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Characterization of Incorporating RAP Materials to the Asphalt Layers of Pavement Structure

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ABSTRACT

Recycling the old paving waste and reusing it in the construction of new highways was resorted to, and this is a good step from an economic point of view, as well as from an environmental and health point of view, as it reduces carbon emissions and eliminates a large amount of disposable reclaimed asphalt pavement materials (RAP). This study aims to evaluate the best layer of pavement structure; base, binder, and surface layers for inclusion (RAP) materials based on stability and indirect tensile strength. In addition, highlight the best percentage that can be added from RAP to achieve positive results and better than that associated reference mixture in terms of Marshall test and Indirect tensile strength test RAP materials collected from different sources Karbala and Fallujah, were adopted in this study at percentages of 20%, 30%, and 40% by weight of the asphalt mixture. Two scenarios of incorporating RAP materials have been adopted : The first is considered that RAP as a black rock in which the effect of aged binder surrounding the aggregate of RAP is neglected while the second is not considered RAP as black rock and the influence of aged binder in RAP materials has been taken into consideration. Dora bitumen has been adopted in the current study which is used commonly in Iraq. It has been highlighted that the best layer in which RAP can be incorporated is the base layer, with a percentage up to 40% that RAP without considering RAP black rocks regardless of the sources of RAP.

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1. Introduction

The road network is considered one of the most important infrastructure of the civilized service in the country, and the asphalt paving is one of the most important layers on which the construction of this network depends, and this in turn depends on the raw materials and raw bitumen. Recycling the old paving waste and reusing it in the construction of new highways was resorted to, and this is a good step from an economic point of view. In this regard, the process of recycling the waste of the old paving is a good step from an economic and environmental point of view. Increase in the cost of producing asphalt during 1970, the period of the Arab oil embargo, led to a tendency to recycle old asphalt (RAP) in the production of asphalt mixtures **(Kandhal, 1997)**. In fact, there are other reasons, including economic, environmental and social **(Willis, 2014)**. RAP is considered the best alternative to aggregates in the asphalt mixture because it contains high quality materials in addition to being within the standard specifications. Large quantities of RAP can be recycled up to (100%), how to obtain RAP is either by using a skimmer machine that removes a thickness of 50 mm or using heavy machinery to

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completely remove the old asphalt layer. The first method is completely better because it can get RAP free from bugs and also allows traffic operation through working. The results indicate that the inclusion of RAP in manufacturing asphalt mixture gives better mechanical properties than that of the conventional mixture **(Tabaković, 2013)**. The old asphalt can be recycled by up to 100%, meaning that the virgin aggregate can be dispensed which could lead to great benefit from an economic and environmental point of view **(Zaumanis et al., 2014)**. It is therefore that the use of RAP in the manufacture of asphalt mixtures has become more common in many countries, including America, Holland, Spain, France, India, Australia, China, Japan and other countries. Can RAP be considered as black rocks? is the old bitumen found in RAP can be effective and rejuvenated and mixed with the new bitumen? This question has not been answered definitively, even after 30 years of submitting the application **(Shingles, 2014)**. Most US agencies specify that adding 15% or less of RAP to the asphalt mixture does not change the degree of added bitumen, i.e. RAP is considered black rocks , but if the proportion of RAP exceeds (15%) here, the degree of bitumen must be modified, which means that RAP cannot be considered as black rocks **(McDaniel & Anderson, 2001).**

(Oliver, 2001) produced an asphalt mixture containing 50% of RAP and 50% virgin materials and made a hot asphalt mixture but added the proportion of bitumen half the calculated percentage assuming that the RAP contained pre-bitumen to evaluate the performance of asphalt mixtures containing RAP materials. **(Stephens et al., 2001)** preheated RAP before mixing it with virgin materials, the aim was to determine the degree of mixing between RAP and virgin bitumen. Therefore, if RAP is considered black rock, the preheating does not affect RAP, but the result was the opposite, as it was noted that there was a partial blending between RAP and virgin bitumen. **(Miró et al., 2011)** manufactured three high moduli of asphalt mixtures containing different percentages of RAP materials 15, 30, 50% as well as a reference mixture that does not contain RAP martials. It was concluded that the rutting depth of high modulus asphalt mixes containing RAP had better performance in terms of rutting resistance than that of reference mix. **(Pradyumna et al., 2013)** reported that adding 20% of RAP to the hot asphalt mixture of surface layer with the addition of a regeneration agent of 10% by weight of bitumen resulted in higher rutting resistance than the reference mixture, as the rutting depth of the mixture containing 20% of RAP was (7.6) mm, while the rutting depth of the reference mixture was (8.2) mm after (20000) passes which made the mixture containing RAP had higher resistance to rutting than the reference mixture. In Iraq, RAP has not been used in road construction or maintenance yet, but there are laboratory studies from a number of researchers in Iraq to support the use of RAP and to get a benefit from it applying these research outcomes. **(Abd et al., 2018)** adopted advanced technique, Nanoindentation to investigate level of blending between RAP and virgin materials for mixtures incorporating some warm additives such; Sasobit, Rediset WMX and Rediset LQ and concluded that RAP cannot be considered as black rocks even with inclusion RAP materials up to 40%. Furthermore, a novel protocol was reported to fine a complete blend between RAP and virgin materials.

