Effect of High RAP Content on Marshal Performance of Hot Asphalt Mixture for Surface and Binder Layers

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Abstract. Recently, the exhaustion of new aggregates and the rising price of " raw materials" have caused the increasing exploitation of "reclaimed asphalt pavement "(RAP) in pavement construction and rehabilitation. It is being reported that the usage of RAP does not only reduce the cost of pavement construction projects due to the less consumption of asphalt and aggregate but also saves land resources and greatly protects the environment, Where the same materials used in the construction of the original highway system can be reused to rebuild, repair and maintain it. Where appropriate, recycled Aggregates and other highway construction materials make a good economy; in the" environmental and engineering' sense, with supply limited and demand increasing, HMA producers have begun the use of "Reclaimed Asphalt Pavement" (RAP) as a value component of the" HMA." For this reason, there is renewed interest in increasing the amount of RAP used in hot mix asphalt (HMA). Although many factors affect the use of RAP in asphalt paving, the two main factors are "Economic savings " and " Environmental benefits." RAP is a useful alternative to raw materials. It reduces the use of virgin aggregates and the amount of "virgin asphalt binder required HMA productions, this study highlight how RAP impacts environmental and economic terms through the use of different percentages of RAP (10, 15, 20, and 25%) from the total weight of the mixture for the surface layer, and the change of (30, 40, 50, and 60%) of the total weight of the mixture for the binder layer used in the "HMA-RAP" composition that was heated at a temperature of “150°C” and then mixed with a total temperature of “170-180°C” plus asphalt at a temperature of “153°C” so the new mixing temperature, obtained at “148- 153 ° C" to obtain the ideal recovery of the reclamation, where the asphalt binder is restored rheological properties as this temperature is considered the recovery point of the asphalt binder. The results of mixing different ratios of RAP in the hot mixture showed that a large amount could be mixed in both layers and does not exceed (20%) in the surface layer and (50%) in the bond layer. This is because the Marshall stability was the highest possible during these ratios. As for increasing or decreasing these ratios, it led to a decrease in Marshall stability. The test results showed that with the increase of the amount of RAP in the mixture asphalt, the optimum value of the asphalt level (OAC) included in the asphalt mixture decreased as the percentage of asphalt used in the surface layer was reduced from (4.9 to 3.92%) When adding 20% of the RAP, and (4.6 to 2.3%) When adding (50%) of the RAP for the binder layer. This, in turn, leads to a decrease in the cost of asphalt, which is included in the asphalt mixture, and the results showed that the mixture stability to the influence of water, changes in temperature, and bonds between new materials (asphalt and aggregate) with RAP material was still good.

Keywords: Reclaimed asphalt pavement; Marshall stability; HMA-RAP.

1. INTRODUCTION

Sustainability is a societal concept of high importance today; this concept can be described as meeting the needs of the present time without compromising the ability of "future generations" to meet their own needs. Sustainability has a broad scope ranging from "economics to agriculture to building." In construction, sustainability can be achieved through raw materials, reduced emissions, and energy consumption [1]. It also mentioned that asphalt concrete producers evaluated "sustainable building practices" by adding" recycled materials" and using new technologies. Therefore, the sustainability of asphalt concrete is met today in our society easily by using "Reclaimed asphalt pavement" (RAP) with hot mix asphalt (HMA). Because of the increased cost of construction and rehabilitation programs of the sidewalk," recycled asphalt pavement," RAP has proven to be" economical and a valuable resource [2,3]. The cost of asphalt can be reduced due to less use of asphalt and aggregates, but also saves land and significantly safeguards the" climate" [4,5] in the early 1990s (FHWA)The (US Environmental Protection Agency) has estimated that just under 100 million tons of asphalt pavement reusable material is reclaimed each year. Over 80 percent of RAP is recycled, making asphalt one of the most frequently recycled materials [6].RAP is widely used as a substitute in bonding raw asphalt into reclaimed asphalt paving and is also used as a sub-base or as a granular base, the stable base aggregate, and the filling material or the dam. It is also used in other construction applications. RAP is a file of high-quality, valuable material that can replace more expensive virgin aggregates and binders.

