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FATIGUE AND MOISTURE SUSCEPTIBILITY CHARACTERISTICS OF RECLAIMED ASPHALT PAVEMENT MIXTURES IN IRAQ

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Abstract: One of today's most important societal concepts is sustainability. This ideal can be described as meeting the needs of the present without compromising the ability of future generations to meet their own needs. Hot mix asphalt (HMA) recycling produces an eco-friendly mixture known as Reclaimed Asphalt Pavement (RAP). The main objective of this paper is to determine the effect of RAP percentage usage on the characteristics and properties of asphalt concrete mixtures. In this paper, a detailed laboratory study is carried out by preparing asphalt mixtures specimens using aggregate from Al-Nibaay quarry, (40-50) grade asphalt from dourah refinery and four different percentages of RAP material: 0%, 5% ،10%, and 15%. The experimental testing program included four point repeated load and Indirect Tensile Strength tests. The experimental results indicate that, that the inclusion of RAP materials improves fatigue properties of HMA mixtures; fatigue life (N_f) at RAP content of (% 15) increases by (157.1%), (100%), and (150%) at testing temperature 25, 10, and 40°C respectively. Based on the modified Lottman test, it was found that HMA with RAP additive had a high resistance to moisture damage through increasing the indirect tensile strength of such mixtures. The results of four point repeated load test and IDT test indicate that the amount of new binder that needs to be added to the RAP mixture can be reduced without significant effects on the quality of the produced mix.

Keywords: *HMA, Recycled Asphalt Pavement (RAP), Marshall Properties, Indirect Tensile Strength, fatigue life*

خصائص تشققات الكلل والحساسية للرطوبة للخلطات الإسفلتية المعاد تدويرها في العراق

الخلاصة: اليوم تعد الإستدامة واحدة من اهم المفاهيم في المجتمع. ويمكن وصف الإستدامة بأنها تلبية إحتياجات الحاضر دون المساس بقدرة الأجيال القادمة على تلبية إحتياجاتها الخاصة. إعادة تدوير الخلطات الإسفاتية الساخنة ينتج خلطات إقتصادية وصديقة للبيئة تعرف بالخطات الإسفلتية المستدامة (RAP). الهدف الرئيسي من هذا البحث هو تحديد تأثير نسبة إستخدام ال(RAP) على خصائص وصفات الخلطات الإسفلتية. في هذا البحث تم عمل دراسة مختبرية مفصلة بتحضير نماذج خلطات إسفلتية بإسخدام الركام من مقلع النباعي، إسفلت بدرجة إختراق (40-50) من مصفاة الدورة، وأربعة نسب مختلفة من مادة ال(RAP) (0، 5، 10، و 15)% . برنامج الفحص المختبري تضمن فحص الإنحناء لأربعة نقاط تحت تأثير الحمل المتكرر وفحص مقاومة الشد الغير المباشر. النتائج المختبرية تشير الى إنه تضمين مادة ال(RAP) في الخلطات الإسفلتية يحسن من خصائص الكلل لتلك الخلطات; عمر الكلل(Nf) لمحتوى (RAP) 15 % يزداد ب (157.1%), (100%)، و(150%) بدرجة حرارة فحص 25، 10، و 40 درجة مئوية على التوالي. بالإعتماد على فحص Lottman المطور، وجد بأنه إضافة ال RAP للخلطات الإسفلتية ينتج خلطات بمقاومة أعلى لتأثير الضرر الناتج

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نتائج فحص الإنحناء لأربعة نقاط تحت تأثير الحمل المتكرر وفحص مقاومة الشد الغير المباشر تشير الى إنه كمية الأسفلت الرابط الجديدة واللازم إضافتها للخلطات الأسفلتية المستدامة يمكن تقليلها دون التأثير على نوعية الخلطة المنتجة.

1. Introduction

Meeting sustainability requirements in asphalt concrete pavements generally requires the process of recycled materials or the employment of energy saving technologies. The most common form of energy saving technology readily available to asphalt producers is warm mix asphalt (WMA) as discussed by [5].

The produced materials during roadways maintenance and rehabilitation of existing asphalt pavements or from utility cuts across the roadways which were necessary to gain access to underground utilities are usually known as Reclaimed Asphalt Pavements (RAP), which is normally created when existing asphalt concrete surfacing or crushing materials resulting from old asphalt pavements removal. Since most of roadways are constructed using high-type bituminous pavements, RAP materials, if properly processed, will consist of superior, well-graded asphalt coated aggregates which can be used in a number of highway construction applications. Use of RAP material in asphalt mixes helps in reducing costs, protects asphalt and aggregate resources, and limits the amount of waste material going into landfills [6].