In Iraq, some limited studies have addressed the possibility of using RAP materials in asphalt layers. **(Hasan, 2012)** used RAP with a recycling agent to create a hot asphalt mixture for a surface layer. Based on the results, RAP is recommended to be used up to 60% and this percentage is very useful, especially from an economic and environmental point of view, Therefore, it is recommended to check the use of a better recycling agent as well as study the mixing blending case between raw materials and recycled materials. **(Ismael 2018)** studied the possibility of using RAP materials in a cold asphalt mixture. In fact, the improving in the moisture resistance could be due to the presence of cement (replace filter) with presence of water. Therefore, further investigation is needed Another study carried out by **(Mohammed 2019)** to evaluate the applicability of inclusion of RAP materials in the mixtures of surface and base layers but with limited results and scenarios. The recommendation was also reported also to investigate the different source of RAP and its regeneration. **(Dawood 2021)** evaluated the moisture damage of asphalt mixture containing 20% and 40% RAP materials with inclusion of regenerating agent It was found that all values of tensile strength ration TSR were higher than that of reference and greater than 80% especially in case of inclusion regenerating agent which worked to increasing the adhesion between RAP and virgin materials in which the TSR ratio improved and increased.

Accordingly, this research addresses the possibility of using RAP materials in the layers of asphalt mixtures of pavement structure based on the results of stability and indirect tensile strength taking into account the scenario of inclusion such materials either black rock scenario or not a black scenario.

2. Materials

Materials were collected locally from inside Iraq. Laboratory tests for these materials were conducted as shown below.

2.1 Binder

One source of bitumen was used in the current research, namely Dora, which is commonly used in Iraq nowadays in constructing pavement and was brought from the Dora refinery directly. Basic laboratory tests in terms of penetration, softening point and viscosity were conducted in order to find the raw properties of bitumen, as shown in **Table 1**.

Table 1- Physical properties of Dora bitumen

Property	Value	ASTM Designation
Penetration at 25°C (0.1 mm)	48	(ASTM-D5, 2012)
Viscosity at 135°C(cp)	525	(ASTM-D4402, 2012)
Viscosity at 165°C(cp)	143	(ASTM-D4402, 2012)
Softening point °C	47	(ASTM-D36, 2012)
Specific gravity	1.03	(ASTM-D70, 2010)

2.2 Aggregate

Coarse aggregate was brought from the Tigris arm quarry which is located north-east of Ramadi, while fine aggregate was brought from Hammurabi Company which is a governmental company worked in the field of construction at Governorate of Anbar. Physical properties of both aggregate were performed in the Roads Laboratory at University of Anbar, College of Civil Engineering as shown in **Table 2**. It should be noted, as previously mentioned, three asphalt mixtures were adopted in the current study, surface, binder and base **Table 3** & **Figures** 1, 2, and 3 show the gradation of those mixtures.

Table 2- Physical properties of aggregate

Laboratory Test	Coarse aggregate	Fine aggregate	ASTM Designation
Bulk Specific Gravity	2.611	2.513	**(ASTM-C127, 2015)**
Apparent Specific Gravity	2.626	2.628	**And**
Water absorption%	0.2	1.7	**(ASTM-C128, 2012)**

Table 3: Weight of asphalt for all mixtures

Sieve No.(in)	base course		binder course		surface course	
	Specification limit (SCRB 2003/R9)	Passing (%)	Specification limit (SCRB 2003/R9)	Passing (%)	Specification limit (SCRB 2003/R9)	Passing (%)
37.5	100	100	100	100	100	100
25	100-90	95	100	100	100	100
19	90-76	83	100-90	95	100	100
12.5	80-56	68	90-70	80	100-90	95
9.5	74-48	61	80-56	68	90-76	83
4.75	59-29	44	65-35	50	74-44	59
2.36	45-19	32	49-23	36	58-28	43
0.3	17-5	11	19-5	12	21-5	13
0.075	8-2	5	9-3	6	10-4	7

