Effects of Reclaimed Asphalt Pavement on Mechanical Characteristics of Asphaltic Mixtures for Surface Layer

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Abstract. Reclaimed asphalt pavement (RAP) is considered one of the valuable alternatives to raw materials due to reducing the need to use raw materials, which are less in some world regions. It additionally reduces the highly-priced new bitumen required inside the asphaltic mixture manufacturing and contributes to the preservation of natural resources. To achieve maximum benefit from the integration RAP in asphaltic mixture, it is necessary to investigate the advantages and disadvantages of the recycling process on the properties of asphalt pavement. This study examines the effect of adding reclaimed asphalt pavement by different percentages on the mechanical properties of asphaltic mixture for the surface layer in terms of Marshall's stability, Retained Marshall stability, indirect tensile strength, and compressive strength. Two types of asphalt grade (40-50) and (60-70) were used in addition to one type of aggregate gradation of the wearing course to prepare the asphaltic mixture. The Superpave system was applied to select the best aggregate gradation and optimum asphalt content using Superpave Gyratory Compactor (SGC) and to prepare compacted asphaltic specimens of 100 mm diameter for simulating Marshall's molds. PAP is added by four different percentages of (7, 13, 19, and 25) % by the weight of the total asphalt mixture, and samples are prepared to compare the mechanical properties with conditional ones. The results show that adding RAP to the asphalt mixture improved the measured properties. In contrast, the mix containing RAP showed lower loss of stability, lower loss in indirect tensile strength, higher stripping resistance, and better durability than the mixture without RAP.

Keywords: Reclaimed asphalt pavement (RAP); asphalt mixtures; durability; Superpave gyratory compactor

1. INTRODUCTION

In Iraq, the traffic density and axle loading were significantly increased over the past years [1]. In addition to low maintenance services, road structures deteriorate more rapidly [2]. Therefore, one solution to this problem is improving the asphalt mixture to resist high stress and bad climate, reduce damage to the pavement, and increase its durability [3-6]. Currently, several additives and modifiers are utilized in asphalt production to improve its properties related to its performance [7,8]. However, using an alternative material like reclaimed asphalt is considered less expensive and environmentally beneficial [9,10]. And thus serve the sustainability that the world is heading towards today [11], besides the serious problems related to increasing waste disposal that leads to environmental pollution [12]. Reclaimed asphalt pavement (RAP) can be obtained from scraping old asphalt and is often grinded and stored for use in the new pavement as a part. However, aggregates and asphalt are constantly exposed to weather conditions that affect their properties during the years of service [13].

Hussain and Yanjun [14] evaluated the effect of RAP on the properties of asphalt mixtures. Various mixtures have been investigated, including two types of raw aggregates and two different sources of RAP. Marshall's approach has been used to design several RAP blends of mixtures (0 to 100%). The results of experiments have demonstrated that adding RAP material would enhance the properties of the mixtures.

In 2008, Al-Rousan [15] have prepared two hot asphalt mixes, one mix consisted of new aggregate and new asphalt, and the second one included 30% and 70% of RAP mixed with new aggregate and asphalt, respectively. Six compacted samples were in a water bath experiment at 60ºC for each mix. It has been noticed from experiments that including the recycling aggregates and asphalt in the "RAP Mix" enhanced the Marshall stability and decreased the loss of Marshall Stability over the "Control Mix" as well. It has been proven that using RAP strengthens the asphalt and makes it more solid, which leads to increased stability due to high viscosity of asphalt [15].

Colbert and You [16] presented that adding different values of RAP e.g. (15, 35, and 50) % increased resilient modulus by 52% and decreased rutting by 24%. In addition, it leads to dynamic modulus increasing and resilient modulus decreasing when the RAP value rises. Interestingly, including a higher percentage of RAP contents points out more rutting-resistant mixtures [16]. In [17], the author exhibited that the addition of different values of RAP (e.g., 10, 20, and 40) % to the mixture increased the importance of indirect tensile strength and tensile strength ratio; however, these values were decreased when the range of RAP content was equal to 50% [17]. The work explores the effect of adding RAP by various percentages on the mechanical properties of asphaltic mixture for the surface layer in connection with Marshall Stability, indirect tensile strength, Retained Marshall stability, tensile strength ratio, compressive strength, and index of retained strength.

