THE INFLUENCE OF USING SUSTAINABLE MATERIALS ON PAVING COST OF AL-KUT-MAYSAN HIGHWAY USING COST-BENEFIT ANALYSIS

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ABSTRACT

Paving is regarded as one of the essential layers in the construction of a road since it directly affects traffic loads and is subject to environmental factors. As a result, appropriate asphalt mixes that can support the designed traffic loads and environmental conditions must be developed. From an economic and environmental aspect, recycling the waste from the old pavement is a good step in this regard. This paper comprises detailed laboratory work that tested the impact of using different recycled asphalt pavement (RAP) content in addition to 3% crumb rubber (CR). The (CR) is used as fine aggregate. The tests were evaluated based on the response of hot asphalt mixes (HMA). The objectives of this study are to analyze the volumetric or weight change in hot mix asphalt of the different percentages and then analyse the costs of Kut-Maysan Road as a case study in case of using the different percentages of RAP and CR. The results show that the cost analysis of using RAP reduces the cost of a produced ton of HMA. On the other hand, the use of CR increases the cost of producing HMA. Using 10% RAP reduces the cost of one ton of HMA by 0.64 $ while using 20% RAP reduces the cost by 1.10 $, and the cost is reduced by 1.41 $ when using 30% RAP. On the other hand, the use of 3% CR with 10% RAP increased the production cost of one-ton HMA by 1.47 $. While decreased by 0.82 $ with 20% RAP content and by 0.28 $ with 30% RAP.

KEYWORDS

Sustainable Materials, pavement costs, cost-benefit analysis, Recycled asphalt pavement, crumb rubber

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INTRODUCTION

A road pavement in both types (flexible and rigid) is a structure which is made of multi-layers of processed and compacted materials, which have different thicknesses due to a special design consideration that is found in both bound and unbound forms. These forms are forming a structure that has a primary mission that is supporting the loads applied by vehicles in addition to providing a smooth riding quality [1]. Flexible pavements are most commonly used [2]. When bituminous material is added to granular materials to be bounded and then placed over granular layers such as base and sub-base layers that are supported by a sub-grade layer, this is called a flexible pavement System. The loads applied by vehicles are distributed with depth after being absorbed [1]. Paving is regarded as one of the essential layers in the construction of a road since it primarily affects traffic loads and is exposed to environmental factors. Asphalt mixtures must therefore be made in a way that is capable to manage the designed traffic loads and weather conditions. In this light, the process of recycling the waste of the previous paving is a useful move from an economic and environmental point of view. reusing recycled paving materials RAP was first used in 1915, but its extensive use began in 1970 during the Arab oil embargo, which increased the price of virgin bitumen and was the major reason for the rise in the usage of RAP in significant amounts [3,4]. RAP is regarded as one of the greatest aggregate choices for the production of asphalt paving using hot, cold, or warm mixing processes. RAP can be recycled using plants or on the job site. The previous researches show that using RAP when making asphalt mixture resulted in superior mechanical qualities than using the regular mixture.

RECYCLED ASPHALT PAVEMENT (RAP) AS A SUSTAINABLE MATERIAL

The majority of US institutes state that adding RAP in amounts of 15% or less to asphalt mixtures does not affect whether bitumen is added., i.e. RAP is regarded as black rocks, but if its percentage exceeds this limit (15%), the amount of bitumen must be adjusted, therefore RAP is no longer regarded as a black rock. [4,5]. 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 bitumen to evaluate the performance of asphalt mixtures containing RAP materials [6]. reported that adding 20% of RAP to the hot asphalt mixture of the 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 several researchers in Iraq to support the use of RAP and to get benefit from it applying these research outcomes [7]. used an advanced technique, Nano-indentation to investigate the level of blending between

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RAP and virgin materials for a mixture incorporating some warm additives such as; Sasobit, Rediset WMX and Rediset LQ and concluded that RAP cannot be considered as black rocks even with the inclusion RAP materials up to 40%. Furthermore, a novel protocol was reported to find a complete blend between RAP and virgin materials [8]

CRUMB RUBBER (CR) AS A SUSTAINABLE MATERIAL

Modifying asphalt pavement materials have been begun many decades ago. The use of asphalt pavement incorporating rubber first appeared in the 1840s aimed to test the ability of rubber to make paving surfaces last longer due to its flexibility [12, 13]. Using recycled rubber for tires (crumb rubber CR) in the flexible pavement enhances asphalt pavement performance, sustainability and cost. In the last decades, considerable attention has been growing to the use of CR. Several previous studies have indicated several improvements in the flexible pavement, such improvements were resistance to pavement rutting, reduced costs of pavement construction and maintenance, and enhancing the ability of pavement to resist fatigue cracks [14]. CR is then added to modify the physical and chemical characteristics of asphalt cement that is utilized to produce pavements containing rubber. There are two methods adopted to add CR dry process and the wet process. in a comparison of these methods, the dry method is simpler and more limited than the wet method [13,14].

