 mm by 300 mm by 53±6 mm) was prepared using the hot aging asphalt concrete loose mix. A metal stripe of 30mm height and 1.5 mm width was fixed on the base plate of the slab before pouring the asphalt concrete to insure having weak point for beams after compaction of the slab, then cut by the cutter-water into dimension previously mentioned. In the fatigue test, results should be monitored and recorded at the selected load cycle intervals and the test should be terminated when the beam has reached a 50 percent reduction in stiffness. The initial strain was plotted versus the number of repetition to failure on log scales, collapse of the beam was defined as failure, the plot can be approximated by a straight line and has the form shown below in **Eq. 7**. **EN12697-33 2003.** The test was conducted at NCCLR (National center for construction laboratories and research).

$$Nf = k_1\,(\mathcal{E}t)^{-k2} \qquad \textbf{(7)}$$

Where
Nf = fatigue life
Ɛt= Initial tensile strain
*k*1= fatigue constant, value of Nf when = 1

$k2$ = inverse slope of the straight line in the logarithmic relationship

5. TEST RESULTS AND DISCUSSION

5.1 Effect of Moisture Damage on Indirect Tensile Strength

The indirect tensile strength (ITS) property of an HMA mix gives an indication on the overall strength of the mix. **Fig. 5** depicts the effect of unconditioned and conditioned mix on indirect tensile strength. Results indicated that tensile strength at 60 º C for condition shows lower resistance than unconditioned by 19 %, at optimum asphalt content.

Tensile Strength Ratio (TSR) has been used for predicting moisture susceptibility of mixtures. The recommended limit of (80 %) for tensile strength ratio (TSR) is used to distinguish between moisture susceptible mixture and moisture resistance mixtures (**AASHTO T-283**). **Fig. 5** show the unconditioned and moisture conditioned mixture. The data show that optimum asphalt content mixtures have resistance to the action of water. The tensile strength ratio was 81%, at optimum asphalt content mix.

5.2 Effect of Moisture damage on Resilient Modules

The resilient modulus (Mr) properties were obtained from indirect tensile test, and used to evaluate the moisture damage of the HMA mixtures for two reasons. The first one is that Mr test is a nondestructive test that can be conducted on the same samples before and after moisture conditioning, and the second one is that the Mr is an engineering property that can be used to estimate the response of HMA pavements under traffic loads. **Table 4** summarizes the Mr properties of the unconditioned and moisture conditioned HMA mixtures. The data show that the resilient modulus of moisture condition was significantly lower than the values obtained for unconditioned mix with 21% at optimum asphalt content. Similar findings were reported by **Sarsam, 2009.**

5.3 Effect of Moisture damage on Resistance to Permanent Deformation

Table 5 shows effect of unconditioned and moisture condition mix on permanent deformation. It can be seen that slop increase in condition mix and intercept increase, that give indication that the unconditioned mixtures have low permanent strain compared with condition mix. The analysis of the Table indicated that the moisture condition mix lower resistance to permanent deformation (at 1000 cycles) by 93% as compared with the unconditioned mixture, and also fail before the unconditioned mix. **Fig. 6** Shows the relationship between strain and load repetition for unconditioned, and condition mixture with at (40°C).

5.4 Effect of Moisture damage on stiffness

Also noted when micro-strains level increase, the stiffness of specimen decrease. **Fig. 7** depicts the effect of unconditioned and condition moisture mix on stiffness. It can be seen that stiffness decrease at condition moisture mix by 62 % from unconditioned mix (in 250µƐ and optimum asphalt content) the reason may be due to the lack of bond between asphalt and aggregates.

5.5 Effect of Moisture damage on Fatigue Life

Table 6 and **Fig. 8** Depicts the effect of unconditioned and moisture condition mix on fatigue life. The analyses of the figure shows that fatigue life after impact to moisture condition decrease by 70 % from unconditioned mix (at 250 µƐ, and optimum asphalt content), also noted that the K2 (which represents the intercept) was decreased from (3.46 to 3.28) and K1 (which represents the slope) was increased from (9.15E-09 to 1.52E-08) at optimum asphalt content.