2. MATERIALS AND TESTING

2.1 Bitumen

Two types of asphalt grade were used in this research: (40-50) and (60-70) which were brought from Al-Doura refinery in Baghdad. Physical tests were conducted and conformed to the limits of Iraqi specifications [18] and ASTM requirements [19]. The properties results were successful, as shown in Table 1. AASHTO M 323 specification [20] for calculating the amount of RAP used in the asphalt mixture indicated that the binder must be softened when using a RAP ratio of more than 15%, as shown in Table 2. Soft binder is more expensive; contractors do not want to pay additional amounts. For this reason, asphalt type 60-70 was used because it is suitable for high PAP ratios in super pave mixtures.

Table 1: Physical properties of (40-50) and (60-70) asphalt cement.

Test	Standard	Test Conditions	SCRB/ R9, 2003 specifications	Test value	
				(40-50)	(60-70)
Penetration	ASTM D5	100 gm, 25°C, 5 sec., (0.1mm)	40-50 And 60-70	44	66
Specific gravity	ASTM D70	25°C	-----	1.032	1.025
Ductility	ASTM D113	25°C, 5cm/min	+100	+113	+125
Loss on heating	ASTM D1754	163°C, 50gm, 5 hr	< 0.75	0.242	0.365
Flash and fire point	ASTM D92	…..	> 232 °C	335°C ,339°C	296°C, 320°C
Kinematic viscosity	ASTM D88	Pa.sec	-----	0.537@ 135°C 0.15 @ 165°C	0.475@ 135°C 0.113@ 165°C

Table 2: Guidelines for binder selection for RAP mixtures [20].

RAP Percentage in mix, %	Recommended Virgin Asphalt Binder Grade
<15	No change in the binder selection
15-25	Select virgin binder one grade softer than normal.
>25	Follow recommendations from blending charts

2.2 Aggregate

The crushed aggregate is brought from Al-Sedour quarry. It is commonly used in local road works. Table 3 shows some of its physical properties and conformity with the limits of ASTM specifications.

2.3 Mineral Filler

Limestone dust was used as a filler material in this research, and it was brought from the lime factory in Karbala Governorate. The physical properties of the limestone dust are shown in Table 4.

2.4 Reclaimed Asphalt Pavement (RAP)

The RAP was brought from one of the projects for the Mayoralty of Baghdad located in the Al-Talbiya area in Baghdad. An extraction test was performed on the RAP according to AASHTO T 164-01 [21]. The extraction test showed that the percentage of asphalt present in the RAP mixture was 4 percent, and the gradation of aggregates is shown in Table 5.

Table 3: Physical properties of used aggregates.

Tests		ASTM Specifications	Result			
Specific gravity	Coarse aggregates	ASTM C127	Sieve size	Apparent Gs	Bulk Gs	Abs.%
			12.5mm	2.64	2.623	0.41%
			9.5mm	2.614	2.583	0.54%
			4.75mm	2.591	2.573	0.47%
			Crashed sand (<#4)	2.679	2.64	0.63%
Soundness		ASTM C88 10-20% Max	4.3%			
Angularity		ASTM D 5821 Min 95%	97%			
Toughness, (Los Angeles Abrasion)	Aggregate Size < 25mm	ASTM C131 35 Max	20.88%			
Flat & Elongation aggregate	Flat	ASTM D4791 Max 10%	1%			
	Elongation		2%			
Equivalent sand (clay content)	Crashed (<#4)	ASTM D2419 Min 45%	96%			

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Table 4: Limestone dust physical properties.

Properties	Results
%Passing Sieve No.200 (0.075 mm)	96
Specific gravity	2.72

Table 5: RAP's sieve analysis after extraction.

Sieve size opening	% Passing for used RAP (by weight)	% Passing for SCRB Requirements (by weight)
19 mm	100	100
12.5 mm	99	90-100
9.5 mm	97	76-90
4.75 mm	73	44-74
2.36 mm	54	28-58
0.3 mm	30	5-21
0.075 mm	4.4	4-10

2.5 Mix Design

The gradation of the aggregates was designed to calculate the optimum asphalt content according to the superpave system. The gradation of the aggregates was selected according to the Iraqi specifications for surface layer SCRB, R9, and the superpave system. Figure 1 shows the selected gradation of the aggregates.

The percentage of optimum asphalt content was adopted according to 4 percent air voids, and it was concluded that the optimum asphalt contents were 4.8% and 4.7 % for (40-50) and (60-70) asphalt grades, respectively. Other properties of the asphaltic mixture were examined at the designed asphalt ratio to ensure that it conforms to the specification AASHTO M323-12. Table 6 shows the properties of the asphaltic mixture for (40-50) and (60-70) asphalt grades.