PAVEMENT STRUCTURAL DESIGN

The method of constructing the most cost-effective mix of pavement layers, taking into account both type of material and depth to fit the soil foundation and vehicular load throughout the design phase, is known as pavement design. The design of pavement constructions might well be carried out with a variety of techniques. One of the widely authorized design methods is the AASHTO design procedure. The AASHO design procedure was established as a result of empirical equations that were developed as a result of the AASHO Road Test, which was conducted in Ottawa, Illinois, from 1956 to 1960. Experience and experimentation are key components of an empirical approach. This means that experiment, experience, or a mix of the two are used to determine the relationship between the input factors and the design thicknesses. As a result, the AASHTO methodology is limited to the circumstances and material types used in the AASHO Testing [9].

THE COST-BENEFIT ANALYSIS

The cost analysis was completed by calculating the savings of implementing RAP in each highway application. It must be recognized that this approach to cost analysis primarily aims to identify material cost savings. When adding RAP and CR to the mix, it simply considers the decrease in resources such as aggregate and asphalt cement. Decreased usage of large quantities of these expensive materials results in savings. Based on the similarity in these procedures between recycled and virgin materials, the costs associated with transporting, milling, placing, and compacting are not included

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in this cost analysis. Additionally ignored are social and environmental benefits, whose worth is hard to quantify and differ between projects [15].

STUDY OBJECTIVES

The objectives of this study can be summarized as follow:

1. To seek out Marshall test response in case of the addition of RAP and CR as an aggregate replacement in Hot Mix Asphalt HMA.
2. For determining Marshall stability of asphaltic mixes as well flow, and bulk density. These mixtures are containing three percentages of RAP which are 10%, 20% and 30% then adding 3% CR to these percentages.
3. To estimate the optimum asphalt content by conducting a Marshall Stability test for virgin mix, 20% RAP-containing mix, and 30% RAP-containing mix.
4. To analyze the volumetric or weight change in hot mix asphalt of the different percentages.
5. Cost analysis calculation of Kut-Maysan Road as a case study in case of using the different percentages of RAP and CR.

MATERIALS

The material used in this research are all available in local areas and are widely utilized for pavement construction nationally. One asphalt concrete was used in this study which was a binder course. One type of asphalt binder, one type of aggregate gradation, and one type of mineral filler were used. The properties of the materials selected are described in the following subsections.

MINERAL AGGREGATE USED

The mineral aggregate utilized in the tests of this study was natural aggregate collected from Badra quarries in Wassit Governorate. To fulfil the binder course degree as expected by the SCRB standards [13].

Table 1. Physical properties of aggregate

Physical properties	Specification no.	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	ASTM C-127 and C-128	2.583	2.668
Apparent Specific Gravity	ASTM C-127 and C-128	2.546	2.633
(%) Water Absorption	ASTM C-127 and C-128	0.369	0.48
Los Angelo's	ASTM C 131	13	-

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This aggregate is commonly used for asphaltic mixes in Kut city- Wassit Province in Iraq. Aggregates in both gradations (fine and coarse) which were used in this work had been sieved and remixed to the right extent. To assess the physical characteristics, typical standard tests were conducted on the aggregate. Table 1 above shows the summary of the test results. The results of these tests show that the aggregate being chosen met the specifications for the SCRB.

MINERAL FILLER

Fine-grained mineral aggregates that are either normally found in the aggregate system or that are added externally to it make up the mineral filler utilized in asphalt mixes. The percentage of aggregates that pass through a 0.075 mm sieve is a common definition for it. The filler utilized herein stands for Portland cement produced from Crista Factory in north Iraq. The characteristics of filler are illustrated in Table 2 below which shows that all results are acceptable and dependable

Table 2. Physical characteristics of the filler

Property	Result
Specific gravity	3.14
Per cent passed No.200 sieve (0.075mm)	100%

ASPHALT CEMENT AC

In this work, penetration of (40-50 mm) asphalt cement grade was utilized. Which was brought from the refinery that lies in Al-Duarah, southern side of Baghdad, with PG (64-16). The physical properties of this asphalt cement are described in Table 3 below. The results show that the physical properties of asphalt cement used met the requirements of the specification.

