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EVALUATION OF RECYCLED ASPHALT MIXTURE TECHNICALLY AND ECONOMICALLY

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ABSTRACT

Using of Reclaimed Asphalt Pavement (RAP) has been become indispensable in most of the world nations as for its many benefits as significant cost savings and provide environmental benefits. Many factors such as virgin materials, binder content, availability of RAP, viscosity of binder and extent of deterioration had important role in effecting on Optimum percentage of RAP. In this study, effect of using RAP on the asphalt mixture properties and the its optimum ratio was determined to achieve the objective of the study. The glass fiber (GS) was used as additives to improve the asphalt mixture. It has been observed from the previous researches that the optimum percentage of reclaimed asphalt use is not determiner and is disagreed from project to project. So, different percentages of RAP was (25%, 50%, 75%, 100%) by weight of aggregate were added as well as using the additive GS at optimum bitumen content. The study is revealed that untreated 100% RAP materials are not good as a bituminous mix. and was showed that mix prepared with 25% RAP gave nearly the same physical and strength parameters as virgin bituminous mix. From results of study, the use of RAP until (%50) as a maximum percentage in unmodified asphalt mixture course sustained good results. To achieve better performance, the percentage of 25% RAP was used with percentage of 0.26% GS. This mix achieved the specification requirements and ensured the degree of better performance for paving. The economical evaluation of using percentage of 25% RAP with percentage of 0.26% GS was also studied. The results indicated that, about 21% of the cost was saved.

Keywords: Reclaimed Asphalt Pavement (RAP), Marshall Mix Design, Material Testing, Stability, Glass fiber, Optimum Bitumen Content, Cost effectiveness.

1. Introduction and literature review

RAP is old asphalt pavement that is milled up or ripped off the roadway [1]. The increasing RAP use of asphalt mixes has been become the focus of attention. The performance of RAP can be improved by compensating the aged bitumen by using rejuvenators or softening additives, Hence virgin mix was given performance better than RAP that contained aged bitumen and aggregate as it still can be them reuse again. In the current years, the maintenance cost will give same as the construction cost of new roads where maintenance of roads in Egypt costs annually high percentage of the total road construction costs. In Egypt Roads usually failures were its appearance in an early stage of pavement life. Old road pavements due to repeated overlays being placed over the years was the reason in the increase of the road levels compare to nearby built up areas by increasing the thickness of its layers and Due to the large availability of the aggregates in Egypt where was produced approximately 5 million tons per year of reclaimed asphalt pavement that are not used. On the other side, the continuous rise in asphalt binder price day by day due to increase in the cost of the crude oil, so it should be exploited RAP materials in recycling the HMA mixtures; this will be contributed to get advantages such as conservation of aggregates, and binder, decrease in pavement thickness and reduced cost of asphalt mix. Arshad et al., 2017 stated that deteriorated roads can be used as a source of RAP materials which had appropriate properties for the surfacing layers [2]. RAP materials can be use also to save non-renewable resources especially with high cost of materials and little supply [3].

Several studies stated that, with increasing the percentage of RAP content, the optimum binder was reduced. Also, recycled mixes with 10-35% RAP may give the same physical and strength parameter as virgin mixes. Even more, better results can be obtained compared with conventional HMA under the same conditions [4-6]. At low RAP percentages, resistance to moisture damage may be better than high percentages [7].

El-kashef and Williams, 2017 stated that, fatigue performance was improved by adding rejuvenators [8]. Some studies concluded that, Using Waste Cooking Oil (WCO) and paraffinic oil optimized the binder in the RAP material and are given an excellent potential to be used as a good rejuvenator in the hot mix asphalt industry [9]. However, other study summarized the performance of WCO as a rejuvenator as it is given adverse effects [10].

Presently in USA and Japan, asphalt pavement material removed from use is recycled into new pavements. Field performance studies confirmed that the performance of mixes containing RAP was equivalent to that of virgin mixes [11-13].