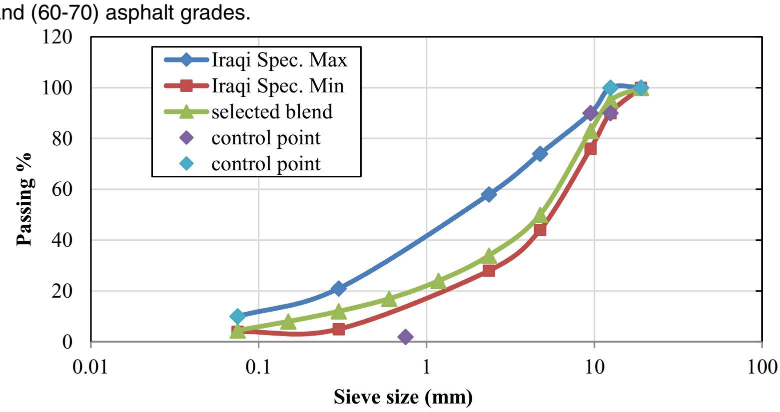

Figure 1: Gradation of the selected blend with specifications.

Table 6: Mixture properties at optimum binder contents according to superpave system.

Mix Properties	AASHTO M323 Criteria	Test Results	
		Asphalt grade (40-50) at 4.8% OBC	Asphalt grade (60-70) at 4.7% OBC
%VA	4.00%	4	4
%VMA Est.	13 % min	15.05	14.97
VFA est.	65% - 75%	73.44	73.3
Dust proportion	0.6 - 1.2	0.93	0.955
% G_{mm}@N_{ini}	less than 89%	88.47	87.8

3. RESULTS AND DISCUSSIONS

3.1 Marshall Properties

Figures 2 and 3 show the effect of RAP percent on flow and stability at optimum asphalt content (opt. AC) and plus 0.5% of optimum asphalt content (+0.5% Opt. AC), respectively. It is observed from Figure 2 that the value of flow is decreased gradually with increased RAP percent. Also, it can be noted that when the amount of asphalt added to the mixture is inserted, the amount of flow will also decrease with the increase in the amount of RAP added to the mixture. Figure 3 shows that the stability values increase with increasing the RAP contents added to the asphaltic mixture, where the highest stability value is achieved at 25% RAP. It is noticeable that these values are significantly lower when the optimum amount of asphalt is increased by 0.5%.

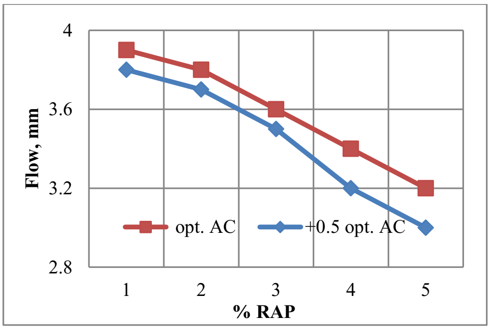

Figure 2: Relation between flow and RAP content at opt and +0.5 opt. AC.

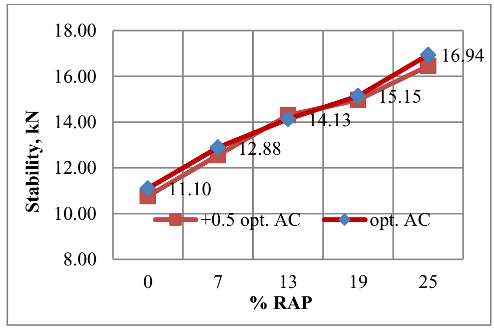

Figure 3: Relation between stability and RAP content at opt and +0.5 opt. AC

3.2 Retained Marshall Stability (RMS)

Figures 4, 5, and 6 illustrate the RMS with the immersion days. It is noted that these values are reduced when the water periods are increased from 1 to 7 days. It is found that RS values at the opt. AC is higher than values obtained when the amount of asphalt increases by 0.5%. This result is caused by water that attacks the adhesive bond between bitumen and aggregates in the asphaltic mix (stripping), leading to loss of cohesion (strength) and reduced mixture stiffness.

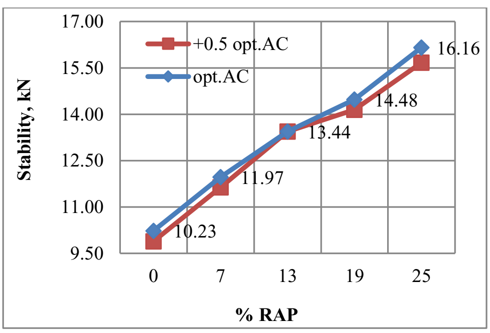

Figure 4: Stability for 1 day with % RAP.