There are five recycling methods as defined by the Asphalt Recycling and Reclaiming Association: cold planning, hot recycling, hot in- place recycling, cold in - place recycling, and full depth reclamation. Hot recycling, the focus of the present study, combines RAP with virgin asphalt and/or aggregate to produce HMA. Either a batch or drum type hot mix plant may be used to produce the recycled mix, and the mix is placed and compacted in the same way as virgin HMA [7].

In the United States, and for the time being, the average percentage of RAP recommended to be added in HMA is about 12%. Less than half of state DOT use equal or less than 20% RAP. Referring available states specifications 30% RAP in HMA represents the upper accepted limit. The effect, therefore, of RAP on pavement performance is of tremendous importance and is receiving much attention as evidenced by numerous recent publications on the subject, reference to a journal publication [4].

Kennedy and Perez [13], and Kennedy and McGanus [14], evaluated and compared fatigue performance of asphalt concrete with RAP. Fatigue properties were evaluated by the repeated load in indirect tension test. Longer fatigue lives were found for the recycled mixtures than for the conventional mixtures. Reference to conference proceedings [15], also reported that recycled mixtures exhibit very good fatigue characteristics. However, (Whitcomb et al, 1981) stated that conventional mixes have better fatigue properties than the recycled mixes.

Gardiner and Wagner [9], used the tensile strength ratio (TSR), ratio of unconditioned tensile strength and moisture-conditioned tensile strength, to evaluate moisture sensitivity. They showed that the inclusion of coarse RAP decreased moisture susceptibility.

Reference to conference proceedings [8], published data for the relationship between Marshall Stability and proportion of reclaimed material indicated that Marshall Stability is somewhat higher for mixes with higher proportion of reclaimed material content. However, the Marshall quotient was similar for all mixtures.

Intisar M. J. [11], concluded that RAP materials are not suitable to be used in cold mix alone as base materials without certain process or treatment to improve their characteristics.

2. Objectives

Experimental Evaluation of fatigue cracking and moisture susceptibility characteristics for local surface HMA mixtures containing different percentages of screened RAP that meet the Iraqi specification [12] throughout a designed experimental program.

3. Materials And Testing Methods

3.1. *Materials*

Selected materials to be used in this study are locally available and currently used in road construction in Iraq.

3.1.1. Asphalt Cement

The asphalt binder used in this study with penetration grade of (40-50) was supplied from Daurah refinery plant. Which is a local asphalt binder producer. The physical properties of the asphalt binder are presented in Table 1.

Table 1. Physical Properties of Asphalt Cement.

Test	Unit	ASTM	SCRB[a] Specifications, 2003	Result
Penetration (25˚C, 100g, 5sec),	1/10 mm	D 5	40-50	47
Ductility (25˚C, 5cm/min)	Cm	D 113	≥100	164
Flash point	˚C	D 92	≥232	259
Specific gravity	…..	D 70	…..	1.041
Absolute Viscosity at 60°C (*)	Poise	D 2171	2065	…..
Kinematics' Viscosity at 135C (*)	C St.	D 2170	370	…..

(*)The test was conducted in Dourah refinery
ª: State Commission of Roads and Bridges [12]

3.1.2. *Aggregate*

Natural fine and crushed coarse aggregates are used in this research. The source of aggregate is from Al-Nibaay quarry in Taji, north of Baghdad. To produce identical controlled gradation, aggregates were sieved and recombined in laboratory to meet the wearing course gradation as required by Iraqi specification [12]. The gradation, physical and chemical properties for the aggregate are shown in Table 2, Table 3, Table 4 and Fig.1.

Table 2. Combined Gradation of Aggregate and Mineral Filler for Wearing Course.

Sieve Size	*Sieve Opening, mm*	*Percentage passing by Weight of total Aggregate*	
		Specification Limits [S.C.R.B]	Mid-Point Gradation
3/4"	19	100	100
1/2"	12.5	90 - 100	95
3/8"	9.5	76 - 90	83
No.4	4.75	44 - 74	59
No.8	2.36	28 - 58	43
No.50	0.3	5 - 21	13
No.200	0.075	4 - 10	7

Table 3: Physical Properties of Al-Nibaay Aggregates.

