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Experimental Evaluation of Thermal Cracking Characteristics of Reclaimed Asphalt Pavement Mixtures

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Abstract

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 is the pavement recycling. Reclaimed Asphalt Pavements (RAP), which is normally created when existing asphalt concrete surfacing or crushing materials resulting from old asphalt pavements removal. This paper investigates the thermal cracking resistance of RAP laboratory-prepared Marshall asphalt concrete mixtures. The asphalt mixtures were produced with 0%, 5%, 10% and 15% RAP contents. The experimental testing program included Semi – Circular Bending test. The mechanical criteria for the performance of such mixtures against thermal cracking in this research is stress intensity factor. The effects of different RAP contents on the stress intensity factor of the asphalt mixtures have been mainly investigated. Moreover, the influences of testing temperatures and rate of loading have been observed. Test results revealed that the inclusion of 15 percent RAP significantly increased the stress intensity factor by 20, 27, and 78.8% for testing temperatures -10, 0, and 10˚C respectively. The same trend appears with stress intensity factor at rate of loading (0.5 in/min).

Keywords: Recycled Asphalt Pavement (RAP); HMA; Marshall Properties; Old Aggregate; Old Asphalt; Stress Intensity Factor.

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1. Introduction

" Sustainable" in the context of pavements refers to system characteristics that encompasses a pavement's ability to (1) achieve the engineering goals for which it was constructed, (2) preserve and (ideally) restore surrounding ecosystems, (3) use financial, human, and environmental resources economically, and (4) meet basic human needs such as health, safety, equity **,**employment, comfort, and happiness [1].

Reclaimed Asphalt Pavement (RAP) is any removed or reprocessed pavement material that contains aggregates and asphalt cement. RAP is obtained during rehabilitation or reconstruction of existing asphalt pavements, or from utility cuts across the roadways which are necessary to gain access to underground utilities. When RAP is properly crushed and screened, it will consist of high-quality aggregates coated with asphalt cement binder which can be used in a number of highway construction applications. The use of RAP in asphalt mixes helps reduce costs, conserves asphalt and aggregate resources, and limits the amount of waste material going into landfills [2].

Thermal cracking is attributed to the contraction of the asphalt mixture under extremely temperatures changed. Low temperature cracking is manifested as a set of parallel surface-initiated transverse cracks of various lengths and widths. The cracks are predominantly perpendicular to the centerline of the roadway.

Gardiner and Wagner [3], reported that the inclusion of RAP in hot mix asphalt mixtures increases the probability of the presence of thermal cracking at low temperatures, but decreases the rutting potential.

Thermal cracking is a primary mode of failure in asphalt concrete pavements and it leads to other forms of pavement deterioration. This issue is a seriously concern to many pavement and materials engineers in the world. Researchers are continuing to minimize low-temperature cracking in the asphalt concrete pavements without compromising other performance characteristics [4]. Few literatures have been found on the low temperature properties of RAP mixtures **.** McDaniel and Shah [5], mentioned that with the IDT tests conducted under NCHRP 9-12, the addition of RAP does not significantly affect the tensile strength of RAP mixture, but does increase the stiffness of RAP mixture. This means the thermal stress due to the restraint from the free shrinkage of asphalt layer can build up faster and results in less resistance to low temperature cracking. They suggested that, the grade of virgin binder should be adjusted to properly account for the stiffening effect from adding RAP, especially at large contents.

2. Objectives

The main objective of this research is to investigate the thermal cracking potential for local surface HMA mixtures containing different percentages of screened RAP that meet the SCRB specification [6] and what is the suitable percentage of RAP which can be used in the mixture to get the maximum advantages throughout a designed experimental program.

3. Materials and Testing Methods

3.1. Materials

The 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 [7]	SCRB Specifications [6]	Result
Penetration (25˚C, 100g, 5sec),	1/10 mm	D 5	40-50	47
Softening point	˚C	D 36	50-60	51
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	…..

3.1.2. Aggregate

Natural fine and crushed coarse aggregates are used in this research. The source of aggregates 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 SCRB specification [6]. The gradation, physical and chemical properties for the aggregate is 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] [6]	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

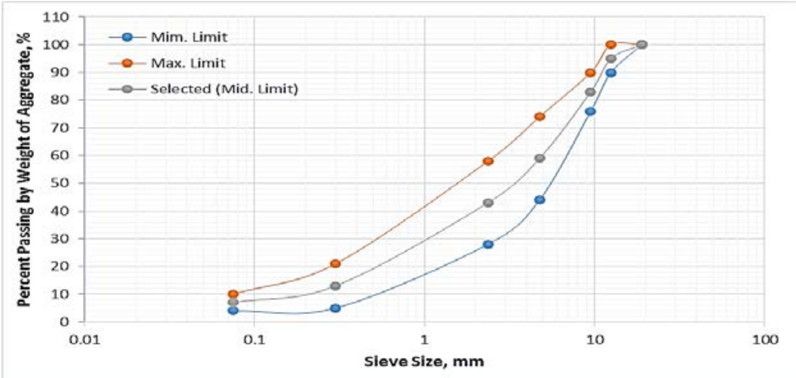

Figure 1: Specification Limits and Mid-Point Gradation of SCRB specification [6] for Wearing Course Layer.