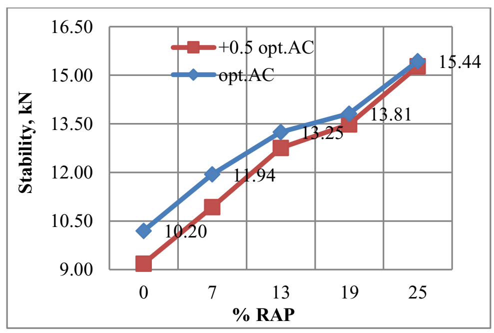

Figure 5: Stability for 3 days with % RAP.

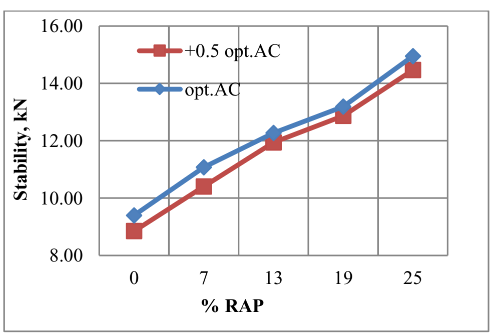

Figure 6: Stability for 7 days with % RAP.

It can be seen from Figures 7 and 8 that the RMS values decreased for all RAP percentages along immersion periods. Also, it is noted that RS increased when RAP content increased during one immersion period. Marshall Test results showed that adding PAP to the asphaltic mix improved Marshall Stability and reduced the loss of stability compared with conventional mixes. The reason may back to RAP hardening the asphalt mixture, which leads to an increase in stability because of an increase in the viscosity of the asphalt. It is noted that hardened asphalt had a higher viscosity than the origin asphalt; therefore, it would be less affected by the hot water when subjected to immersion, increasing RAP mix's stability.

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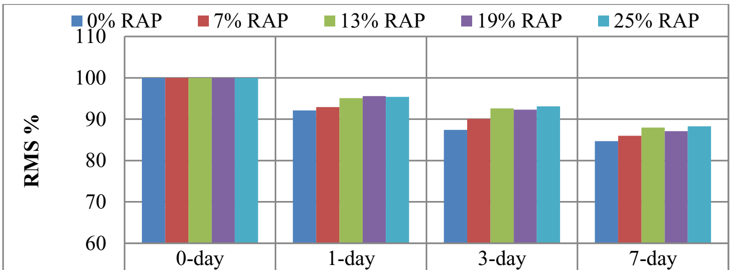
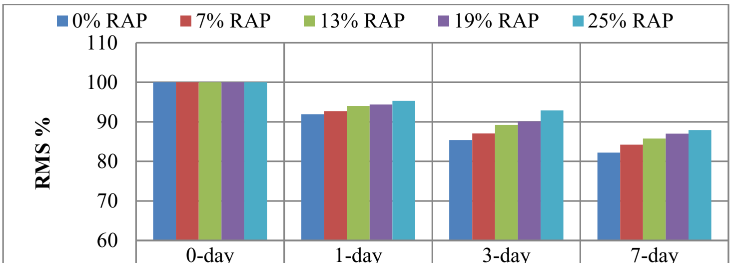


	0-day	1-day	3-day	7-day
0% RAP	100	92.1	87.4	84.7
7% RAP	100	92.9	90.1	86
13% RAP	100	95.1	92.6	88
19% RAP	100	95.6	92.3	87.1
25% RAP	100	95.4	93.1	88.3

Figure 7: Comparison between RMS values for RAP percentages at Opt. AC.



	0-day	1-day	3-day	7-day
0% RAP	100	91.9	85.4	82.2
7% RAP	100	92.7	87.1	84.2
13% RAP	100	94	89.2	85.8
19% RAP	100	94.4	90.1	87
25% RAP	100	95.3	92.9	87.9

Figure 8: Comparison between RMS values for RAP percentages at +0.5% Opt. AC.

3.3 Indirect Tensile Strength Test (ITS)

Figures 9 and 10 present the effect of the RAP adding on the results of (ITS) for the unconditioned sample at 25ºC and 60ºC for optimum asphalt ratio and + 0.5 percentage of optimum asphalt. The results have been compounded by the fact that ITS values increase with RAP increases. However, ITS values decrease with asphalt content increasing in the mixture.