Property	Coarse Aggregate		Fine Aggregate	
	Result	ASTM Designation [3]	Result	ASTM Designation [3]
Bulk Specific Gravity	2.632	C 127	2.629	C 128
Apparent Specific Gravity	2.670	C 127	2.69	C 128
Percent Water Absorption	0.433	C 127	0.642	C 128
Percent Wear (Los-Angeles Abrasion)	20.2	C 131	…..	C 131

Table 4. Chemical Composition of Al-Nibaay Coarse Aggregates

Chemical Compound	Content, %
Silica, Sio2	82.52
Lime, CaO	5.37
Magnesia, MgO	0.78
Sulfuric Anhydride, SO3	2.7
Alumina, Al2O3	0.48
Ferric Oxide, Fe2O3	0.69
Loss on Ignition	6.55
Total	99.09
Mineral Composition	
Quartz	80.3
Calcite	10.92

* The tests were done in cooperation with National center for construction laboratories

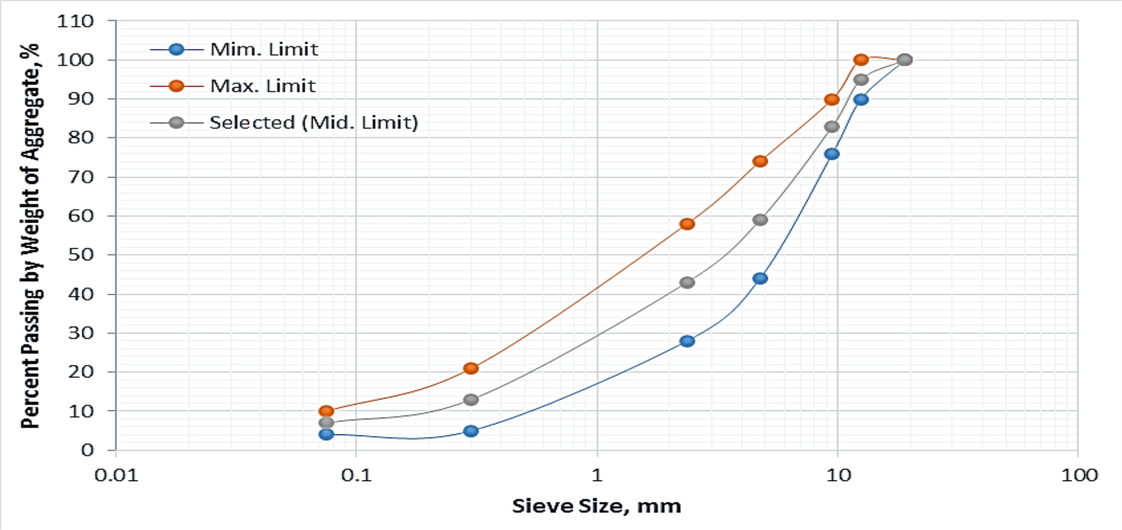

Figure 1. Specification Limits and Mid-Point Gradation of SCRB [12] for Wearing Course Layer.

3.1.3. *Mineral Filler*

Two types of mineral fillers (ordinary Portland cement (OPC) and hydrated lime) are used in this study.

3.1.4. ***Rap Material***

The RAP material was collected from Al-Adel neighborhood in the west of Baghdad city, the capital of the Republic of Iraq and its asphalt content was found to be 4.6 % with penetration grade of (40-50). The top 50 mm of the asphalt layer was removed and collected from the damaged surface of pavement layer. The collected RAP was milled, sieved and recombined in predetermined percent with new aggregate and new asphalt grade (40-50). Two types of RAP were used in terms of fraction: coarse RAP and fine RAP. Fig.2 represents the gradation of recycled asphalt pavement used in this study. Plate 1 shows samples of Recycled Asphalt pavement.

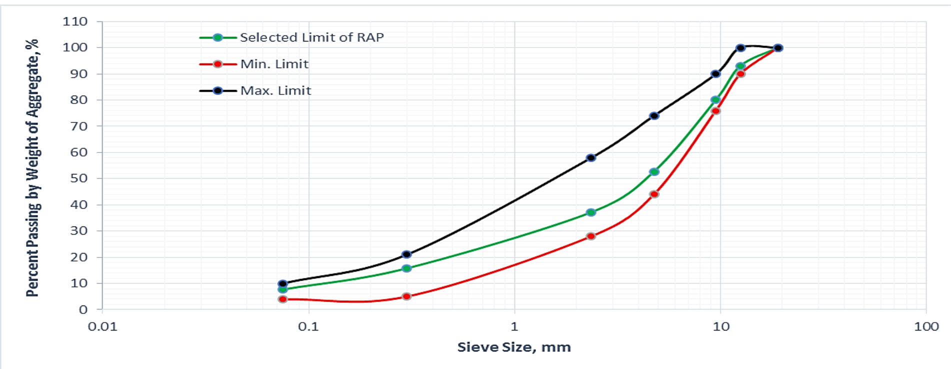

Figure 2. Specification Limits and RAP Gradation of SCRB [12] for Wearing Course Layer.