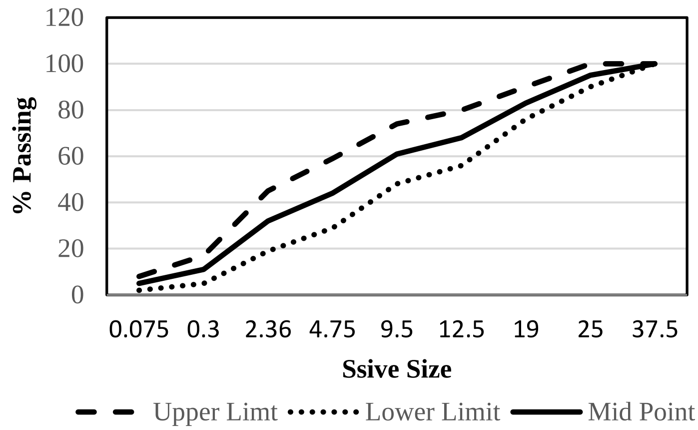


Fig. 1: Gradation of aggregate for Base coarse mixture

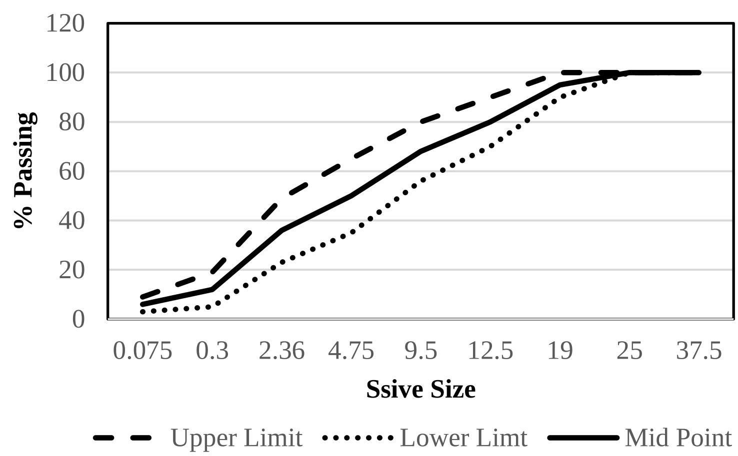


Fig. 2: Gradation of aggregate for binder course mixture

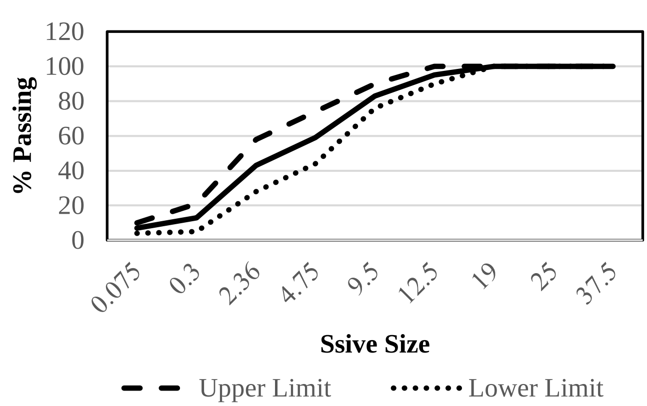


Fig. 3: Gradation of aggregate for surface course mixture

2.3 Filler

The used filler is locally manufactured dust limestone collected from Fallujah. Laboratory tests were performed in order to measure some properties as presented in **Table 4**

Table 4: Physical properties of limestone filler

Property	**Test Result**
Bulk specific gravity	2.770
Passing sieve% No.200 (0.075 mm)	75

2.4 Reclaimed asphalt pavement materials

RAP is one of the most important materials that are widely used in recycled asphalt mixtures, especially in Europe, America and Canada. It is used as a substitute for aggregates as it contains raw materials and binder. In the current study, two sources of RAP were adopted. The first was brought from Governorate of Karbala (Karbala Cement Factory Road), with the help of the Andi Company. The RAP age was more than 10 years. The second type was brought from the city of Fallujah (Service Street to Tharthar- bypass Street) and was used by Wasit Company. The RAP age was 3 years . The physical properties of both RAP sources present in **Table 5**.

Table 5: Physical properties of RAP bitumen

Property	RAP (Karbala)	RAP (Fallujah)
% binder	4.7	3.7

3. Mix Design

According to the Marshall method, **(ASTM-D6926, 2010)**, asphalt mixtures were designed for each type of three layers (base, binder, and surface). optimum binder content was found by mixing five asphalt binder content according to the (mid-point) method. Forty five samples were prepared in order to find the optimum asphalt content; three samples for each percent of asphalt binder content.. In order to design the base layer mixture, Asphalt binder content was added as follows; 3.5% ,4% ,4.5%, 5% and 5.5. While for the binder and surface layer, the range was as follows; 4%, 4.5%, 5%, 5.5% and, 6. The required weight for each sieve was determined as presented in Table 6. After that, the aggregate was mixed with the filler and heated in an oven at a temperature of 160°C(Based on viscosity test at 135°C and at 165°C). The bitumen is also heated 160°C and mixed with the heated aggregate and filler until the bitumen completely coats aggregate and filler ,as shown in Figure 4.

Fig.4 : Marshall device-testing machine and compaction

After that the mixture was placed in a Marshall mold (4-inch diameter, 2.5-inch height) and compacted with 75 blows for each face using an electrical hammer that falls free from a height of 457.2 mm. Then after 24 hours, the samples were de-molded. The volumetric properties in terms of bulk density and air voids were measured according to **(ASTM-D2726, 2012; ASTM-D3203, 2017)** respectively. The optimum bitumen ratio is (5, 5, 4.5) % for the (surface, binder, and base) layer, respectively shows figures (5 , 6 , 7).