6. CONCLUSIONS AND RECOMMENDATIONS

Best on the limited testing program, the following conclusion could be drawn:

1. The impact of moisture conditioning of superpave asphalt concrete was lowering the indirect tensile strength by (19%) as compared with unconditioned mix.
2. At (40˚C), Mr was reduced by (21%) due to the impact to moisture damage.
3. The permanent deformation increases by 93 percent after subject the specimens to moisture damage (at 40˚C).
4. Stiffness at (250µƐ, 750 µƐ) was reduced after subjecting the asphalt concrete to moisture damage (conditioned mix) as compared with unconditioned mix by (-62%, -16%) respectively.
5. The results of repeated four point flexural fatigue beam testing indicated that fatigue life decreases by 70 percent after subjected asphalt concrete to moisture damage. For a microstrain change from 250 µƐ to 400 µƐ, the fatigue life decreases by 87 percent.

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Table 1. The physical properties of asphalt cement.

Property	Unit	ASTM Designation	Penetration Grade (40-50)	SCRB Specification
Penetration @ (25°C, 100 gm, 5sec)	1/10 mm	D-5	41	40-50
Softening Point.(Ring & Ball)	(◦C)	D-36	49.4	-----
Specific Gravity @ 25◦C	-----	D-70	1.04	-----
Ductility @ (25 ◦C, 5cm/min)	cm	D-113	144	>100
after thin film oven test				
Penetration of Residue 25 °C, 100 gm, 5 sec	1/10 mm	D-5	27	-----
Mass loss (163˚C, 50gm, 5 hr	%	D-1754	0.3	<0.75
Ductility of Residue (25 oC , 5 cm/min)	cm	D-113	87	-----

Table 2. Physical properties of Al-Nibaie aggregate.

Property	ASTM Designation	value	SCRB Specification
Coarse aggregate			
Bulk Specific Gravity	C-127 -01	2.584	-------
Apparent Specific Gravity	C-127 -01	2.608	-------
Percent Water Absorption	C-127 -01	0.57 %	------
Loss Angeles Abrasion	C-131-03	13.08	35-45 Max.
Percent Soundness loss by sodium sulfate solution	C-88	2.678	10-20 Max.
Percent flat and elongated particles	ASTM D4791	1.6%	10% Max.
Percent Fractured faces		97%	95 Min.
Fine aggregate			
Bulk Specific Gravity	C-128-01	2.604	------
Apparent Specific Gravity	C-128-01	2.664	------
Percent Water Absorption	C-128-01	1.419	------
Percent Sand equivalent	D-2419	51	45 Min.*

* According to Asphalt Institute SP-2, (2001)

Table 3. Physical properties of Portland cement.

Property	Limestone
% passing No.200	96
Bulk specific gravity (gm./cm^3)	3.14

Table 4. Resilient modulus value for moisture damaged mixture.

Mix	Resilient Modulus (psi)
	40℃
Unconditioned	96970
Condition	76190

Table 5. Slops, intercepts, and permanent deformation at 1000 cycle value for, unconditioned and conditioned mixtures.

Mix	40˚C		
	Slop	Intercept (microstrain)	Permanent def. @1000 cycle
Unconditioned	0.441	149	3158
Condition	0.457	259	6083

Table 6. Parameter K1, K2, and fatigue life for, unconditioned, and conditioned mixtures.