(a) (b)

Plate 1. Samples of the Recycled Asphalt Pavement. a) Fine RAP b) Course RAP

3.2. *Mix Design*

The Marshall Mix design method was employed to determine the optimum asphalt content (O.A.C) for the mix with zero RAP percent. The optimum asphalt content for HMA mixture with 0% RAP was found to be 4.8%.

3.3. *Methodology Of Adding Rap*

Virgin HMA mixtures were mixed with three different percentages of RAP (5, 10, and 15) % (by weight of total mix) .

First the fractionated RAP obtained from Al-Adel neighborhood is dried to make it workable and to mix it with the virgin materials. The RAP is heated to a temperature of 110°C (230°F) for a time of no more than 2 h. In this study the RAP was fractionated into coarse RAP (+4.75 mm) and fine RAP (−4.75 mm).

Half of the weight of RAP selected to be added to the virgin HMA was coarse RAP and the other half was fine RAP.

When batching out the RAP aggregates, it is important to remember that part of the weight of the RAP is binder. It is necessary to increase the weight of RAP and decrease the amount of new binder added to take the presence of this RAP binder into account.

3.4. *Specimens Preparation*

3.4.1. Marshall Specimens

The aggregate is first dried to constant weight at 110 °C, separated into desired size and recombined with mineral filler in order to meet the required gradation for each specimen .The aggregates are heated to a temperature of 175 to 190 °C, the compaction molds assembly and hammer are cleaned and kept pre-heating to a temperature of 100 to 145 °C.

In the case of mixture with the different percent of RAP (5, 10, and 15 %), the RAP is added to the HMA mixture in the method described above. The asphalt is heated to temperature of 121 to 138 °C and the required amount of asphalt is added to the heated aggregate (and for heated aggregate with heated RAP) in the mixing bowl and thoroughly mixed until the aggregate completely coated. The mix is placed in a preheated mold and it is then spaded vigorously with a heated spatula or towel 15 times around the perimeter and 10 times over the interior.

The temperature of the mixture immediately prior to compaction temperature (142 to 146 °C) and compacted with standard number of blows (75) on each face with the mechanically operated compaction hammer (Marshall Hammer) with free fall 18". In order to prevent distortion, the compacted specimen in the mold is left to cool at room temperature for 24 hours and then it is removed from the mold.

3.4.2. Beam Specimens

In order to study the fatigue characteristics of the RAP mixtures, asphalt concrete beams samples are prepared. The standard beam dimensions are 15 inch (381.0 mm) length, 3 inch (76.2 mm) width, and 3 inch (76.2 mm) height made of wearing layer.

To represent the wearing surface layer, an asphalt beam weights (5199 gm.) of asphalt mixture is prepared with (0, 5, 10, and 15) % RAP content. The aggregate, asphalt, and RAP are heated prior to reach adequate mixing temperature and mixed together in hot mixing bowel by hand on hot plate until homogeneity reached, then the hot bowel with the hot mix is stored in the oven for 30 min. at 150˚C. The mixture was spread uniformly and spaded vigorously in the iron mold with a heated spatula after the internal surfaces of the mold are oiled, and a sheet of aluminum foil is placed on the base of the mold to prevent the mixture from sticking. The beam was compressed by static Compression Machine with (30kN) capacity applied to steel plate that covers the asphalt mixture to apply uniform load. The applied pressure was maintained at (30kN) for 3 minutes at 120°C to achieve the desired bulk density as in Marshall specimen and the load was released slowly. The mold was left for 24 hours and then the beam was extruded from the mold.

3.5. *Test Methods*

The flow chart shown in Fig.3 is clearly describes the experimental tests design.

3.5.1. Moisture Susceptibility Test

The moisture susceptibility test evaluates the effect of saturation and accelerated moisture conditioning on compacted HMA samples utilizing freeze-thaw cycles according to standards [1], “Resistance of Compacted Bituminous Mixture to Moisture Induced Damage". Marshall Specimens were used to evaluate the compacted RAP mixtures. The ITS test was performed on three dry specimens and three conditioned specimens. The unconditioned (dry) samples were placed in a Plastic bag to prevent water leakage into the sample. The specimens were then placed in a water bath for 2hours ± 10 minutes at 25±0.5 ˚C (77±1F) . The specimens were removed from water bath and the indirect-tensile strength was measured.