Reclaimed asphalt pavement(RAP) innovation is a fix coming about because of the asphalt scratching process that contains asphalt and total. This material is created when the asphalt layer is eliminated for recreation, returning the surface layer or destroying the asphalt because of utility establishment, this strategy was tried in the field in Indonesia in 2007 by the innovative work organization for public deals with the(

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Palimanan – Jatibarang) street with a length of roughly 3.5 km, while in 1989 the asphalt foundation utilized hot asphalt blended RAP [7], in light of the above issues, creating asphalt innovation, one of the technologies is vital, that has been created is the utilization of old recovered asphalt (RAP) as an asphalt material.

Reclaimed asphalt pavement (RAP) is an elective innovation that is valuable for asphalt materials since it diminishes the requirement for normal total use and materials of the new asphalt binder required in the asphalt mix with the goal that it can save development costs and less squander material which significantly affects the climate. In light of studies that were directed by the American asphalt affiliation, the normal level of RAP utilized in asphalt mixes expanded in 2009 by 15.6%, expanding to 20.4% in 2014, with an expected number of RAP utilized in asphalt mix at 71.900.000 tons. Accepting a 5% asphalt level on RAP, it is equivalent to 3.6 million tons of asphalt investment funds and 68 million tons of normal total [8]; there are four major asphalt production cost categories: materials, plant production, trucking, and lay down (i.e., construction). Materials are the most expensive production cost category, comprising about 70 percent of the cost to produce HMA. The asphalt binder is an asphalt mixture's most expensive and economically variable material. It is most commonly used in the intermediate and surface layers of flexible pavement to provide tensile strength, resist distortion, protect the asphalt pavement structure and subgrade from moisture, and provide a smooth, skid-resistant riding surface that withstands wear traffic. One of the causes of pavement deterioration is traffic loads and the aging factor [9]. The Asphalt Institute (2007) stated that the most economical use of RAP is in the intermediate and surface layers of flexible pavements, where the less expensive binder from RAP can replace a portion of the more expensive virgin binder [6]. Figure 1 shows estimated asphalt production cost categories according to (FHWA).

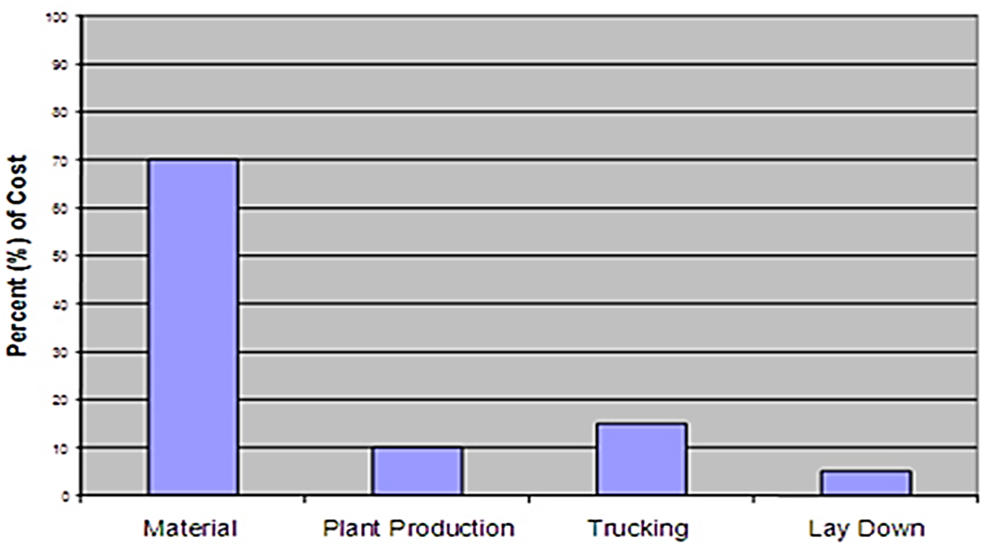

Figure 1: Estimated asphalt industry cost levels according to [5].

The following points can summarize the objective of the present study:

- Analysis of the laboratory characteristics of the performance of HMA mixtures containing different ratios of RAP and compatible with (SCRB) and accepted specifications using laboratory tests.
- Evaluation of the optimal ratio of RAP added to both the surface and bond layers.
- Evaluating and analyzing the laboratory results for the decrease in the optimal asphalt content and reducing the production cost of the local asphalt content.