The effect of adding fiber on bitumen binder and HMA was considered before in many studies, as it increased asphalt binder stiffness and the stability of modified asphalt mix. On the other hand, decreasing the content of air voids comparing with the control mix [14, 15]. Accordingly, the resistance of rutting and fatigue was also improved accompanied by high indirect tensile strength for asphalt layers [16]. The length of fiber and its diameter should be taken into consideration which affect significantly in the mechanical properties of asphalt mix [17].

1.1. Objectives of study

The main objectives of this work are:-

- studying the effect of the RAP materials on HMA properties,
- determining OBC for control mix with different RAP%,
- studying the effect of fiber glass on the recycled HMA properties; and finally
- studying the cost effectives of recycling bituminous pavement material.

2. Materials and experimental investigation

2.1. Materials used

Figure (1) shows the suggested experimental program which began with selecting the study HMA materials, the recycled materials, and glass fiber. The siliceous aggregate was used from Sohag city- Akhmim- East Ellahywa. The glass fiber was obtained from Sohag Company for modern construction. Table (1) showed that physical properties of Glass

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Fiber. After that, qualifications tests were conducted on the collected materials that used to achieve the require objectives

Table 1.
Glass Fiber Properties

Detail	Property
Glass Fiber (E- class)	Fiber type
12	length (mm)
2.54	Density (g/cm3)
3400	Tensile Strength (MPa)

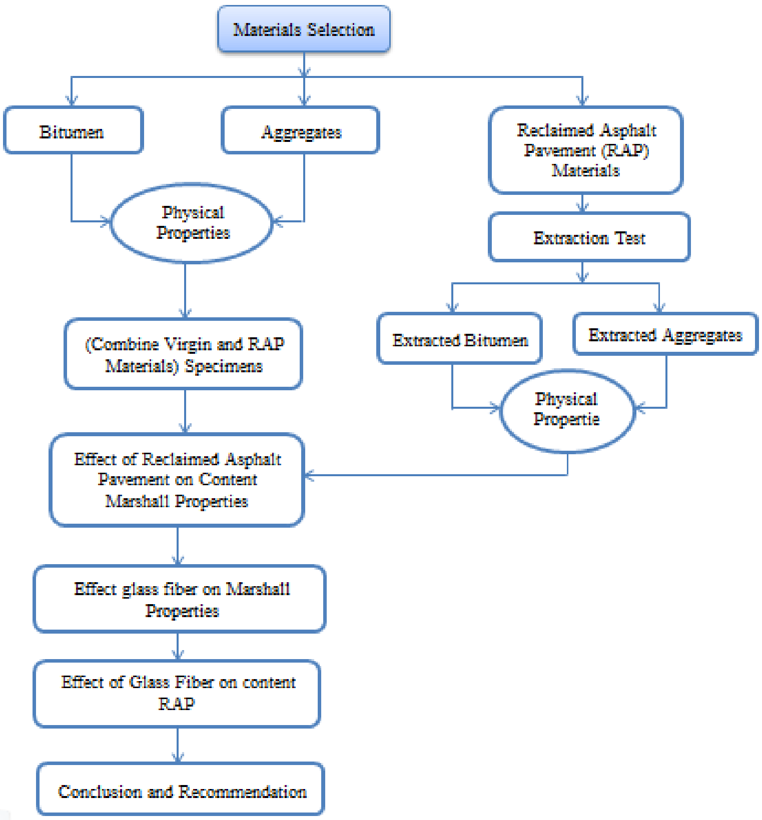

Fig. 1. Steps of Experimental Work

The chunks of RAP material were obtained from agriculture Sohag – Aswan highway which was paved form more than 10 years ago. It appears from visual inspection the effect of aging on the highway. The chunks of RAP were obtained from the site to crush and screen into different sizes. The extraction test was carried out on the RAP material to determine its asphalt content (AC). The gradations of RAP materials from two different sectors of highway after extraction are shown in Table2 and Figure 2 respectively. The proportion of asphalt extracted from the recycled asphalt sample was 3.68%.