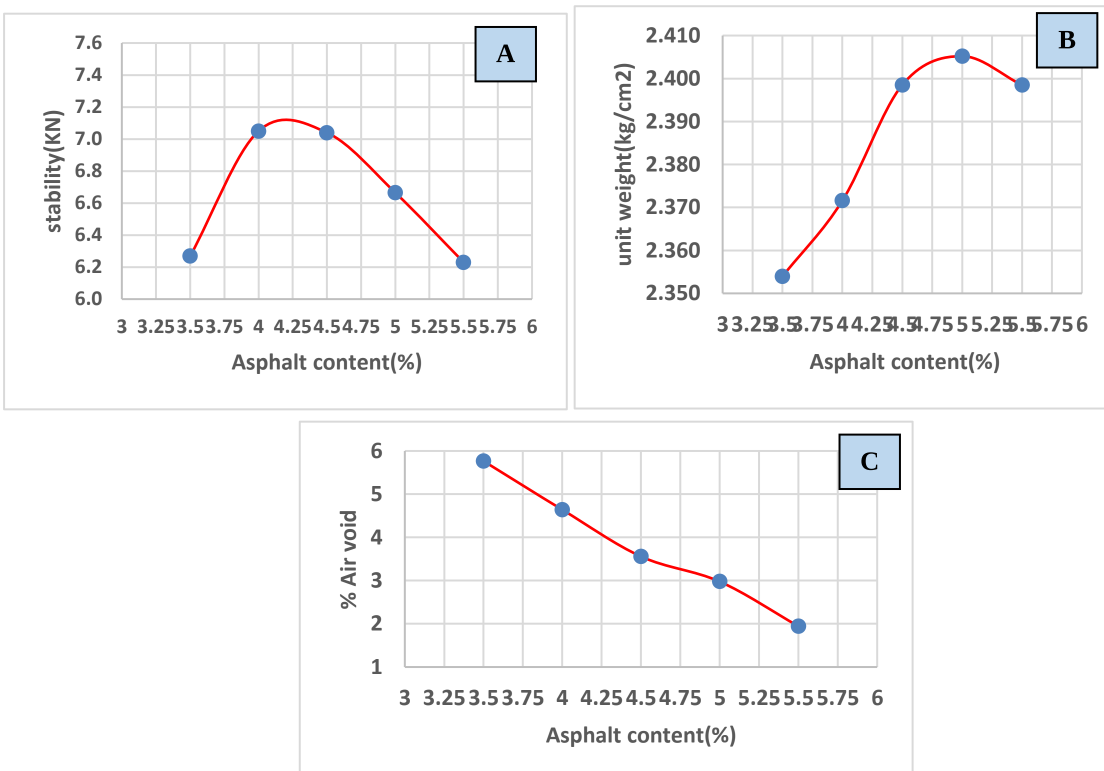
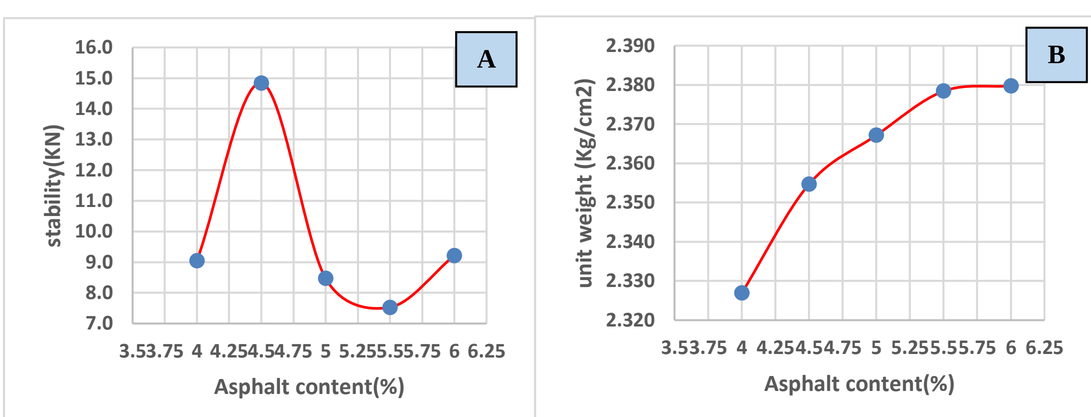


Fig. 5 Marshall Test Results for Base Control Mixture: A- Stability, B-unit weight and C-air voids



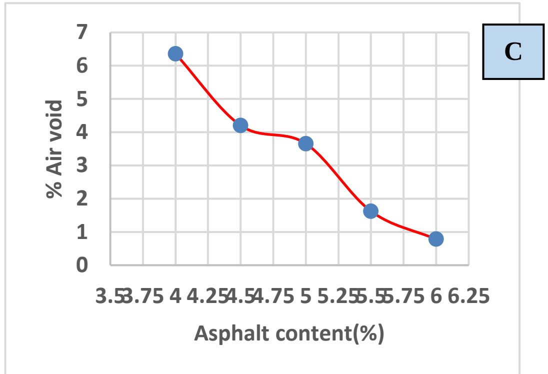


Fig. 6 Marshall Test Results for Binder Control Mixture: A- Stability, B-unit weight and C-air voids