2. MATERIALS AND METHODS

2.1 Properties of RAP Materials

The RAP material was collected from Baghdad city, the capital of the Republic of Iraq, and its asphalt content was found to be 4.6% according to ASTM D6307-10 “Asphalt content by ignition. Furnace” [15] with a penetration score (40-50) and its gradation according to [14] represented in Figure 2 (Municipality Baghdad, 2014).

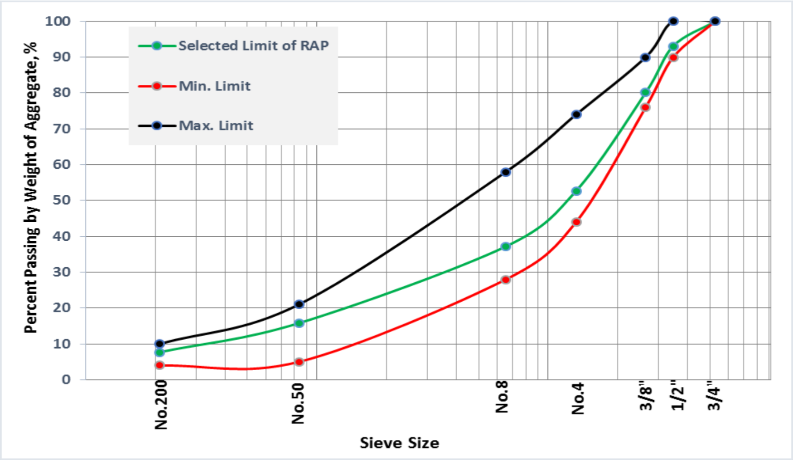

Figure 2: Specification limits and RAP gradation of (SCRB, 2003) for surface course layer.

50 mm removed from the asphalt layer's top and collected from the damaged paving surface. RAP was ground after collection and sieving. They are recharged in predetermined proportional amounts percent with virgin aggregate and new asphalt grade (40-50). Coarse and fine RAP were used in this study. Figures 3 and 4 show fractionated samples (coarse and fine) of the Reclaimed Asphalt Pavement (RAP).

Figure 3: Process RAP from Baghdad city.

(a) Fine RAP (b) Coarse RAP

Figure 4: Fractionated samples (course and fine) of the reclaimed asphalt pavement (RAP).

3.2 Asphalt Properties

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

Table 1: Physical properties of asphalt cement.

Tests	Standard	Unit SCRB	Tests value	Standards Limitations as per to SCRB / R9, 2003
Penetration, 25°C	ASTM D 5	1/10 mm	42	40-50
Ductility, 25°C	ASTM D113	cm	164	>100
Softening Point	ASTM D36	˚C	52	……
Specific gravity, 25°C	ASTM D70	……	1.04	……
Flash and fire points	ASTM D92	˚C	295°C	> 232°C
Rotational Viscosity a (centistokes)	ASTM D4402	……	543@135ºC	……

3.3 Aggregate

This study used two coarse and fine aggregates from (Al-Nibaee quarry in Taji). This aggregate combination was chosen in order to produce the following:

For the surface layer, a 12.5 mm mixture, according to (SCRB/R9, 2003). The gradation of coarse aggregate ranges between 3/4" (19 mm) and No.4 sieve (4.75 mm), and the binder layer is a 19 mm mixture according to [14]. The gradation of coarse aggregate ranges between 1" (25 mm) and No.4 sieve (4.75 mm). In comparison, the gradation of fine aggregate for both layers ranges between passing the No.4 sieve (4.75 mm) and retaining the No.200 sieve (0.075 mm) according to SCRB specification [14]. The physical properties of the used aggregate are shown in Table 2. The coarse and fine aggregate used in this study is sieved and recombined in the laboratory in the proper proportions using a sieve shaker vibrator to prepare the selected gradation and to meet the surface course gradation, as required by SCRB specification [14].

Table 2: Physical properties of (Al-Nibaee quarry in Taji) aggregates.