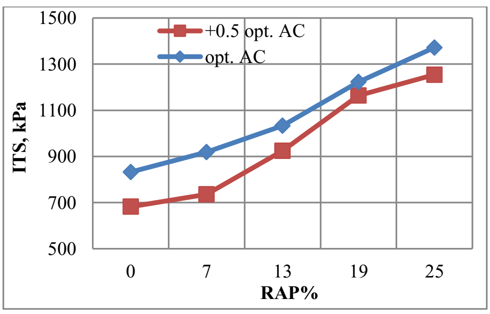


Figure 9: ITS for unconditioned sample at 25 ˚C.

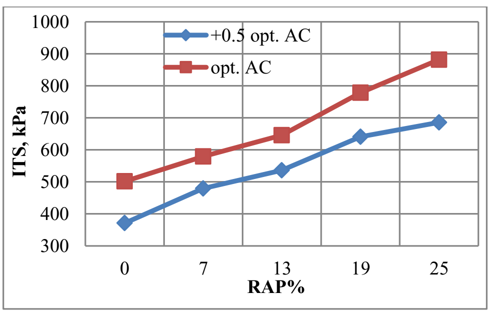


Figure 10: ITS for unconditioned sample at 60˚C.

Figures 11 and 12 show the results of ITS at 25ºC and 60ºC for optimum asphalt content and +0.5 plus the optimum asphalt ratios for the conditioned sample. The results show a decrease in its values when it is exposed to water, but it increases when the amount of RAP is increased, and it is found that the ITS values at the optimum asphalt content are higher compared to that contain +0.5 opt. AC of the mixture.

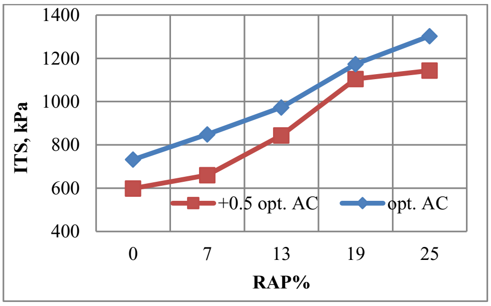


Figure 11: ITS for conditioned sample at 25˚C.

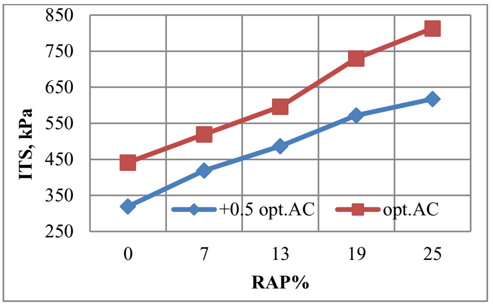


Figure 12: ITS for conditioned sample at 60˚C.

3.4 Tensile Strength Ratio

The results of the tensile strength ratio for asphaltic mixes at (opt. AC and +0.5 opt. AC) at 25ºC and 60ºC are shown in Figures 13 and 14, respectively. Results show that TSR is higher for mixes containing RAP than the original mix, and these values are increased with RAP increasing until 19% and then begin to decrease when the amount of RAP reaches 25%. Also, there is a decrease in TSR when the percent of asphalt content in the mixture is increased.

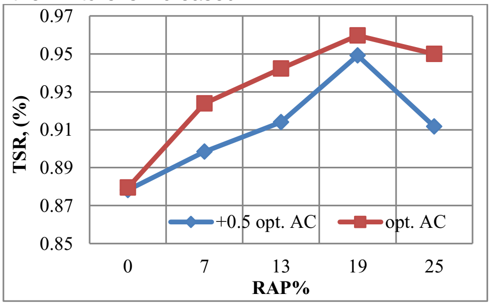


Figure 13: Result of TSR at 25ºC.

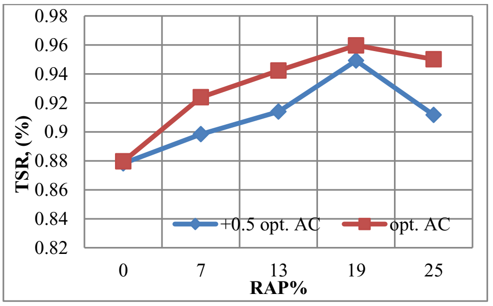


Figure 14: Result of TSR at 60ºC.