Table 3: Physical Properties of Al-Nibaee Aggregates.

Property	Coarse Aggregate		Fine Aggregate	
	Result	ASTM Designation	Result	ASTM Designation
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-Nibaee 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 and researches (Baghdad).

3.1.3. Mineral Filler

One type of mineral filler is used: ordinary Portland cement was brought from local market. Itis thoroughly dry and free from lumps or aggregations of fine particles.

3.1.4. RAP Material

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. Figure 2 represents the gradation of recycled asphalt pavement used in this study. Figure 8 shows samples of Recycled Asphalt pavement.

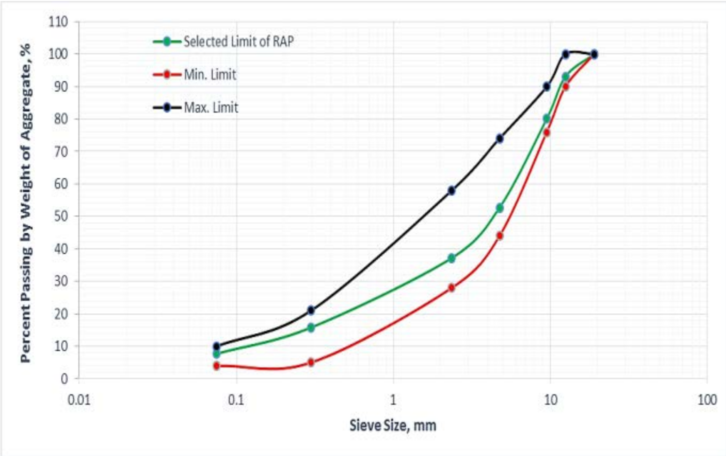

Figure 2: Specification Limits and RAP Gradation of (SCRB, 2003) for Wearing Course Layer.

a b

Figure 8: 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 neighbourhood 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. Semi – Circular Marshall Specimens Preparation

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 15times 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 [7]. prepared Marshall specimen are cut into half and, a notch of (5 mm) depth and (3 mm) width are made using a cutting machine, as shown in Figure 9 and 10.

Figure 9: Semi – Circular Specimen with Notch Depth of 5mm.

Figure 10: Specimens Preparation Using Saw – Cut Machine

3.5. Semi – Circular Bending Test (SCB)

In this study, the SCB test, as shown in plate, was used to determine the fracture toughness of an asphalt mixture Specimen containing RAP. Similar to the indirect tensile (IDT) strength test [8], the SCB test was set up for monotonic loading in which the semicircular specimen was loaded in a three-point bending setup at a constant rate of 50 mm/min and 12.7 mm/min until failure occurred as shown in Figure 11. The fracture toughness is calculated for the samples from the peak load.

Figure 11: Semi – Circular Specimen.

4. Semi – Circular Bending Test Results and Discussion

The SCB test setup for fracture toughness tests is shown in Figure 3 was conducted at sufficiently low temperature to ensure the asphalt mixture behavior is brittle. The data obtained from this test will be used to calculate stress intensity factor (K) of RAP mixtures to evaluate its fracture resistance. A loading parameter, stress intensity factor (KI), is employed to calculate local stress and describes the stress field around a crack tip. The critical (maximum) value for the stress intensity factor determines the fracture toughness, (KIC). The relationship between the loading parameter (KI) and the material property (KIC) is similar to the relationship between stress and strength.

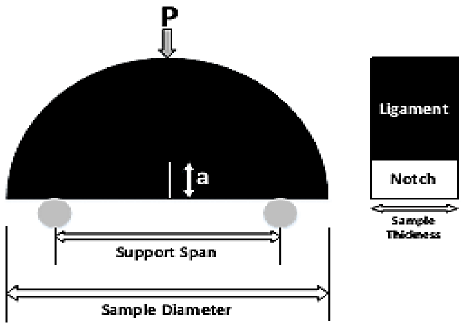

Figure 3: Simplified SCB loading setup with a specimen

In current SCB facture energy test protocol, fracture toughness parameter, (KIC) (maximum value of KI), is estimated by a suggested equation by [9], and [10]. (KIC) defines the fracture resistance at the onset of crack extension by substituting the peak loading, Pmax.