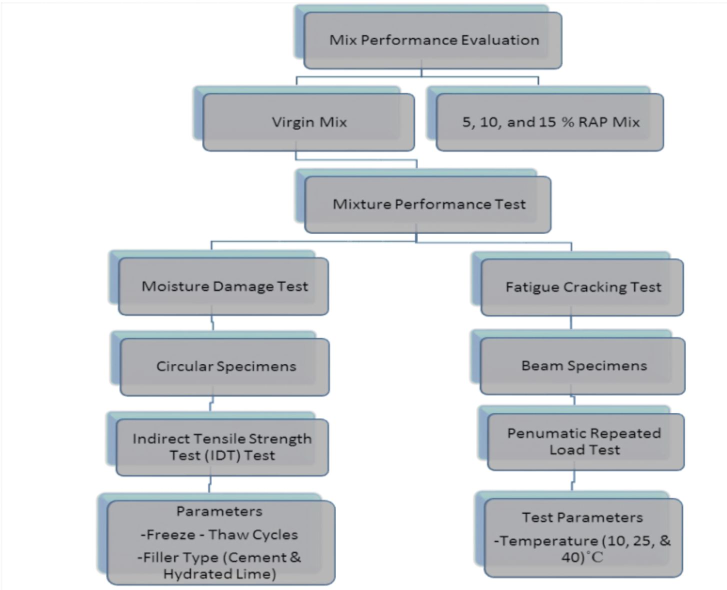

Figure 3. Flow Chart of Experimental Work

The conditioned samples were divided into two subset. The first subset were placed in a vacuum container filled with potable water at 25˚C for 1 hour ± 10 minute as shown in plate 2. After vacuum conditioning, the samples were immersed in water bath at 25 ± 0.5˚C for 10 ± 1 minute. The specimens were removed from the water bath. After that the ITS was conducted on the samples and the tensile strength ratio (TSR) was calculated by dividing the average IDT strength of the conditioned saturated only subset by the average IDT strength of the unconditioned subset. While, the second subset was subjected to vacuum saturation followed by the freeze-thaw cycle, and then tested for IDT. The vacuum saturation process was the same as that described for conditioned saturation only.

Each specimen after vacuum saturation was covered with a Plastic bag and kept in the freezer at a temperature of -18±3°C (0±5°F) for a minimum of 16 hours. After the freeze-thaw cycle, specimens were transferred to the water bath at 60±1°C (140±2°F) and the plastic bag was removed from the specimen as soon as it was placed in the water bath. The remaining process was the same as that described for the first subset.

$$\mathbf{ITS} = \frac{\mathbf{2\,Pult}}{\boldsymbol{\pi}\,\mathbf{t\,D}} \tag{1}$$

Where:
Pult= Ultimate load up to failure (N).
t = Thickness of specimen (mm), and
D = Diameter of specimen (mm).
While the tensile strength ratio (TSR) is calculated as follows:

$$\mathbf{TSR} = \frac{\textbf{ITS of Conditioned Subset}}{\textbf{ITS of Unconditioned Subset}} \tag{2}$$

Plate 2. Samples Conditioning and Testing

* The tests were done in cooperation with National center for construction laboratories

3.5.2. Pneumatic Repeated Load Test

Pneumatic repeated load system (PRLS) apparatus was used to test the repeated flexural bending of RAP mixtures reference to thesis [2], as shown in Plate 3 and Fig.4. The purpose of using four points loading test was to estimate cracking potential in the flexural beam fatigue test. The number of cycles (fatigue life) that caused complete failure of the beam was considered as an indicator of fatigue cracking potential [10].

The details of the factorial variables in the experimental design of the flexural beam fatigue test includes a Stress Level of 5 psi which was selected as a target control stress, loading time of 0.1second and rest period of 0.4 second and the flexural deformation at the central third of the specimen is measured under each load repetition, as recommend by Huang [10]. A range of stress was selected so that the specimens would fail within a range from 100 to 100,000 repetitions. The specimen is left in chamber for one hour at testing temperature (10, 25, and 40) to allow uniform distribution of temperature within the specimen and its position of applied loading is checked exactly, as shown in Figure (4). Two digital cameras have been used: one to record the deflection at mid span of the beam until failure with a dial gauge, and the second to monitor the crack evolution during the test. Then, the recorded data is analyzed for finding strain at any number of cyclic desired for each specimen.

Plate 3. Pneumatic Repeated Load Device

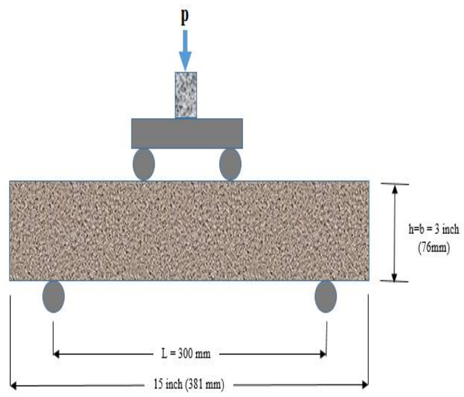

Figure 4. Four Point Loading Test

*The test is carried out in Civil Engineering Department at Baghdad University in the Laboratory of Transportation

4. Results And Discussion

4.1. *Moisture Susceptibility Test Results*

The AASHTO T 283 test procedure [1], is used to evaluate the resistance of the RAP mixtures to moisture damage. The specimens were loaded using Versa-Tester until failure at a rate of 2 inches per minute (50.8 mm per minute). Two types of data were obtained from this test. The first was the indirect tensile strength (ITS) of the dry and wet conditioned specimens. The second was the tensile strength ratio (TSR). The indirect tensile strength (ITS) is a measure of the strength and durability of the asphalt mixture, whereas the TSR ratio is a measure of its resistance to damage from freezing and thawing [17].