Table 3. Physical characteristics of asphalt cement AC

Test	Standard	Unit	Result	Specification Requirement
Penetration of bitumen At 25˚C,100 gm,5 sec. (0.1mm).	ASTM D 5-06	1/10mm	44.6	40-50
Ductility of bitumen at 25˚C, 5cm/min, (cm).	ASTM D 113-07	(cm)	108	≥100
Flash Point (Cleveland open cup)	ASTM D 92-05	(˚C)	280	≥230
Bitumen’s specific gravity (25 ˚C).	ASTM D 70-08	----	1.02	----
Softening Point	----	(˚C)	48	Not Limited

THE RECYCLED ASPHALT PAVEMENT (RAP)

The recycled (or reclaimed) asphalt pavement (RAP) that was utilized in the study was excavated from a road lying in Al-Kut city, Wassit Province in Iraq. RAP used was

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15 years in service which claimed from different layers of pavement (service layer, binder layer, and base layer). The RAP was also sieved and recombined in the right proportion of gradation for the binder layer. The graduated recycled asphalt pavement was added to the asphalt mixture with (10%, 20%, and 30%) percentages.

THE CRUMBED RUBBER (CR)

One of the sustainable materials used in the study is the polymer, represented by crumbed rubber of cars' tires as waste materials, which was brought from a hashing factory in Al-Diwanyeh town in Iraq. The crumbed rubber was used as a 3% replacement from 2.36 mm and 300 μm. of fine aggregate gradation which will be referred to later as 3% CR. This replacement is used as a combination addition with the 10%, 20%, and 30% RAP as a virgin aggregate replacement. Table 4 Below shows the physical properties of the crumb rubber used.

Table 4. Physical characteristics CR used.

Property	Result
Colour	black
Moisture content (%)	< 0.75
Textile Content	< 0.65
Max. Density ; C.N.R UNI-1, ASTM C128, UNE 12597-5:2009	(%Ø0.4-2.36mm ; %Ø2.36-4.75mm)
Max. specific gravity for rubber (gm/cm3)	1.16

STUDY METHODOLOGY

The study methodology can be summarized in 4 states as follows:

1. Specimens of the virgin mix and recycled mixtures were prepared depending on the Marshall mix design method (ASTM D1559). 15 samples were prepared for the virgin mix with 100% virgin aggregate using (4%, 4.3%, 4.6%, 4.9%, and 5.2%) asphalt cement per cent for every 3 samples. Then the optimum binder content OBC was determined. The same procedure was followed for mixtures containing 20% RAP, and 30% RAP. Then the Marshall test was conducted for 3 samples of mixtures mixed with the OBC for comparison.
2. Calculation of the depth of binder course for a segment of 6 km. of Kut-Missan highway as a case study.
3. Calculation of asphalt concrete materials quantities to be used in Kut-Missan highway as a case study.
4. Cost analysis of the materials used

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MARSHALL SPECIMEN SAMPLING

1. After washing the aggregate it was dried in the oven at 110 Cº for 24 hours for wiping moisture content as it may increase falsely the weight of aggregate.
2. Sieving the aggregate and distributing it as binder course gradation as it separated into groups as retained on each of the following sieves (25 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, 2.36 mm, 300 am, 75 μm, and pan) using dry sieve analysis.
3. Weigh of aggregate retained on the pan has been replaced with mineral filler (Portland cement).
4. Each sample of Marshall specimen is weighing 1200 gm. Which means that 3600 gm. For every 3 samples, An addition of 2000 gm. aggregate was added to conduct volume-specific gravity (Gmm).
5. This procedure was used to determine the O.B.C. for the control specimen, 20% RAP and 30% RAP. Then depending on the result of this step the OBC that has been determined has been used for the virgin mix and mix with 10% RAP.

MARSHALL SPECIMEN MIXING

Marshall Tests were conducted to calculate the volumetric properties of mixes. The volumetric properties included mass/bulk density, sample air voids (AV), voids filled with bitumen (VFB), Marshall Stability, and flow. The Optimum asphalt content (OBC) for the reference mix and RAP were settled from the plots of stability, AV, VFA, flow, density, and VMA. The bulk specific gravity of every sample was entirely settled by test techniques D2726, D1188, or D6752.