Property	Coarse Aggregate		Fine Aggregate	
	Result	**ASTM Designation**	**Result**	**ASTM Designation**
Bulk Specific Gravity	2.574	C127	2.604	C128
Apparent Specific Gravity	2.633	C127	2.69	C128
Percent Water Absorption	0.362	C127	0.480	C128
Percent Wear (Los-Angeles Abrasion)	20.8%	C535	-	C131

3.3.1 Aggregate Gradation

The selected gradation for the aggregate is shown in Table 3, Figures 5 and 6, and met the surface course gradation, as required by SCRB specification [14] for hot-mix asphalt paving mixtures of aggregate nominal size (12.5 mm)for the surface layer, and the selected gradation for the aggregate is shown in Table 4, Figures 6 and 7, and met the surface course gradation, as required by SCRB specification [14] for hot-mix asphalt paving mixtures of aggregate nominal size (19 mm)for binder layer.

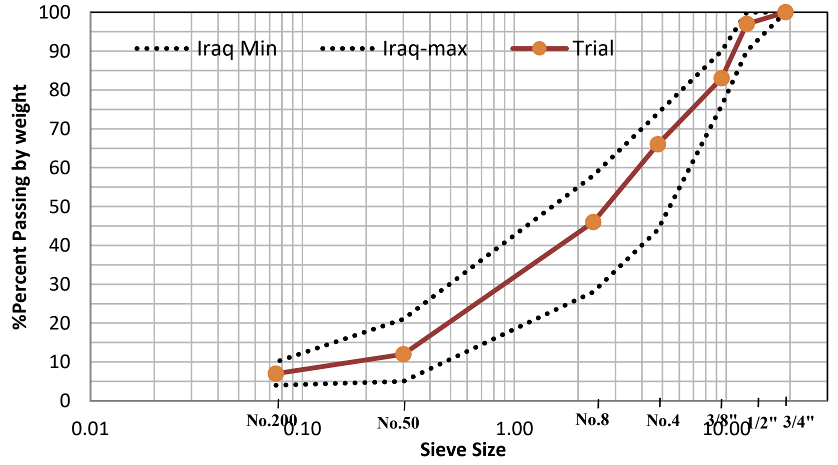

Figure 5: Specification limits and mid-point gradation of (SCRB,2003) for surface course layer.

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Figure 6: Selected surface course gradation to produce RAP mixtures.

Table 3: Combined aggregate and mineral filler gradation for surface course layer.

Sieve Size	Sieve size (mm)	Percentage passing by Weight of total Aggregate	
		Specification Limits [S.C.R.B]	Selection Gradation
3/4"	19	100	100
1/2"	12.5	90 - 100	97
3/8"	9.5	76 - 90	83
No.4	4.75	44 - 74	66
No.8	2.36	28 - 58	46
No.50	0.3	5 - 21	12
No.200	0.075	4 - 10	7

Table 4: Combined Gradation of Aggregate and Mineral Filler for Binder Course Layer.

Sieve Size	Sieve size (mm)	Percentage passing by Weight of total Aggregate	
		Specification Limits [S.C.R.B]	Selection Gradation
1"	25	100	100
3/4"	19	90 - 100	94
1/2"	12.5	70 - 90	88
3/8"	9.5	56-80	64
No.4	4.75	35-65	50
No.8	2.36	23 - 49	35
No.50	0.3	5 - 19	10
No.200	0.075	3 - 9	6

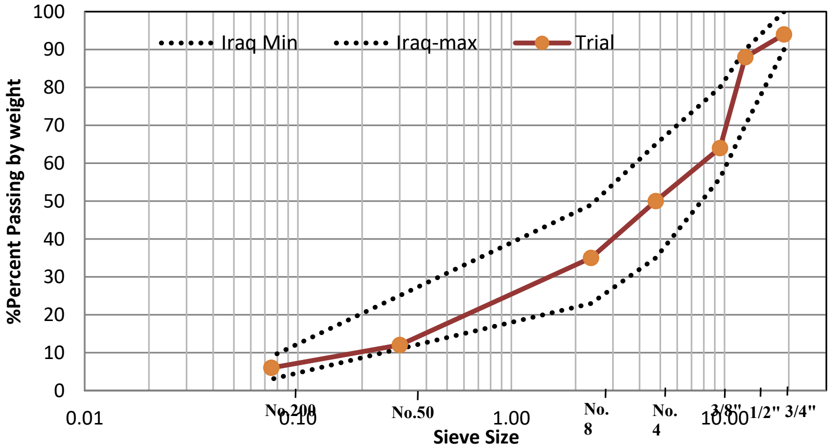

Figure 7: Specification limits and mid-point gradation of (SCRB,2003) for binder course layer.