Table 2.
Extraction Test Results for the Recycled Material

Sieve Size	Recycled Material Gradation for sample number		Specifications
	1	2	
1 inch	100	100	100
3/4 inch	98.95	92.75	80-100
1/2 inch	88	86.55	------
3/8 inch	75.06	76.63	60-80
No. 4	50.98	56.81	48-65
No. 8	45.29	46.09	35 – 50
No. 30	31.14	26.75	19-36
No. 50	13.39	13.62	13-23
No. 100	3.32	3.55	7-15
No. 200	1.72	1.85	3-8
Asphalt Content, %	3.68	4.23	

Fig. 2. Appearance of Coarse Aggregate from RAP

2.2. Laboratory tests

Tables from 3 to 5 indicate the gradations of selected materials in the study. Figure 3 shows the adopted gradation of aggregate used. The abrasion of aggregate1 and aggregate 2 by Los Angeles test after 500 revolutions was 25 and 32% respectively. The asphalt cement with (63 penetration, 322 centistokes Kinematic viscosity, 270 ˚C Flash point, 51 ˚C Softening point) was used. The properties of extracted asphalt of chunks of RAP materials were indicated in Table 6.

Table 3.
Gradation of Filler Used

Sieve size	% Passing by weight	Specification limits
No. 30	100	100
No. 100	95.22	≥ 85
No. 200	78.52	≥ 65

Table 4.
Coarse Aggregate Gradation

Sieve size	% Passing by weight	
	Agg 1	Agg 2
1 inch	____	100
3/4 inch	____	87.92
1/2 inch	____	18.60
3/8 inch	87.19	2.10
No. 4	19.60	0.27
No. 8	0.54	0.25
No. 30	0.44	____

Table 5.
Gradation of Sand

Specification limits	% Passing by weight	Sieve size
	97.24	No. 4
	90.87	No. 8
≤ 65	51.36	No. 30
	23.15	No. 50
	8.10	No. 100
	3.48	No. 200

Table 6.
Properties of Asphalt RAP

Specs limits	Result	Test	Test No.
60-70	65 (0.1mm)	Penetration	1
≥ 320	322 centistokes	Kinematic viscosity	2

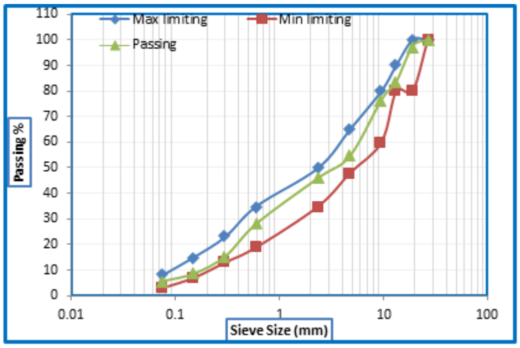

Fig. 3. Adopted gradation of aggregate used

2.3. Mix design

The mix design for virgin and RAP mixes was carried out according to Egyptian specifications by using aggregate, sand, and filler with ratio 50%, 45% and 5% respectively. The design mix asphalt was performed by using job mix formula as specified in Table 7 based on Egyptian Code of dense surface course (4C) specifications. The recycled materials were added to virgin materials with different percentage; 0%, 25%, 50%, 75% and finally 100% RAP. To measure the proposed properties of the suggested recycled mixtures, Marshall test was used.