Fig.5 shows result of the ITS test for unconditioned RAP samples prepared with two different types of filler (Ordinary Portland Cement (O.P.C) and Hydrated Lime). Generally the results which are average of three samples show that the addition of RAP in HMA improves the tensile strength values compared with the control mixture for the two types of filler.

Fig.6 and Fig.7 show results of the ITS test for conditioned RAP samples with saturation only and saturation plus freeze and thaw cycle respectively. It is noticeable that the inclusion of RAP material improves the tensile strength for the two types of filler, but the addition of hydrated lime as anti-stripping agent has a beneficial effect on the mixture with regard to moisture-damage resistance, particularly with saturation conditions and saturation plus freeze and thaw condition. When lime is added to hot mix, it reacts with aggregates, strengthening the bond between the bitumen and the stone. At the same time that it treats the aggregate, lime also reacts with the asphalt in the mix to form water-soluble soaps that promote stripping. When those molecules react with lime, they form insoluble salts that no longer attract water, reference to report [16].

In addition, the dispersion of the tiny hydrated lime particles throughout the mix makes it stiffer and tougher, reducing the likelihood the bond between the asphalt cement and the aggregate will be broken mechanically, even if water is not present.

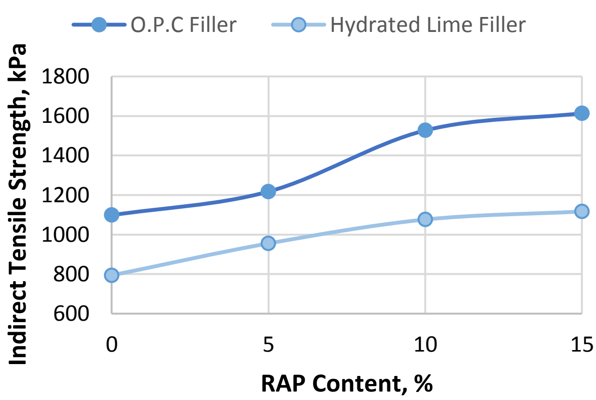

Figure 5. ITS of Unconditioned Subset Using Two Different Types of Filler.

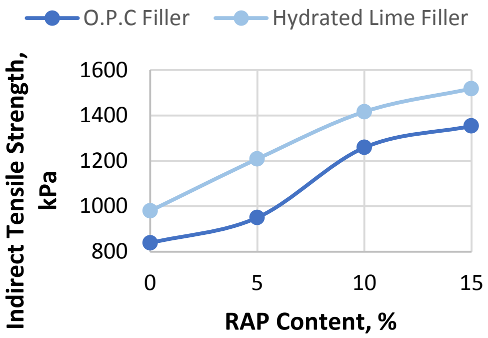

Figure 6. ITS of Subset Conditioned with Saturation Using Two Different Types of Filler

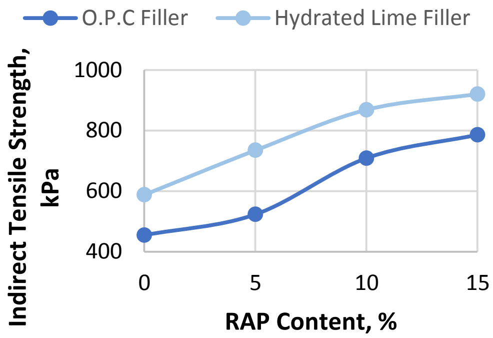

Figure 7. ITS of Subset Conditioned with Saturation Plus Freeze-Thaw Cycle Using Two Different Types of Filler

Fig.8 and Fig.9 illustrate tensile strength ratio for both control and RAP mixtures. It can be illustrated that mixtures containing RAP provide higher TSR than control mixture after saturation conditioning and the all values are located within the specification. After Saturation Plus Freeze-Thaw Cycle, the RAP mixtures endure better resistance to the action of water than virgin mixtures. This is attributed to the fact that RAP contains hardened asphalt that became more viscous as time passes. Thus, mixtures with more viscous materials will perform better under tension, which will lead to smaller reduction in tensile strength when exposed to severe conditions of high temperature and moisture. The highest TSR is obtained when hydrated lime filler is used thus, adding hydrated lime as a filler to the RAP mixture can enhances the moisture susceptibility for all studied conditioning periods.