2.4 Marshall Mix Design

The main objective of the asphalt mix idea is to get an affordable mix that will bear "heavy traffic loads" under different climatic conditions from a few primary mixes. The selected aggregate result and the content of the asphalt binder shall be such that the resulting mixture shall satisfy the accompanying conditions [9]. The test procedure is used in evaluating and designing asphalt pavement mixes and is extensively used in the routine testing plan for paving jobs. There are two major traits of the Marshall process of designing mixes, stability – flow and density–voids analysis test Strength is computation in the limit of the "Marshall's stability" of the mix according to the specification [10], the optimum asphalt content (OAC) for the HMA mixture is determined and is found to be 4.9 % (by wt. of total mix) for surface layer and 4.6% (by wt. of total mix)for the binder layer.

2.5 Methodology of Adding RAP

Virgin HMA mixtures were mixed with four different percentages of RAP (10, 15,20 and 25) % (by weight of total mix) for the surface layer and four different percentages of RAP (30, 40,50 and 60) % (by weight of total mix) for binder layer. First, the fractionated RAP obtained from Baghdad city 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 two h [11], 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. 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 the 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, batching a RAP mixture in this study. Figure 8 represents the theory of incorporation of RAP into the asphalt mixture.

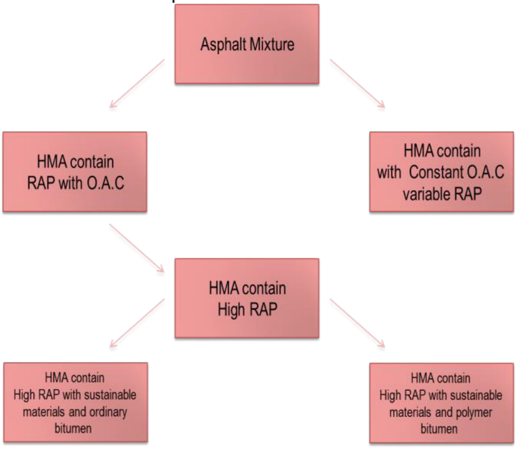

Figure 8: Represents the theory of incorporating RAP into the asphalt mixture.

3. RESULT AND DISCUSSION

3.1 Optimum Asphalt Binder Content in Mixture

The optimum asphalt binder content of the mixtures for the surface and binder layers is determined according to [12,13]. Using five percentages of asphalt contents (3.75, 4.25, 4.75, 5.25, and 5.75%) by weight of the mixture, optimum Asphalt Content is found to be 4.9 and 4.6% for the surface and binder layer, respectively, which is within the range of SCRB specification (R9/2003).

3.2 Optimum Asphalt Binder Content in Mixture with RAP

Marshall's test was carried out to evaluate the performance of the asphalt mixture properties of samples with different ratios of RAP, and the results were taken and analyzed according to [10]. The decrease in the optimum asphalt ratio added to the hot asphalt mixture with RAP was calculated according to the theory that RAP was added to the mixture and the mixing method. The calculations for asphalt binder replacement for different types of RAP used in this study are clearly illustrated in Tables 5 and 6 for the binder layer and Figure 9 for both the surface and the binder layers.

Table 5: The change in the optimum asphalt ratio is shown with the change in the RAP ratios added for the surface layer.

RAP Content, %	Asphalt content, %
10	4.41
15	4.165
20	3.92
25	3.675

Table 6: Change in the optimum asphalt ratio with the change in the RAP ratios added to the binder layer.