It can be observed that asphaltic mixtures containing RAP with different percentages showed lower loss of TSR than control mixes. The reason may be that RAP harden the asphalt mixture leads to increasing viscosity over time. However, asphaltic mixes with higher viscosity would play a better role when exposed to tension force and could show a lower reduction in tensile strength under moisture and high temperature. This result was consistent with the results of Fattah et al. [22].

3.5 Immersion–Compression Results

Figures 15 and 16 illustrate the compressive strength result for unconditioned and conditioned samples at (opt. AC and +0.5 opt. AC). The values of compressive strength at +0.5 opt. AC is higher than the values at opt. AC for an unconditioned sample because increasing the amount of asphalt will decrease the air voids and increase the density of the mixture, while the value at +0.5 opt. AC is decreased from the value of opt. AC for a conditioned sample because asphalt is affected by temperature causing softness in the mixture.

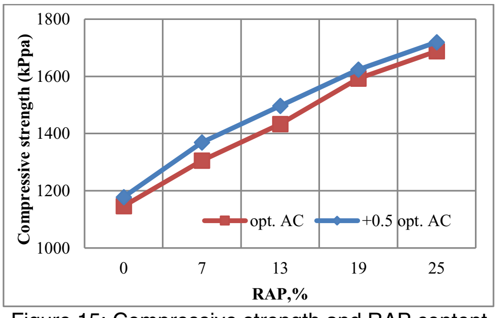


Figure 15: Compressive strength and RAP content for unconditioned sample at opt. AC and +0.5 opt AC.

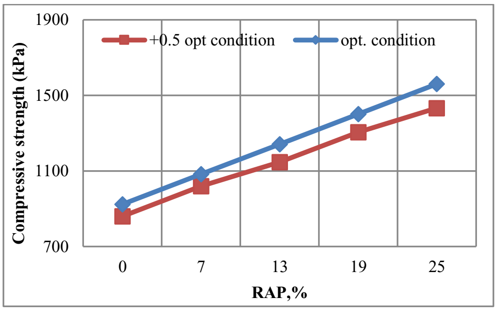


Figure 16: Compressive strength and RAP content for conditioned sample at opt. AC and +0.5 opt AC.

3.6 Index of Retained Strength (IRS)

Results of IRS at (opt. AC and +0.5 opt. AC) are shown in Figure 17. It was found that IRS values increased as RAP content increased and decreased when the amount of asphalt content increased in the mixture.

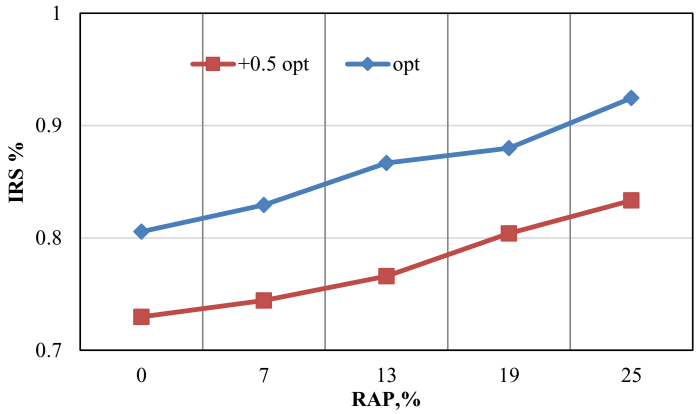


Figure 17: Relation between I.R.S and RAP content.

4. CONCLUSIONS

Based on the obtained test results, the following conclusions can be drawn:

- The Marshall's stability value is higher for the asphaltic mixture contained RAP percentage than the control mixture. These values gradually increase as the added RAP ratio increases to the mixture, reaching the highest value at 25% percent by weight of the total mixture.
- The Retained Marshall Stability (RMS) values for all RAP percentage decreased along immersion periods. The RMS values increased with RAP content increasing for 1 day immersion, and the RMS values for opt. AC is higher than mixture with +0.5 opt. AC.
- The indirect tensile strength for asphaltic mixtures at optimum asphalt content and +0.5 optimum asphalt content increased with RAP percentage for conditioned and unconditioned samples, and the higher value was obtained when the weight of total mix adds 19% of RAP content.
- The values of compressive strength increased with increase RAP percent. The value at +0.5 opt. AC is higher than the value at opt. AC for unconditioned sample, while the value at +0.5 opt. AC is decreased from the value of opt. AC for conditioned sample.
- The index of retained strength value gradually increased when the RAP increased and decreased when the amount of asphalt content added to the mixture increased by 0.5 percent.

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