Fig. 4. Marshal Specimens for different bitumen percentage

Table 7.
Job ix Formula for Mineral Aggregate

Sieve Size	%Pass. of Agg2	20%	%Pass. of Agg1	30%	%Pass. of Sand	45%	%Pass. of Filler	5%	Grading of Mix	Specifications (4C)
1 inch	100	20	100	30	100	45	100	5	100	100
3/4 inch	87.92	17.58	100	30	100	45	100	5	97.58	80-100
1/2 inch	18.60	3.72	100	30	100	45	100	5	83.72	------
3/8 inch	2.10	0.42	87.19	26.16	100	45	100	5	76.57	60-80
No. 4	0.27	.054	19.60	5.88	97.24	43.76	100	5	54.69	48-65
No. 8	0.25	0.05	0.54	0.162	90.87	40.89	100	5	46.10	35 – 50
No. 30	_____	___	0.44	0.132	51.36	23.11	100	5	28.24	19-36
No. 50	_____	___	_____	___	23.15	10.42	100	5	15.42	13-23
No. 100	_____	___	_____	___	8.10	3.65	99.8	4.99	8.64	7-15
No. 200	_____	___	_____	___	3.48	1.57	81.88	4.09	5.66	3-8

The following equation can be used to calculate the new binder (%) for different RAP mixtures:-

$$P_{nb}= [(100^2- rPsb)\ P_b\ /100(100-Psb)\}- \{(100-r)\ P_{sb}/(100-P_{sb})]$$ [18]

Where:-

P_{nb} = New asphalt binder (%) in RAP.
r = The percent of new aggregate to total aggregate in RAP
P_b = Estimated asphalt content of RAP (%)
P_{sb} = asphalt content in RAP (%).

2.4. Addition of glass fiber to asphalt

For preparing asphalt concrete, 60/70 penetration grade asphalt was used. In order to add glass fiber in special mixer apparatus as it mixture method is known "*Wet Method"* has been adopted in this study. The glass fiber was added with different percentages on the asphalt mixes; 0.1%, 0.2%, 0.4%, 0.6%, 0.8%, 1.0 of the HMA total weight. Firstly, fiber was taken in the mixer then the heated asphalt at (150^{o}C) was added and mixed together accurately in shear mixer apparatus at speed 3000 cycle/min until the mix acquires uniformity. This fiber is illustrated in Figure 5.

Fig. 5. Used Glass fiber

3. Results of Marshall Test

The results of Marshal test at different percentage of added RAP without and with using glass fiber modifier respectively were illustrated in Table 8 and 9. The optimum bitumen content for different mixes was varied from 5.1 to 5.00%. The fiber glass content was performed on two stages:

a. Determine the optimum ratio of glass fiber by preparing different asphalt mixes with different glass fiber percentage as mention before at OBC. Percentage 0.26% of fiber glass was achieved the best results.
b. After that, preparing different recycled asphalt mixes of (0%, 25%, 50% and 75% by the weight of total mix) with 0.26% glass fiber.

Table 8.
Marshall Test Results for the Investigated Mixes at OBC

MIX NO.	Bulk Density (t/m3)	Stability (kg)	AV%	VFB%	Flow (mm)
A(0% RAP)	2.338	1600	4.60	71	3.24
B(25% RAP)	2.332	1422	4.10	68.5	3.44
C(50% RAP)	2.324	1351	3.20	60	3.67
D(75% RAP)	2.231	1332.6	6.49	76.51	3.74

Table 9.
Mechanical Properties of RAP with OBC Glass Fiber

RAP % (by total weight of mix)	Bulk density t\m3	Stability (Kg)	VA (%)	(VFB) (%)	Flow (mm)
0	2.351	1760	4.82	73.04	3.38
25	2.341	1580	4.36	71.68	3.61
50	2.336	1474	3.45	70.5	3.85
75	2.296	1422	7.81	78.3	4.37

3.1. Effect of adding RAP on Marshall Properties at OBC

It can notice easily from Figure 6 that, about 2% bitumen content was saving as a result of increasing RAP percent from zero to 100% RAP. This may be attributable to the old asphalt from RAP mixture.