RAP Content, %	Asphalt content, %
30	3.22
40	2.76
50	2.3
60	1.84

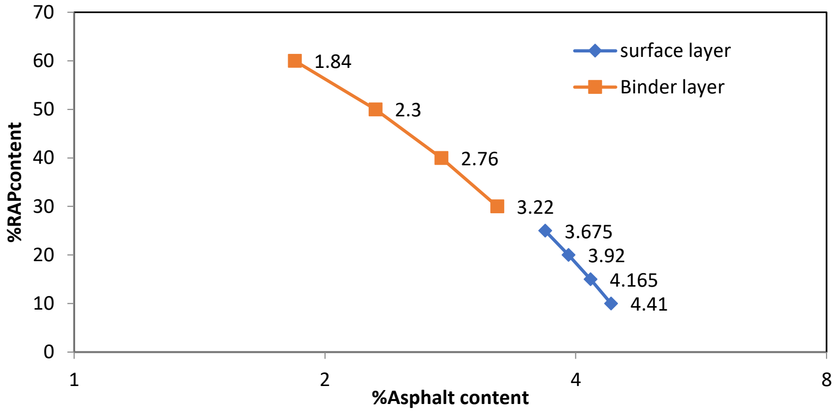

Figure 9: The change in the optimum asphalt ratio is shown with the change in the RAP ratios added for the surface layer and binder layer.

3.3 Marshall Results for RAP Mixtures with (OAC)

In order to study the optimal value of RAP for each paving layer, we had to determine the (OAC) value for each layer, take samples, and perform a Marshall test for it at 20% and 50% relative to the surface layer and the binder layer, respectively, had the highest stability in the Marshall apparatus. Table 7 and Figure 10 represent the calculations of the change in RAP ratios with the stability (OAC) with Marshall's results for the surface and binder layers, respectively**.**

Table 7: The calculations of the change in RAP ratios with the stability (OAC) with Marshall's results for the surface and binder layers.

Surface layer			Binder layer		
Optimum Asphalt content, %	RAP Content, %	Marshall stability, kN	Optimum Asphalt content, %	RAP Content, %	Marshall stability, kN
4.9	10	9.85	4.6	30	11.7
4.9	15	10.42	4.6	40	13.19
4.9	20	11.36	4.6	50	15.37
4.9	25	10.6	4.6	60	14.34

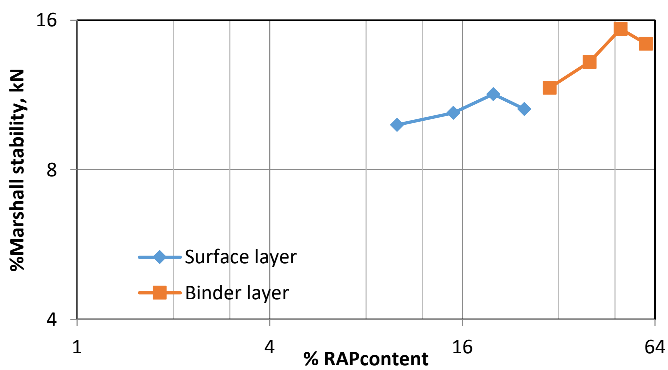

Figure 10: Change in RAP ratios with the stability (OAC) with Marshall's surface and binder layer results.

4. CONCLUSIONS

Based on the analysis and discussion of the effect of RAP material on the performance of the hot mixture, the following conclusions are obtained:

- The overall percentage gradient in the asphalt mixture determines the percentage of RAP that can be used in this study. Variable high percentages (10, 15, 20, and 25) % of RAP in the surface layer and (30, 40, 50, and 60) % used' RAP" material in the binder layer.
- The density of the asphalt mixture containing RAP decreases with the increase in the proportions of RAP added beyond the optimum ratio for each layer because of the method used to add RAP to the asphalt mixture. Therefore, the density decreases with increasing the percentage of RAP added more than the optimum percentage for each layer, where the RAP materials are first heated to 150 °C and then mixed with virgin and new aggregates. Asphalt ratio with a new aggregate temperature of 170-180°C and then the mixing temperature is reduced to 138°C to 141°C.
- Based on the results of Marshall stability, the asphalt mixture containing RAP at a rate of 20% and 50% for both surface and binder layers, the stability was higher at these ratios, which indicates that the percentage of effective asphalt in these asphalt mixtures is sufficient to achieve good and strong bonding between the aggregate and RAP.
- The process of adding RAP to the hot asphalt mix contributes to the decrease in the optimal content of asphalt; according to the calculations made, it was found that the optimal percentage of asphalt for the surface layer is reduced by 20%, and it is reduced by half in the bonding layer, and it was also noted that the amount of new asphalt meets the requirements of asphalt in the mix.
- Adding RAP to the mixture in the binder layer reduces the optimum percentage of asphalt in the asphalt mixture, and accordingly, the cost used is reduced by 50%, but it requires twice the mixing time compared to the usual mixture.

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