CASE STUDY

The case study of this research was a highway that lies in Kut city, Wassit province of Iraq, which is a highway that is supposed to be reconstructed due to a huge failure in serviceability. The highway information is listed in table 5 below:

Table 5. AL-Kut-Maysan Highway information

property	information
Location information	Lies in Wassit Province and it is considered as Al-Kut city entrance from Maysan Province
Coordinates of the centre line	N 576723 E 358049 N 584771 E 3603902
length	10 km
Number of lanes	3 per direction
Length width	3.75

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STRUCTURAL DESIGN OF LAYERS USING PCASE APPLICATION

PCASE is mandated for all vehicle types operating from outside the United States and its territories and possessions, as well as for highways and parking lots. Anyone can utilize PCASE, which is a computer software designed by the Engineer Research and Development Center (ERDC) of the United States Army Corps of Engineers (USACE). The criteria for compaction and pavement thickness may be determined using PCASE. This program was used to calculate the thickness of the binder course asphaltic concrete layer. (CODE,2016)

QUANTITIES AND COSTS ANALYSIS

After the determination of the depth of the binder course, the quantities required for preparing asphalt concrete that was required to surface the highway were calculated depending on the volumetric analysis and on the properties of asphalt concrete individuals that are conducted practically in the laboratory. The cost of individual materials was adopted depending on local prices (according to the local Government and Al-Kut Municipality) but converted to American dollars. Cost analysis of different layers was calculated depending on (NAPA, 2007)

EXPERIMENTAL RESULT

RESULTS OF USING RAP AND CR

The result of using RAP and CR after conducting the optimum binder content OBC is shown in Table 6 below:

Table 6. Effect of RAP on Marshall characteristics

Sample	OBC (%)	Stability (kN)	Flow (mm)	Density (gm/cm3)	AV%	VFA %	VMA %
Virgin	4.55	11.28	3.305	2.329	3.741	68.92	12.04
10 % RAP	4.55	18.03	2.197	2.327	3.653	70	12.14
RAP+CR	4.55	17.467	2.623	2.324	3.705	69.69	12.22
20 % RAP	4.336	18.65	2.143	2.297	3.367	74.62	13.27
RAP+CR	4.336	14.733	2.343	2.275	4.401	68.75	14.08
30 % RAP	4.167	19.53	3.087	2.304	3.212	75.32	13.02
RAP+CR	4.167	16.033	3.267	2.278	4.573	67.22	13.95

The result shows that Marshall stability continued to increase with any addition of RAP while decreasing slightly with the addition of CR, the same response appeared in percentages of voids filled with asphalt VFA% and voids in mineral aggregate VMA%.

The value of density, air voids and flow decreased dramatically when using RAP concerning the virgin mix while increasing with the addition of CR.

DEPTH OF BINDER COURSE CALCULATION

According to the relationship between Marshall stability and resilient modulus of asphaltic mixtures that are found in AASHTO the following equation can be derived for values exceeding those in the chart:

$$M_r(\text{psi}) = \text{Marshall Stability in}\left(\text{Kg}\right) \times 483$$

When Mr: Resilient Modulus

The Mr. values were converted to (Mpa.) as a requirement for PCASE application entries. The other entries are shown in table 7 below as the information was taken from Al-Kut Municipality as a formal reference.

Table 7. PCASE application entries

Category	PCASE entry
PCASE Version:	24-08-2022 7.0.4
Design Name:	Binder
Layer Model Name:	Binder Course
Drainage Station:	Not selected
Frost Station:	Not selected
Pavement Use:	Roadway
Design Type:	Flexible
Traffic Area:	Road Areas
Analysis Type:	LED
Wander Width (mm):	847

The calculation of depth using the virgin mix gave the following results which are shown in Table 8:

Table 8. depth calculation of binder course layer for the virgin mix

Layer Type	Material Type	Analysis	Thickness (mm)	Modulus (MPa)	Poisson's Ratio	Bond
Asphalt Concrete	Asphalt Cement	Compute	197	3830.49	0.35	Fully Bonded
Subbase	Unbound Aggregate	Manual	300	107	0.35	Fully Bonded
Natural Subgrade	Cohesionless Cut	Manual	102	42	0.4	Fully Bonded

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QUANTITIES/COSTS ANALYSIS PROCEDURE

The quantities and costs related that are required for the 10 km of Al-Kut Maysan highway were determined depending on the following procedure :

1. The volume needed to be filled is calculated by the equation below

$$\text{Volume}\ (m^3) = \text{length}\ (m) \times (\text{lane width} \times \text{number of lanes}) \times \text{depth of layer}\ (m)$$