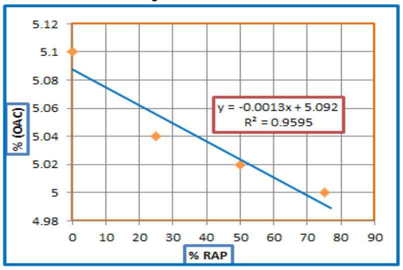

Fig. 6. Effect of RAP% on OAC

3.1.1. Results of unit weight

As shown in Figure 7, the unit weight will be affected slightly by increasing the percentage of recycled asphalt. For example, the unit weight will decrease by about 4.58% when the RAP content increased to percentage 75%.

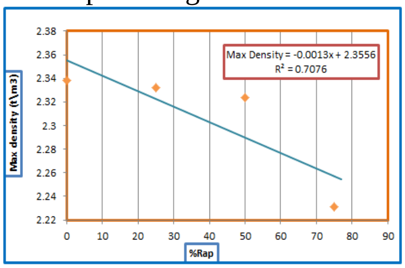

Fig. 7. Effect of Increasing RAP% on Unit weight.

3.1.2. Results of mix stability

As shown in Figure 8, as the RAP percent increase the stability will decrease. This may be as a result of the fatigue of materials by aging. The value of decrease was depending on the percentage of RAP added. For example, the stability value was decrease by about 11.13% at 25% RAP. Whereas, this value became 16.71% at 75% RAP. This means that, the resistance of pavement distress was not affected significantly.

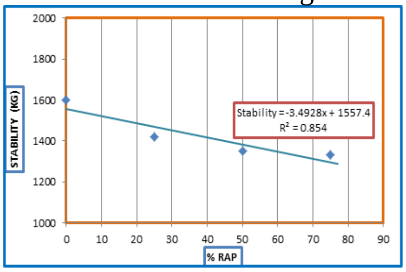

Fig. 8. Effect of Increasing RAP% on Marshall Stability

3.1.3. Results of flow

As shown in Figure 9, although the flow value was increase in conjunction with RAP percent increase, the flow value was accepted until 50%RAP. After that, the flow value was out of specification limits; it became more than 4 mm at 75% RAP. This means that, the expected permanent deformation will increase significantly. So, it is not recommended to add more than 50% RAP.

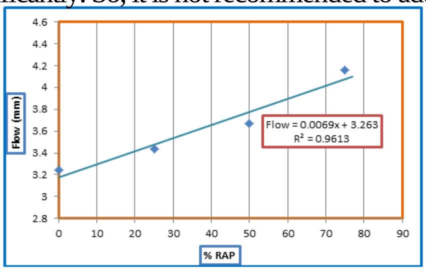

Fig. 9. Effect of Increasing RAP% on Flow.

3.1.4. Results of Air voids

As shown in Figure 10, when RAP% increased from zero to 50%, the air voids value was decrease obviously. For instance, the flow value decreased from 4.6% to 3.2% by adding 50% RAP. This represent about 30.43%. This trend was achieved also for voids filled with bitumen as noticed in Figure 11.

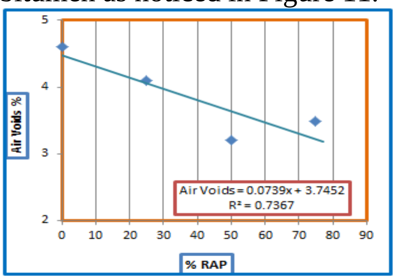

Fig. 10. Effect of Increasing RAP% on Air Voids

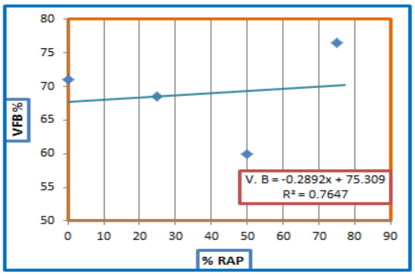

Fig. 11. Effect of Increasing RAP% on VFB

3.2.1. Bulk density &RAP content and adding (GF) relationship

Figure 12 showed that, the unit weight values at OBC decreased as the RAP increases which are decreased from 2.338 to 2.231(t/m3) by about 4.6% in control mix without glass fiber and are decreased from 2.351 to 2.296 (t/m3) by about 2.34% in modified asphalt mix with glass fiber. It should be mentioned that, all values of unit weight of the modified mixtures are higher than the value of control mix. This increase in unit weight is due to a result of the high density of added fiber. From results is deduced that maximum value of unite weight is 2.351t/m3 at 0%RAP in modified mix.