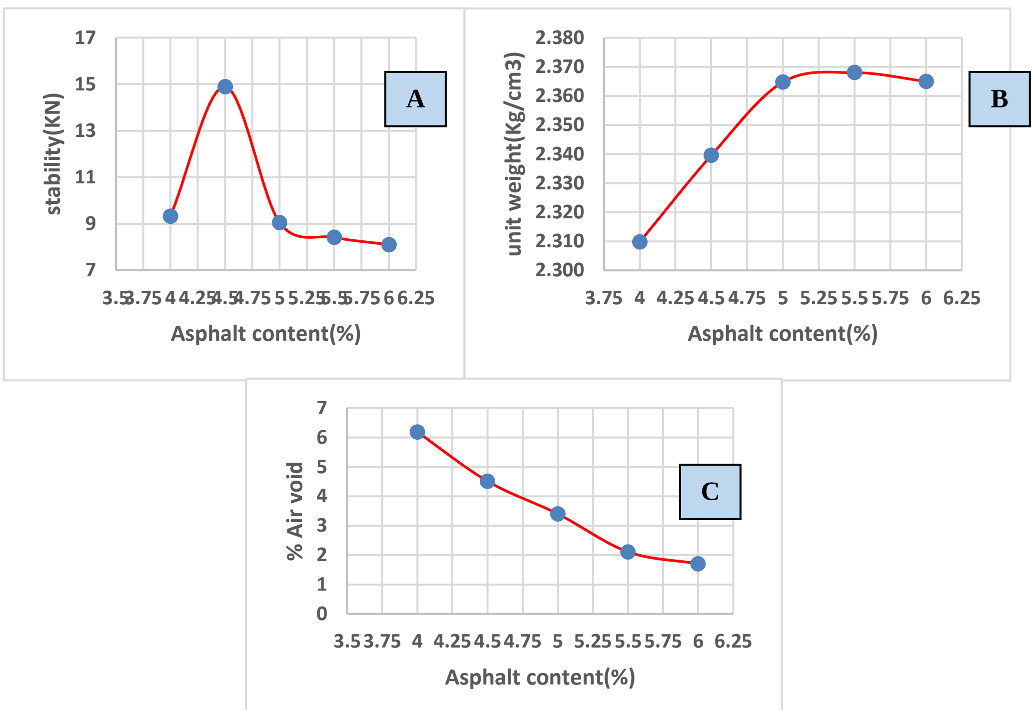


Fig. 7 Marshall Test Results for Surface Control Mixture: A- Stability, B-unit weight and C-air voids

After determining the optimum binder content for each layer, RAP materials were at three percentages 20, 30, and 40% by weight of aggregate and filler. The same previous steps in preparing the Optimum binder ratio were adopted in order to manufacture asphalt mixtures with addition of RAP,two scenarios were adopted in the process of incorporating RAP materials. The first considered the RAP as black rock (Neglecting the bitumen ratio in RAP). While in the second scenario, the bitumen ratio in RAP was considered in the total weight of bitumen prior to mixing. The mixing process was carried as mentioned previously in preparing control mixes.

4. Testing

Three samples were tested in Marshall device according to the specification of **(ASTM-D1559, 1989)** . The samples were placed in a water bath at a temperature of (60±1°C) for a period of 30-40 minute. Then after, they were examined with in Marshall device and the load was subjected to a deformation level of 2in (50.8) mm per minute and while the highest projected load was calculated to cause a failure of the sample. Deformation or flow was measured when the sample was completely failed as shown in **Figure 8**

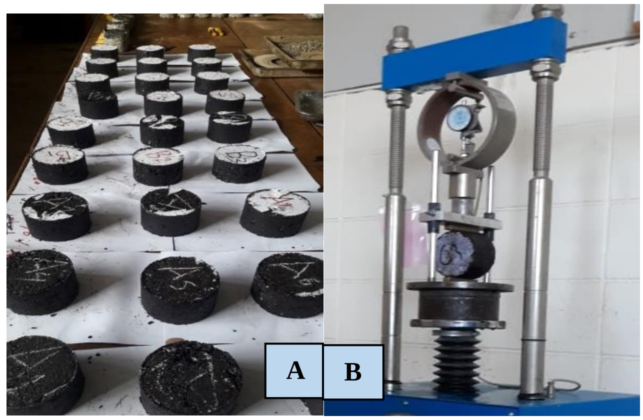


Fig. 8 (A) HMA specimens, (B) Indirect tensile strength (ITS) device

In order to determine the resistance of the mixture to indirect tension, the diameter and thickness of each sample was calculated, and then the samples were placed in a water basin at a temperature of 25°C for a period of 30 minutes, and then samples were loaded until complete damage of sample. The highest failure strength was calculated while the indirect tensile strength was calculated according to equation (1).

$$S_t\left(\frac{KN}{mm^2}\right) = \frac{2000p(KN)}{\pi Dt(mm)} \quad (1)$$

where is:

S_t = tensile strength, $\frac{KN}{mm^2}$

P = maximum load, KN.

t = specimen height immediately before tensile test, mm

D = specimen diameter, mm.

5. Results and Discussion

Tables 6 and 7 shows the results of tests conducted on mixtures containing RAP of Fallujah and Karbala manufactured using Dora bitumen, considering both scenarios. The data includes mechanical properties; stability, and indirect tensile strength.