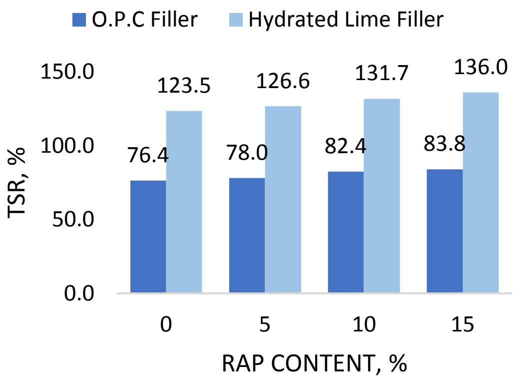

Figure 8. TSR Results for RAP Mixtures Conditioned with Saturation only Using Two Different Types of Filler.

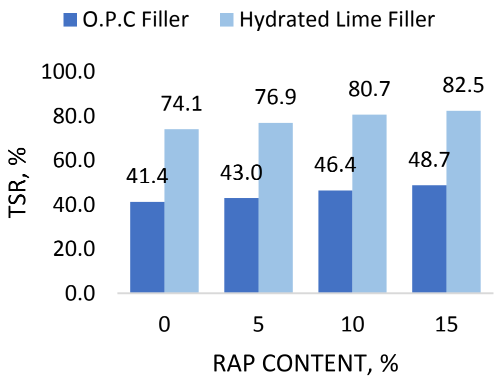

Figure 9. TSR Results for RAP Mixtures Conditioned with Saturation Plus Freeze- Thaw Cycle Using Two Different Types of Filler.

4.2. *Fatigue Life (Four Point Repeated Load) Test Results*

Fatigue performance of the flexible pavement is commonly used in investigations using a correlation of its performance from the laboratory testing. Experimental approaches used to inspect its behavior in the laboratory is the phenomenological approach. In this approach, the fatigue performance is shown as the relationship between the strain induced in the central part of the beam sample in an asphalt mixture and the number of load repetitions.

Fatigue life is defined as the number of cycles corresponding to a 50 percent reduction in initial stiffness; initial stiffness was measured at the 50 load cycle [1].

A user defined stress level was applied to the 36 prepared beams at 5 psi such that the specimen will undergo a minimum of 100 load cycles with (loading time of 0.1 sec and a rest period of 0.4 sec.) and at three testing temperature are selected to be; 10˚C, 25 ˚C, and 40 ˚C. 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.

$$\sigma = \frac{3aP}{wh^2} \quad (3)$$

Where
σ= Maximum Tensile Stress, psi
P= load applied by actuator, lbs.
w= width of beam, in.
h= specimen height, in.

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

Where
ε= Maximum Tensile Strain, psi
δ= maximum deflection at center of beam, in.
a = space between inside clamps.
L = length of beam between outside clamps.

$$s = \frac{\sigma}{\varepsilon} \quad (5)$$

Where
S = Flexural Stiffness, psi

$$\Phi = 360fs \quad (6)$$

Where
Φ =Phase Angle, deg
f = load frequency, Hz
s = time lag between Pmax and δmax, sec.

$$wi = 0.25\,\pi\,\varepsilon^2\,S\,\sin(\Phi) \quad (7)$$

Where
wi = energy dissipated at load cycle I, psi,

εi = strain at load cycle I,
Si = stiffness at load cycle I,
Φi = phase angle between stress and strain at load cycle i.

The end of test is defined by fracture of the sample and the rate of crack propagation in the laboratory is faster because the initial dissipated energy per cycle is high (Pell, 1963).

Fig.10, 11, and 12 show the relationship between the number of repetitions to failure and RAP content; 0%, 5%, 10%, and 15% subjected to three testing temperatures; 10˚C, 25 ˚C, and 40 ˚C. In general, it can be noticed that, when the testing temperature increases the fatigue life reduces. This can be related to the decrease of sample stiffness. However, it can be noticed that increasing the percentage of RAP resulted in a higher fatigue life when compared to the control mixture. (Mix stiffer but smaller load levels, similar to highway conditions, would generally reduce the fatigue life of mixtures). This behavior was explained by the fact that with an increase of RAP percentage, more rejuvenators or softer binder are added to the mix—resulting in a softer mix. For same reasons, the RAP mixes showed at least similar or better fatigue resistance than mixes without RAP.