The unit of measure for fracture toughness (K_{IC}) is MPa×√m.

$$\frac{KI}{\sigma_\circ\sqrt{\pi a}} = YI\ (0.8) \qquad (1)$$

where:

$$\sigma_\circ = \frac{p}{2rt} \qquad (2)$$

P = applied load (MN),

r = specimen radius (m),

t = specimen thickness (m),

a= notch length (m),

YI = the normalized stress intensity factor (dimensionless).

Based upon the semi-circular geometry and dimensions used in this study, YI is approximately given by [9], and [10],

$$YI\ \ (0.8) = 4.782 + 1.219\left(\frac{a}{r}\right) + 0.063\exp\left(7.045\left(\frac{a}{r}\right)\right) \qquad (3)$$

Figures 4 and 5 show the effect of RAP content and testing temperature on the applied load for the semi-circular bending beam test subjected to 0.5 and 2.0 in/min respectively. It can be seen that, the increase in testing temperature under different rates of loading results decreases in peak load to failure, while the increase in RAP content from 0 to 15 % results in increases in peak load to failure.

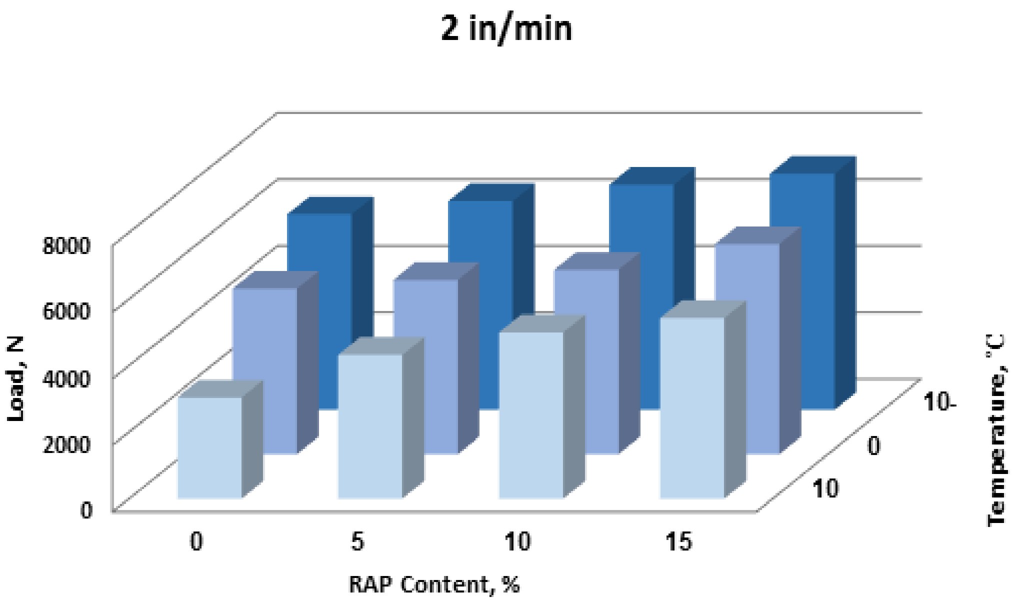

Figure 4: Effect of Temperature and RAP Content on Load at 2 in/min Rate of Loading.

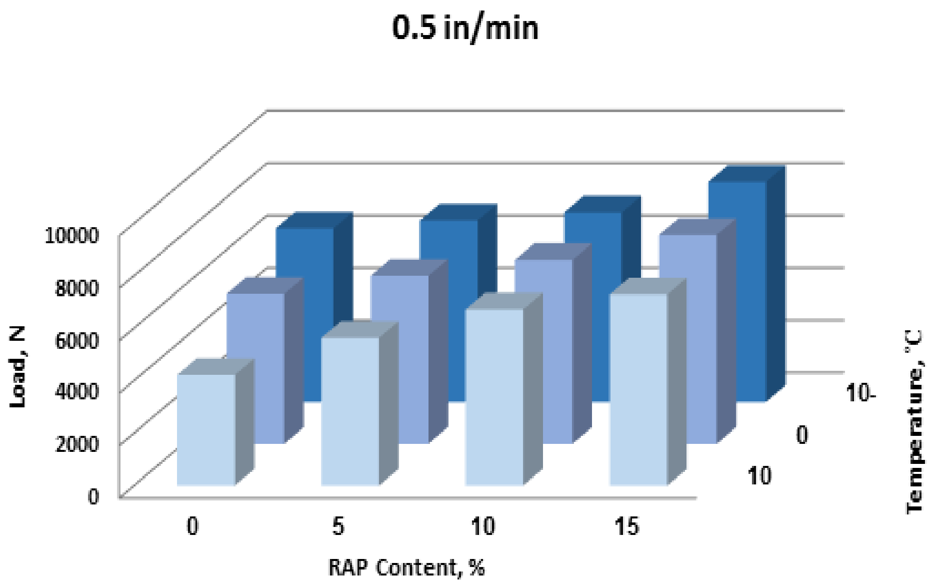

Figure 5: Effect of Temperature and RAP Content on Load at 0.5 in/min Rate of Loading.