State	K1 (slope)	K2 (microstrain)	Fatigue Life (Nf)		
			250με	400με	750με
Unconditioned	9.15E-09	3.46	30082	3860	693
Condition	1.52E-08	3.28	9015	903	319

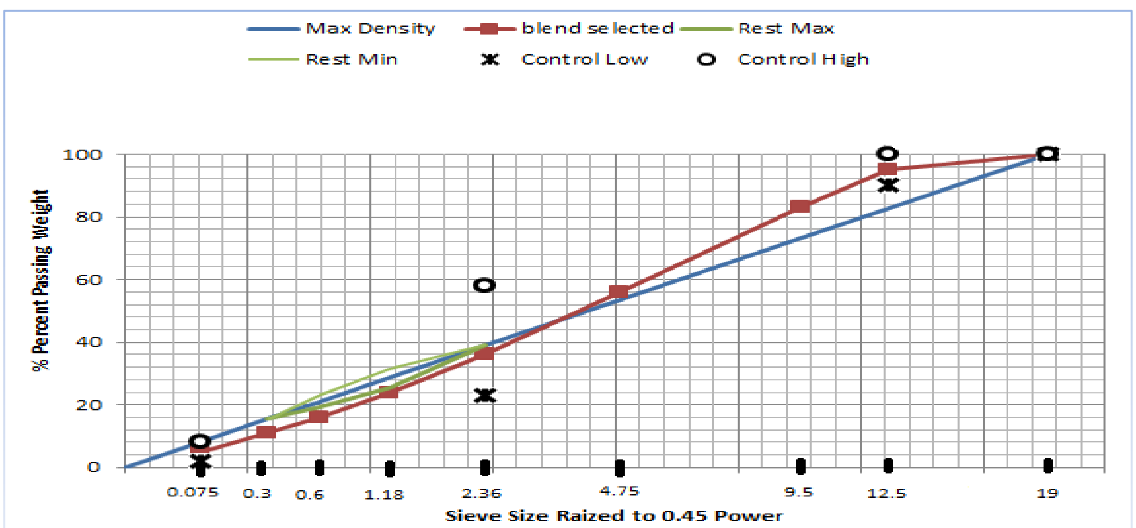

Figure 1. Specification limits and selected gradation for wearing course (normal surface course (12.5 mm) nominal maximum size.

Figure 2. Photograph for ITS test (University of Baghdad laboratories).

Figure 3. Photograph for the PRLS (University of Baghdad laboratories).

Figure 4. Flexural fatigue testing equipment (NCCLR laboratory, Baghdad).

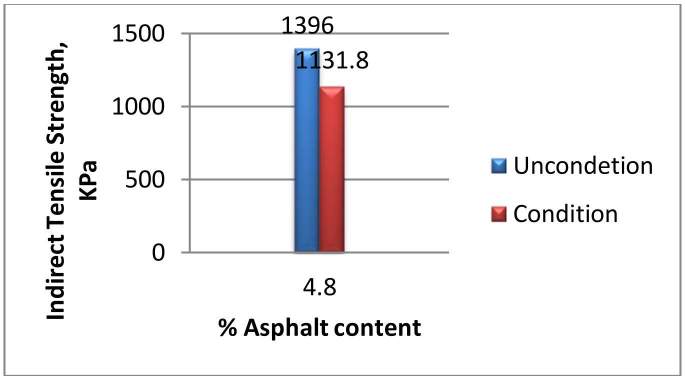

Figure 5. Indirect tensile strength for unconditioned, and condition mixture at 60°C.