2. The mass of the mix is calculated in the equation below

$$\text{mass (ton)} = \frac{\text{Volume}\ (m^3) \times \text{specimen density}\ (kg/m^3)}{1000}$$

3. The mass of materials has been distributed by multiplying the weight per cent of individual material by the whole mass of the mix in step 2.
4. The cost of individual materials has been calculated according to the cost of unit mass or unit volume depending on local agencies' prices.
5. Calculating the approximate reduction in the cost of using RAP in Hot Mix Asphalt is explained in table 9 below:

Table 9. the approximate reduction in the cost of using RAP equations (NAPA, 2007)

A	Savings from Asphalt Cement: $$\textbf{New AC \$/ton ( ) x AC \% in Mix ( ) x \% of RAP in Mix ( )}$$	\$/ton
B	Savings from Fine Aggregate: $$\left(\text{New Fine Agg.}\frac{\$}{\text{ton}}(\ )\text{x \% Fine Agg. in Mix ( )x \% of RAP in Mix ( )}\right) + \left(\text{New Fine Agg.}\frac{\$}{\text{ton}}(\ )\text{x \% Fine Agg. in Mix ( )x of CR in Mix ( )}\right)$$	\$/ton
C	Savings from Coarse Aggregate: $$\left(\text{New Coarse Agg.}\frac{\$}{\text{ton}}(\ )\text{x \% Coarse Agg. in Mix ( )x \% RAP in Mix ( )}\right) + \left(\text{New Coarse Agg.}\frac{\$}{\text{ton}}(\ )\text{x \% Coarse Agg. in Mix ( )x \% CR in Mix ( )}\right)$$	\$/ton
D	Total Gross Savings per ton of Hot Mix (Add A + B + C)	\$/ton
E	Less Acquisition Cost of RAP and CR (includes Trucking Cost): $$\left(\text{Less Acq. Cost of RAP + Acq. Cost}\frac{\$}{\text{ton}}(\ )\text{x \% of RAP in Hot Mix ( )}\right) + \left(\text{Less Acq. Cost of CR + Acq. Cost}\frac{\$}{\text{ton}}(\ )\text{x \% of CR in Hot Mix ( )}\right)$$	\$/ton
F	Less Additional Processing/Crushing of RAP and CR : $$\left(\text{Less Add. Processing of RAP + Process Cost}\frac{\$}{\text{ton}}(\ )\text{x \% of RAP in Hot Mix ( )}\right) + \left(\text{Less Add. Processing of CR + Process Cost}\frac{\$}{\text{ton}}(\ )\text{x \% of CR in Hot Mix ( )}\right)$$	\$/ton

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G Less any Additional Miscellaneous Costs of RAP and CR : $/ton

$$\left(\text{Misc. Cost of RAP} + \text{Misce. Cost}\frac{\$}{\text{ton}}(\ )\text{x \% of RAP in Hot Mix}(\ )\right) +$$

$$\left(\text{Misce. Cost of CR} + \text{Misce. Cost}\frac{\$}{\text{ton}}(\ )\text{x \% of CR in Hot Mix}(\ )\right)$$

H Net Savings per ton of Hot Mix Asphalt (D less E, F & G) $/ton

QUANTITIES/ COSTS ANALYSIS

The results show quantities to be used in the project for any alternative of (virgin mix, 10% RAP, 10% RAP and 3% CR, 20% RAP, 20% RAP and 3% CR, 30% RAP or 30% RAP and 3% CR) are shown in the table below:

Table 10. quantities distribution of materials of the mixtures

mix	Mass of mix (ton)	Coarse aggregate (ton)	Fine aggregate (ton)	Filler (ton)	RAP (ton)	CR (ton)	Asphalt Cement (ton)
Virgin	103255.09	49355.93	43470.39	5926.84	0.00	0.00	10579.52
10 % RAP	103135.41	44390.00	39064.19	5919.97	9272.80	0.00	10547.86
RAP+CR	103037.90	44348.03	38016.14	5914.38	9264.03	1011.11	10537.89
20 % RAP	101814.53	39043.53	34349.98	5844.15	18345.65	0.00	9943.34
RAP+CR	100852.67	38664.60	33154.00	5788.94	18172.34	881.55	9849.40
30 % RAP	102107.07	34307.87	30201.13	5860.95	27642.32	0.00	9598.78
RAP+CR	101007.81	33938.52	29092.07	5797.85	27344.73	773.82	9495.45