The estimated fracture toughness (KIC) results are summarized in Figures 6 and 7, respectively. The estimated KIC values are increased extensively when the temperature is decreased from 10°C to -10°C under different rates of loading. The experimental outputs show that adding more reclaimed asphalt materials benefits asphalt mixtures to prevent cracking as temperature decreases. At –10ºC (14ºF), the stress intensity factor of the mixture increased 27%, as RAP content increased from 0% to 15. At 0ºC (32ºF), the stress intensity factor of the mixture increased 39% as RAP content increased from 0% to 15. At 10ºC (50ºF), the stress intensity factor of the mixture increased 73% as RAP content increased from 0% to 15.

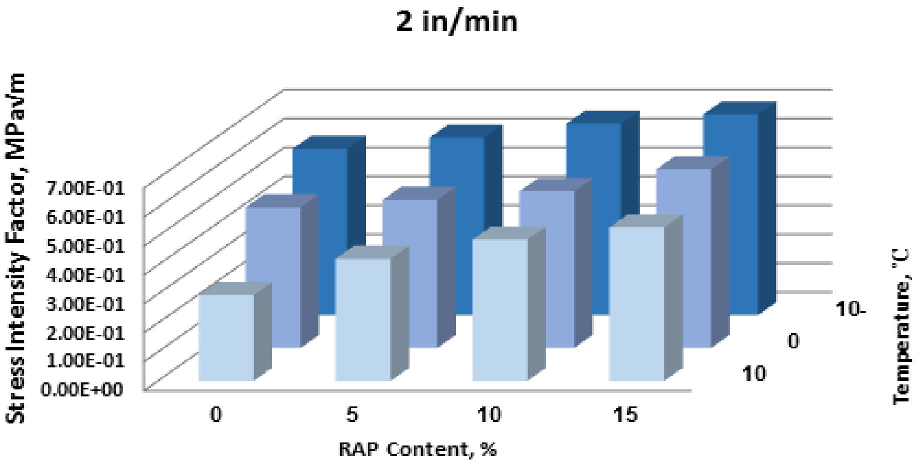

Figure 6: Effect of Temperature and RAP Content on Stress Intensity Factor at 2 in/min Rate of Loading.

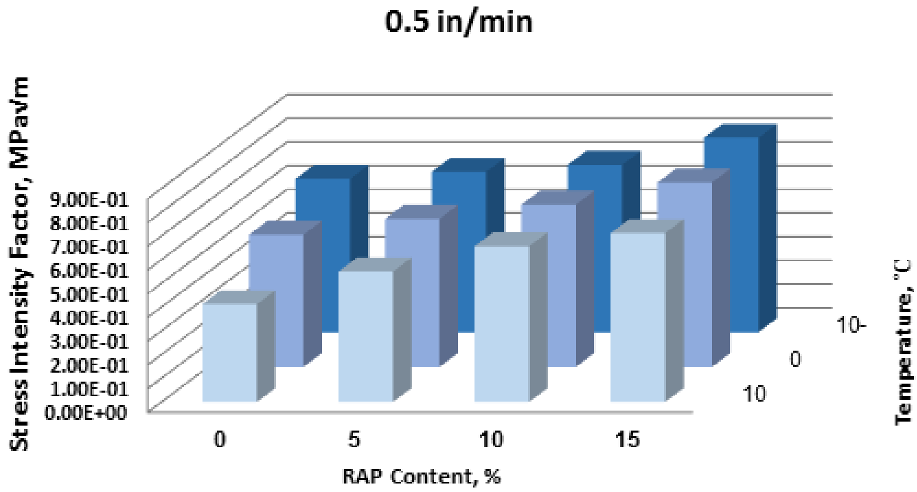

Figure 7: Effect of Temperature and RAP Content on Stress Intensity Factor at 0.5 in/min Rate of Loading.

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 thermal cracking resistance as a part of the performance characteristics of flexible pavement.
2. Inclusion of RAP results in an increase in the mixtures resistance to fracture failure in the SCB notched fracture test as well as the stress intensity factor values. At loading rate 2in/min., the inclusion of 15 percent RAP significantly increases the stress intensity factor by 20, 27, and 78.8% for -10, 0, and 10˚C testing temperatures when compared to control mixtures containing 0 percent RAP. On the other hand, with loading rate of 0.5in/min., the inclusion of 15 percent RAP significantly increased the stress

intensity factor by 26.7, 39.4, and 72.8% for -10, 0, and 10˚C testing temperatures when compared with control mixtures containing 0 percent RAP.

3. 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.

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