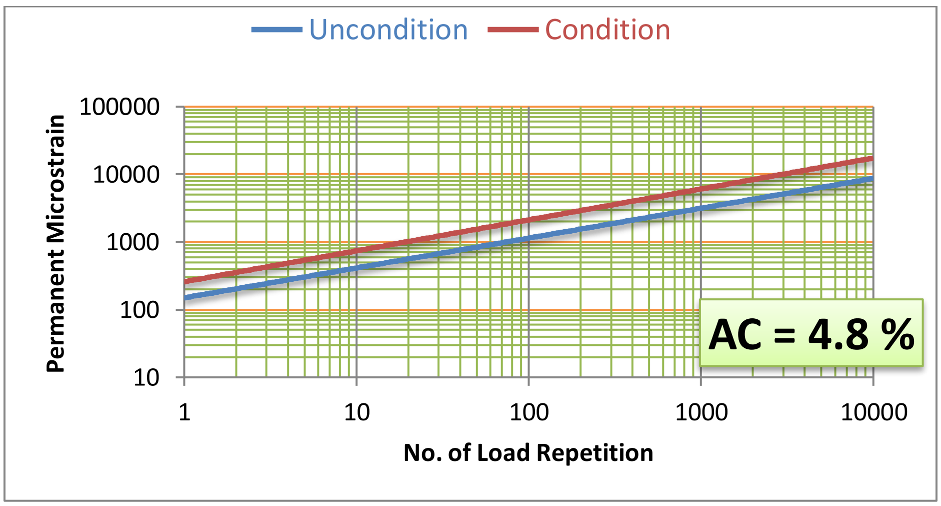

Figure 6. Relationship between strain and load repetition for unconditioned, and condition mixture.

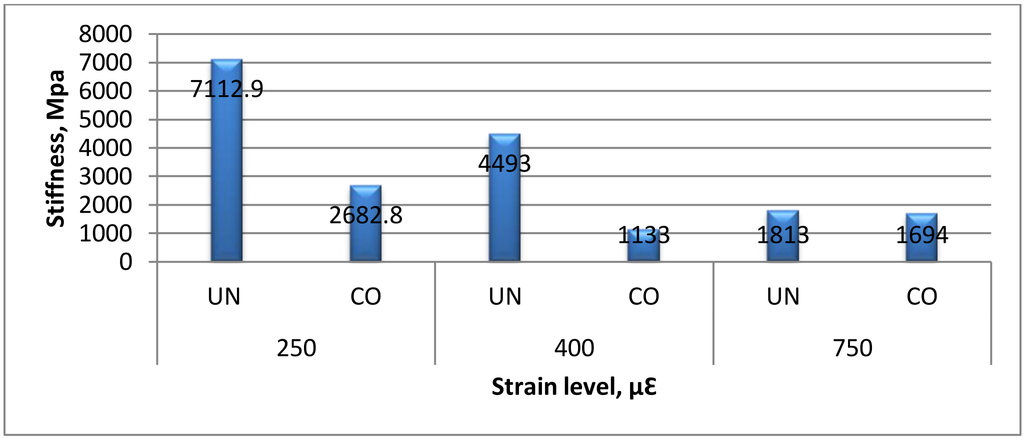

Figure 7. Stiffness for unconditioned and conditioned mixture.

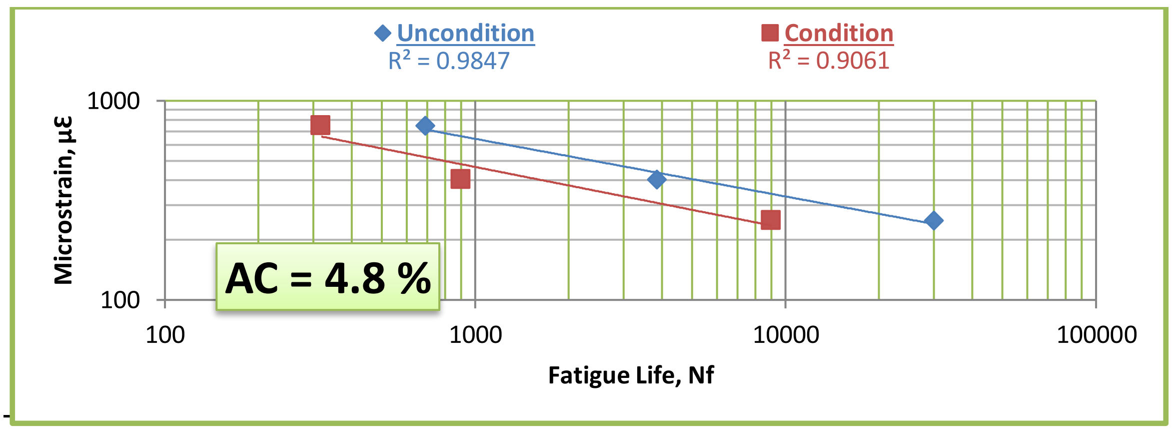

Figure 8. Fatigue life for unconditioned and conditioned mixture.