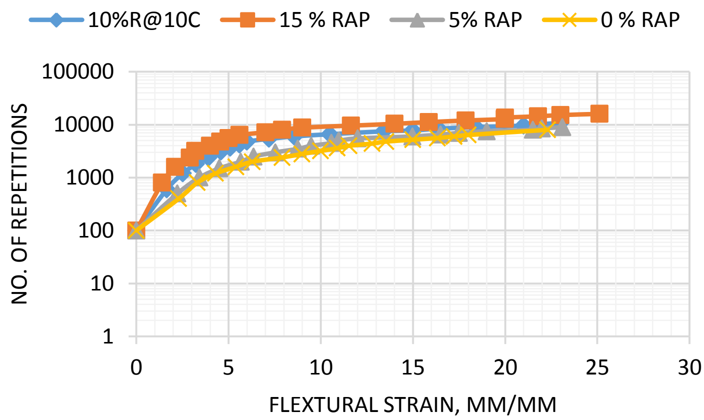

Figure 10. Effect of RAP Content on Nf at Stress Level 5 psi and Testing Temperature 10 ˚C.

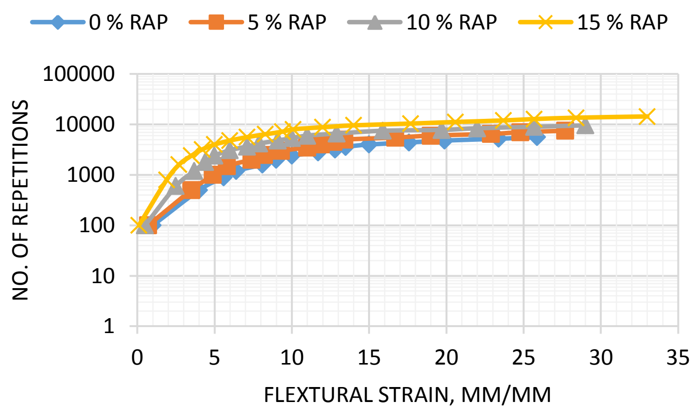

Figure 11. Effect of RAP Content on Nf at Stress Level 5 psi and Testing Temperature 25 ˚C.

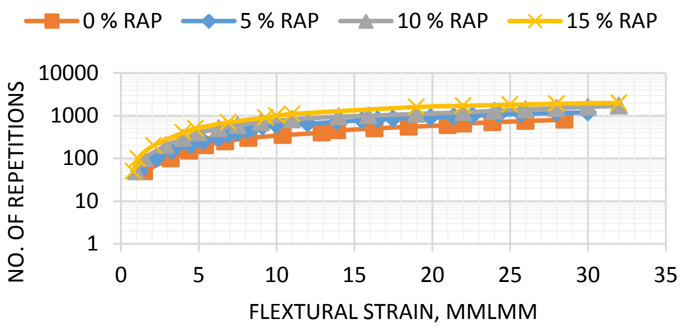

Figure 12. Effect of RAP Content on Nf at Stress Level 5 psi and Testing Temperature 40 ˚C.

5. Conclusions

From this comparative study for various percentages of RAP materials included in Marshall Mixtures, the following conclusions were drawn based on the results and the limitation of this study:

1. In general, it is concluded that, the inclusion of RAP material in specified percentage in this study improves the performance characteristics of flexible pavement (damage resistance and long-term fatigue resistance).
2. The inclusion of RAP materials improves fatigue properties of HMA mixtures; it increases the number of cycles to failure, and reducing the tensile strain occurring at the bottom of the beam sample and this will reduce the development of cracks within the asphalt mixture.
3. As analyses of results, the four point repeated load fatigue tests indicate that; at RAP content of (15 %), N_f increases by (157.1%), (100%), and (150%) at testing temperature 25, 10, and 40°C if compared to the control mixture containing 0 percent RAP.
4. Based on the modified Lottman test, it was found that HMA with RAP additive had a high resistance to moisture damage. The sensitivity of moisture content is affected by replacing the filler in the conventional mixes. The use of hydrated lime as a filler instead of cement shows an increase of Indirect Tensile Strength of HMA due to the increase of adhesion bond between the aggregate and bitumen which tends to increase the stripping resistance.
5. The results of moisture damage test show that, at conditioning state of saturation only and cement used as a filler, the TSR increased by 2.1, 7.9, and 9.7% for 5, 10, and 15 % RAP content respectively compared to control mixtures containing 0 percent RAP. While, the using of hydrated lime as a filler increased the TSR by 2.5, 6.6, and 10.1% for 5, 10, and 15 % RAP content respectively compared to control mixtures containing 0 percent RAP.
6. Results of experimental work indicate that the amount of new binder in the RAP mixture can be reduced without any effect on the quality of the produced mixes.

6. References

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