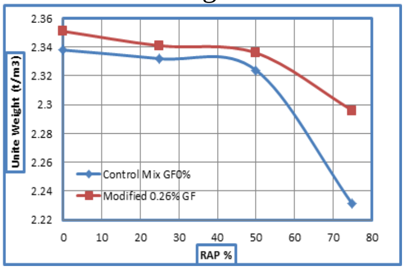

Fig. 12. Relationship between unite weight and RAP % at 0.26% (GF)

3.2.2. Stability &RAP content and adding (GF) relationship

Figure 13 is shown that Marshall Stability decreased as the percentages of RAP increase It is shown that the maximum stability occurs at 0% RAP in modified mix with glass fiber, which is decreased from 1760 to 1580 (Kg) by about 10.23% at RAP% from 0% to 25%.but it is reduced from 1580 to1422 (kg) till reaches to 75%RAP by about 10%.the stability in control mix without GF decreased from 1600 to 1422 Kg which represents about 11.13 when RAP% increased from 0 to 25%.after that it is started to decrease till reaches to 75%RAP from 1422 to 1332.6 Kg by about 6.3%.

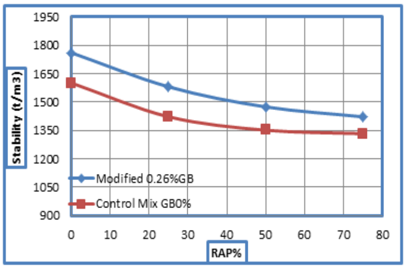

Fig. 13. Relationship between Stability and RAP % at 0.26% (GF)

3.2.3. Air Voids &RAP content and adding (GF) relationship

Figures 14 is shown that the AV% in modified asphalt mix with glass fiber is decreased as the RAP content increases from 4.82% to 3.45% at peak from 0% to 50% RAP by about 28.4%. When RAP is continued to 75%, AV% value is increased to 7.81% and AV% is indicated to out limiting specification. It is found that AV% in control mix without GF is decreased from 4.6% to 3.2% by about 30.4% at peak (0% to 50% RAP). After that is increased to 6.49% at peak 75% RAP. This is indicated to out of limiting specification at range (3 – 5%). It should be mentioned that, all values of AV% of the modified mixtures are greater than the value of control mix. And the maximum AV% is 4.82% at 25% RAP that met specifications.

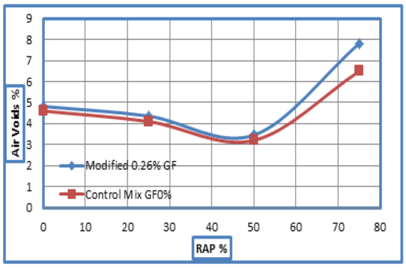

Fig. 14. Relationship between Air Voids and RAP % at 0.26% (GF)

3.2.4. Flow & RAP content and adding (GF) relationship

Figure 15 showed that the modified flow with glass fiber is firstly increases from 3.38 mm to 3.61mm by about 6.8% with an increase in RAP contents up to 25% and then it is increased to 4.37 mm with the increase in RAP till to 75%. Which the maximum flow value is indicated to asphalt mix containing on higher percent from voids that are higher than limiting specification or containing on not sufficient bitumen amount to resistant Durability. After that it is started to increase to 4.37 mm at 75% RAP. In control mix without GF the flow is increased from 3.24 to 3.67mm at RAP percent 50% by about 13.3%. After that the flow value is increased to 4.16 mm as RAP content to 75%. The maximum flow value is 4.82 mm obtained at 0% RAP in modified mix. The high flow values indicate high flexibility which increases the ability of HMA pavement to deform without cracking.