Table 6 -Performance characteristics of asphalt produced from Al-Dora bitumen and RAP of Fallujah

Test	Black rock				Not black rock		
	0	20	30	40	20	30	40
Surface							
Stability(KN)	9.00	9.68	9.50	9.29	10.00	8.30	7.00
St(KN/mm^2)	1166.34	1196.12	1244.93	1337.22	1228.11	1294.97	1479.03
Binder							
Stability(KN)	8.47	9.20	8.40	8.10	8.50	8.98	7.38
St(KN/mm^2)	1018.24	1204.39	1230.19	1241.17	1273.93	1439.75	1643.47
Base							
Stability(KN)	7.04	7.00	6.20	6.00	6.16	6.31	6.23
St(KN/mm^2)	1089.34	1128.42	1173.66	1195.21	1166.66	1304.69	1420.45

Table 7 Performance characteristics of asphalt produced from Al-Dora bitumen and RAP of Karbala

Test	Black rock				Not black rock		
	0	20	30	40	20	30	40
Surface							
Stability(KN)	9.00	8.98	8.27	6.90	9.16	9.27	10.49
St(KN/mm^2)	1166.34	1103.56	1022.15	943.91	1261.27	1335.71	1541.53
Binder							
Stability(KN)	8.47	8.00	7.81	7.71	9.09	9.59	10.82
St(KN/mm^2)	1018.24	1004.84	944.15	900.82	1305.43	1412.86	1508.69
Base							
Stability(KN)	7.04	7.03	6.91	6.13	7.26	7.85	8.18
St(KN/mm^2)	1089.34	990.05	973.43	946.36	1321.30	1466.11	1612.10

5.1 Stability

Figure 9.a shows the results of testing stability of control hot mix asphalt containing RAP of Fallujah considering that RAP as a black rock. It was found that the stability of surface layer has increased with addition of 20% of RAP, however, it decreased with increasing of RAP materials to 30% and 40% respectively. It should however be noted, in all scenarios, the stability values were higher than the reference value of that of control mixtures. Indeed, the reason for this increase is due to an increase in the amount of bitumen associated in RAP. In case of binding layer, there was an increase in the stability value associated with incorporating of 20% of RAP materials in comparison with that of control mix. It however decreased when the percentages of RAP materials increased to 30% and 40%, but they were still within the limits of the Iraqi standard that determines the stability value of the binding which should not be less than (7) KN. Furthermore, in case of base layer, the stability values decreased slightly with the addition of the RAP of Fallujah, but they were still again within the limits of the Iraqi standard, which specifies that the stability values of the base layer should not be less not than (5) KN. It should be in fact noted that the reason for this decrease is due to an increase in the bitumen amount associated with the addition of RAP materials over the optimum value. **Figure 9.b** shows the stability values of the hot asphalt mixture, but not considering the RAP as black rocks. There was a clear in addition of RAP of Fallujah on the stability values as the stability of surface layer increased in case of adding 20% of RAP. However, its value quickly decreased when the RAP materials was increased to 30% and 40% respectively. Moreover, the stability of binder and base layers were almost same as that of control mixtures. As a matter of fact, all stability values of the three layers were within the limits of the Iraqi standard except when 40% of RAP of was incorporated in the surface layer.

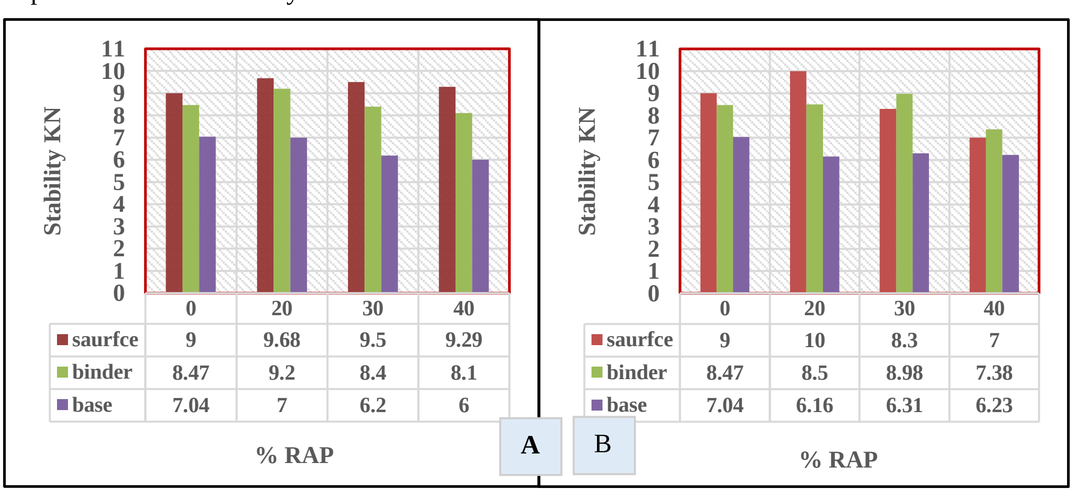
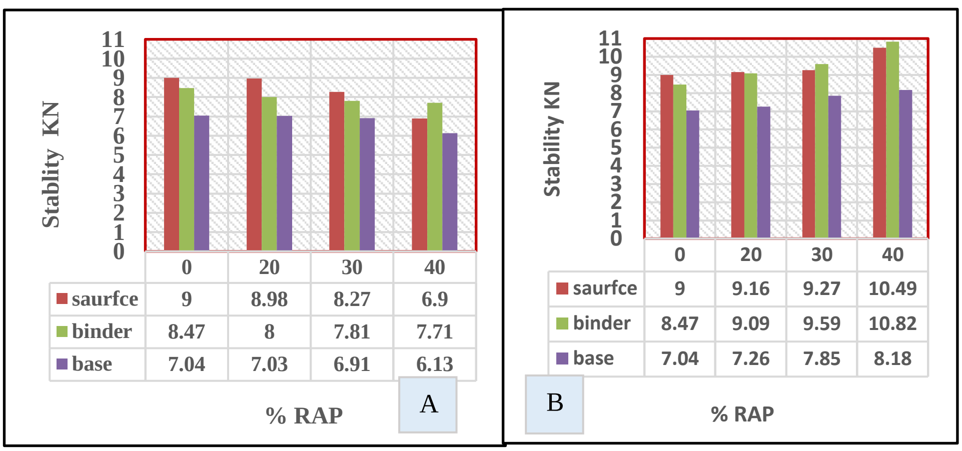