The prices of materials in asphalt mixture in American dollars are shown in the table below:-

Table 11. prices of materials in asphalt mixture

Material	Price $ / ton
Coarse aggregate	6.06
Fine aggregate	3.85
filler	72
RAP	1.25
CR	175
Asphalt Cement	308

Depending on the prices in table 12 above the cost of every individual material can be calculated by the following equation.

$$\text{cost of material (\$)} = \text{weigh of individual material (ton) x Price (\$/ton)}$$

the results are shown in Table 13 below:

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Table 12. The cost of every individual material used in the asphalt mixtures is shown in the table below

mix	Coarse aggregate/ $	Fine aggregate/ $	Filler/$	RAP/$	CR	Asphalt Cement/$	Sum/$
Virgin	299126.86	167301.06	426732.6	0.00	0.00	1386591.9	2279752.4
10 % RAP	269030.28	150343.25	426238.0	11591.0	0.00	1382443.5	2239646.0
RAP+CR	268775.91	146309.71	425835.0	11580.0	176944.4	1381136.4	2410581.5
20 % RAP	236627.45	132200.05	420779.0	22932.0	0.00	1303212.0	2115750.7
RAP+CR	234330.88	127597.20	416803.9	22715.4	154271.8	1290900.4	2246619.7
30 % RAP	207926.51	116232.69	421988.1	34552.9	0.00	1258053.4	2038753.6
RAP+CR	205688.02	111964.34	417445.0	34180.9	135418.6	1244509.5	2149206.5

Now we can calculate the approximate reduction in costs of using RAP by using equations in table 10 and the procedure is shown in table 14 below:

Table 13. the approximate reduction in costs when using RAP and

	10 % RAP	RAP & CR	20 % RAP	RAP & CR	30 % RAP	RAP & CR
Savings from Asphalt Cement:	1.21	1.21	2.31	2.31	3.34	3.34
Savings from Fine Aggregate:	0.13	0.13	0.23	0.23	0.31	0.31
Savings from Coarse Aggregate:	0.23	0.23	0.42	0.42	0.55	0.55
Total Gross Savings per ton of Hot Mix	1.57	1.57	2.96	2.96	4.20	4.20
Less Acquisition Cost of RAP/CR	0.54	0.55	1.08	1.10	1.62	1.64
Less Additional Processing/ Crushing	0.25	1.92	0.5	2.02	0.76	2.08
Less any Additional Miscellaneous Cost:	0.13	0.58	0.27	0.66	0.41	0.75
Net Savings per ton of Hot Mix Asphalt	0.64	-1.47	1.10	-0.82	1.41	-0.28

As it is clear from table 13 above the use of RAP reduces the cost of a produced ton of HMA. As the use of 10% RAP reduces the cost 0.64 $ per ton. And any increase in RAP content will decrease the cost of a produced ton of HMA as it is reduced by 1.10 $ per ton when using 20% RAP and reduced by 1.41 $ per ton when using 30% RAP. The reverse effect of using RAP is shown by using CR as using CR increased the cost of producing one ton of HMA by 1.47 $ then reduces to 0.82 $ when using 20% RAP with it and to 0.28 $ when using 30% RAP with it. This reduction is due to the increase in RAP content not for using CR itself.

CONCLUSION

Finally, we can conclude the following:-

1) The results of laboratory testing for the physical characteristics of mixtures show that the materials' properties utilized in this study all met the required specification.
2) From the Marshall Test result, the OBC for the virgin mix is 4.55%, RAP 20 is 4.336%, and RAP 30 is 4.167%. The OBC for mixtures with RAP dropped as the content of RAP was raised, which is due to the effect of the remaining asphalt in the RAP.
3) The use of RAP and CR results had better performance in Marshall Stability. Compared to the virgin aggregate mix, CR increased AV and RAP decreased it. VFA dramatically raised with RAP, but CR reduced the VFA as it increased AV.
4) The cost analysis shows that the use of RAP reduces the cost of a produced ton of HMA. And the reverse effect of using RAP is shown by using CR as using CR increased the cost of producing one ton of HMA.
5) Using 10% RAP reduces the cost of one ton of HMA to 0.64 $ while using 20% RAP reduces the cost to 1.10 $, and the cost is reduced to 1.41 $ when using 30% RAP.
6) Using 3% CR with 10% RAP increased the production cost of one-ton HMA up to 1.47 $. While decreased to 0.82 $ with 20% RAP content and to 0.28 $ with 30% RAP.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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