Fig. 9 Effect of adding RAP of Fallujah on the stability of the three layers (a) Considering RAP as black rocks (b) Not considering RAP as black rocks

Figure 10.a shows the effect of adding RAP of Karbala on the stability of asphalt mixtures, considering that the RAP is black rocks. It was noticed in the surface layer that the stability value decreased with increasing the addition of RAP ratios 20% and 30 % compared to that control mixture. Despite this reduction, the stability value was within the limits of the Iraqi standard, which specifies that the stability value of the surface layer should not be less than 8 KN. However, in case of using 40% of RAP materials, the stability was less than the aforementioned limits of the Iraqi standard. Moreover, in case of binder and base layers there was a very little discrepancy in the stability values of asphalt mixtures included RAP materials compared to that of corresponded reference values of HMA, although all these values of stability were within the limits of the Iraqi standard.

Figure 10.b presented the stability results of hot asphalt mixtures with addition of RAP of Karbala without considering RAP as black rocks. It was found a clear effect on the stability values of asphalt mixtures due to the inclusion of RAP of Karbala in case of the three layers. The stability increased with the increasing thepercentage of RAP materials in a positive manner. The reason behind this positive effect is due to the reduction in the amount of added bitumen over the optimum value, since the RAP was not considered black rocks, as well as the effect of Karbala RAP gradient, which contains crushed aggregates.



	0	20	30	40
saurfce	9	8.98	8.27	6.9
binder	8.47	8	7.81	7.71
base	7.04	7.03	6.91	6.13

	0	20	30	40
saurfce	9	9.16	9.27	10.49
binder	8.47	9.09	9.59	10.82
base	7.04	7.26	7.85	8.18

Fig. 10: Effect of adding RAP of Karbala on the stability of the three layers (a) Considering RAP as black rocks (b) Not considering RAP as black rocks

5.2 Indirect tensile strength

In direct tensile strength (ITS) was conducted for each mixture to evaluate the strength of asphalt mixtures to cracking. **Figure 11.a** shows the effect of adding RAP of Fallujah on the ITS values of asphalt mixtures considering that RAP as black rocks. It was found that the ITS increased with the addition of RAP ratio's for the three layers, and all the values were higher than that of control mixtures. This indicates that the addition of RAP of Fallujah improved asphalt mixtures in terms of cracking. This in fact was in agreement in case of scenario considering the RAP as not black rocks as presented in **Figure 11.b** . It was found that ITS of asphalt mixtures that contain RAP of Fallujah increased dramatically with increasing RAP ratio's for the three layers. This indicates that the addition of RAP of has a positive effect on improving resist of asphalt mixture against cracking.

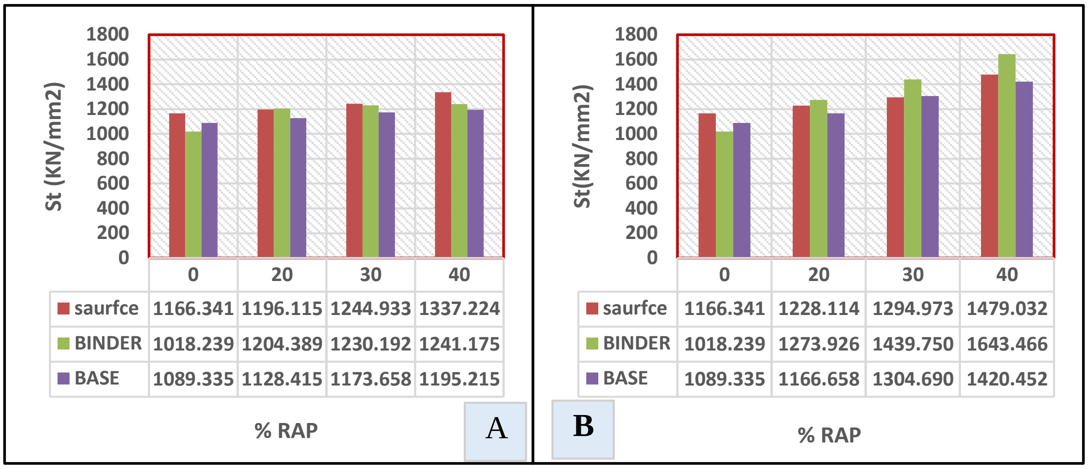


Fig. 11: Effect of adding RAP of Fallujah on ITS for the three layers (a) Considered RAP as black rocks (b) Not considering RAP as black rocks.

Figure 12.a illustrates the results of ITS of control asphalt mixture and mixtures manufactured using RAP of Karbala, considering RAP as black rocks. It was appeared from the figure that the value of ITS decreased slightly with increasing in the addition of the RAP materials. This reduction in the values of ITS is due to the increase in the amount of bitumen presented in the RAP of Karbala. While as can be noted in **Figure 12.b**, there was a clear effect of adding RAP of Karbala on the ITS of asphalt mixtures in case of all layers with the increase in the ratios of RAP and this is due to low amount of presented bitumen when RAP was not considered as black rocks.

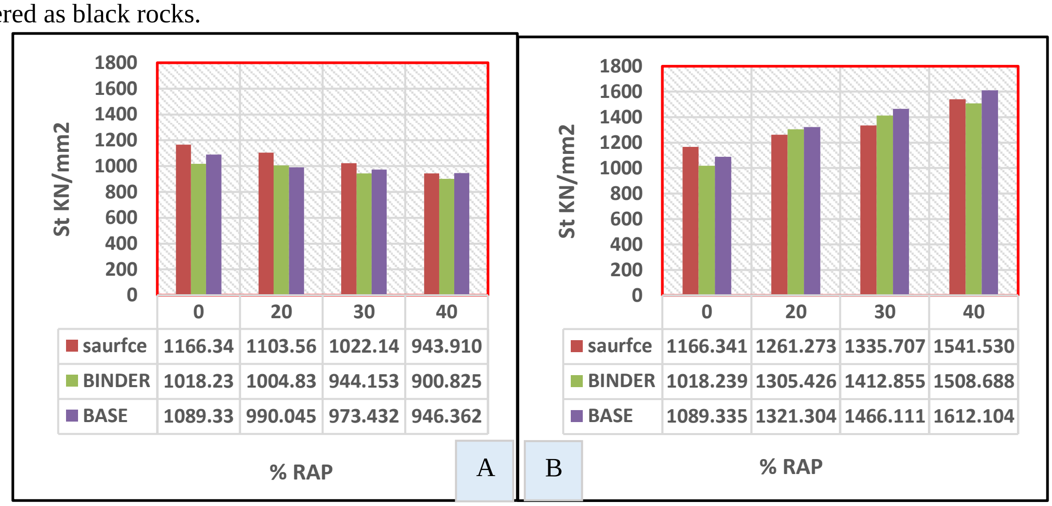


Fig. 12: Effect of adding RAP of Karbala on ITS of the three layers (a) Considering RAP as black rocks (b) Not considering RAP as black rocks.

6. Comparison of performance characteristics between using RAP of Fallujah and RAP of Karbala

Tables (8) and (9) shows a comparison between mixtures containing RAP and the reference mixture and for both scenarios

Table 8 : Total Improvement in the performance of recycled mixtures produced using RAP of Fallujah compared to that of control mixtures

Test	Black rock			Not black rock		
	20	30	40	20	30	40
Surface						
Stability (%)	7.6	5.6	3.3	11.1	-7.8	-22.2
St (%)	2.6	6.7	14.7	5.3	11.0	26.8
Binder						
Stability (%)	8.6	-0.8	-4.4	0.4	6.0	-12.8
St (%)	18.3	20.8	21.9	25.1	41.4	61.4
Base						
Stability (%)	-0.6	-11.9	-14.8	-12.5	-10.4	-11.5
St (%)	3.6	7.7	9.7	7.1	19.8	30.4

Table 9 : Total Improvement in the performance of recycled mixtures produced using RAP of Karbala compared to that of control mixtures

Test	Black rock			Not black rock		
	20	30	40	20	30	40
Surface						
Stability (%)	-0.3	-8.1	-23.3	1.8	3.0	16.6
St (%)	-5.4	-12.4	-19.1	8.1	14.5	32.2
Binder						
Stability (%)	-5.5	-7.7	-9.0	7.3	13.2	27.7
St (%)	-1.3	-7.3	-11.5	28.2	38.8	48.2
Base						
Stability (%)	-0.2	-1.8	-13.0	3.1	11.5	16.2
St (%)	-9.1	-10.6	-13.1	21.3	34.6	48.0

7. Conclusion

The study was aimed to evaluate the best layer of pavement structure; base, binder, and surface layers for inclusion (RAP) materials as well as the best scenario of inclusion such materials. Based on the funding of this study, it can be concluded as follows:

1. The best percentage of RAP added in terms of stability test is 40% of RAP is added in Karbala, without considering RAP as black rocks by using Dora bitumen to manufacture asphalt mixture of surface layer.
2. The best percentage of inclusion RAP based on the indirect tensile strength test is 40% of RAP is added in Fallujah, without considering RAP as black rocks by using Dora bitumen to manufacture asphalt mixture of binder layer which is better than that of reference value by about 61.4%.
3. Laboratory results conducted to evaluate the performance asphalt mixtures confirm that RAP materials should not be considered as black rocks. This inference is based on the results obtained from the stability test and the indirect tensile test
4. The inclusion of RAP materials in asphalt mixtures can be increased more than 40% without affecting the mechanical properties, provided that the optimum bitumen ratio is adequately set.
5. In terms of the stability test, it has been found that adding RAP of Karbala with the Dora bitumen gives a better improvement to performance of asphalt mixture compared to the reference mix and for the three layers, and in the event that RAP should not be considered as black rocks.
6. As for the indirect tensile test, the best values obtained when adding RAP material are in the case that RAP is not considered black rocks and for both sources of bitumen.

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