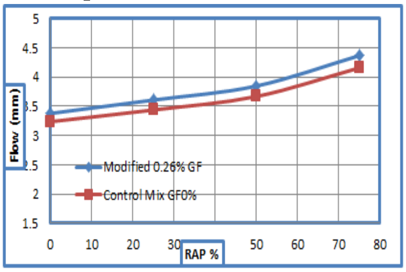

Fig. 15. Relationship between Flow and RAP % at 0.26% (GF)

3.2.5. VFB & RAP content and adding (GF) relationship

Figures 16 show the variation in VFB% after adding GF to asphalt mixes. It is shown; the maximum value of VFB% is obtained at 75% RAP. The Figure shows also that the values of VFB% are greater than those of the unmodified mix for the range of RAP content.

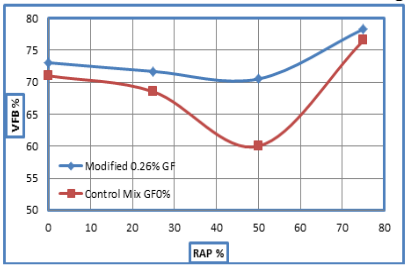

Fig. 16. Relationship between VFB% and RAP % at 0.26% (GF)

3.3. Cost Effectiveness

In this section the cost effectiveness of using RAP in HMA will discuss. Cost and expenditures from available highway construction data for conventional and recycled HMA mixes are summarized. Table 10 show the cost for two mixes. According to the current prices, considering 8500 LE/ton for bitumen and 160 LE/m^3 for aggregate. The cost of conventional HMA mix with 5.10 % asphalt equals 585.34 LE/ton. However, the total cost for RAP mix equals 120 LE/ton including milling machine and hauls. The comparison for the total cost and saving for every mix was indicated in Table 11. It can be noticed that easily by 20.8% of its initial cost with 25RAP%.

Table 10.
Cost for virgin and RAP mix.

Item	Percent used (%)	Cost/ton	Total Cost/ton
Aggregate	94.9	160	151.84
Asphalt Binder	5.10	8500	433.5
Virgin Mix			585.34
RAP			
Trucking		10	20
Milling*		100	100
RAP Mix			120

Table 11.
Savings by using RAP

%, Percent of RAP Savings	Cost/ton	Savings, pound/ton Cost/Ton	%, Savings
0 %	476.25	0	0
25 %	463.61	121.73	20.8
50 %	345.21	240.13	41.02
75 %	226.82	358.52	61.25

4. Conclusions

Depending on the previous results, we can conclude that:

- The study stated that, it is not recommended to use the completely 100% RAP materials in HMA as it's not satisfying the required specifications.
- As the RAP% increases, the unit weight, OBC, and stability decreased, whereas flow increased.
- Increasing RAP% from zero to 50% decreased the air voids % by about 30.43% for mix without modifier but is decreased by about 28.4% with adding glass fiber. After that the RAP% reaches 75%, the AV% was 6.49% as increased by about 41% at mix without modifier. But with adding GS, the AV% was (7.81%) as increased by about 62%. This percentage 75% was out of the specification range (3% – 5%).
- The performance of asphalt mix improved significantly with adding glass fiber with percentage 0.26% in the form of increasing the tensile strength of asphalt mixture.
- From results of study, the use of RAP until (%50) as a maximum percentage in unmodified asphalt mixture course sustained good results. To achieve better performance, 25%RAP was used the percentage with (%0.26GS). This mix achieved the specification requirements and ensured the degree of better performance for paving and was economical by about 21% of the cost was saved.
- To achieve good results with glass fiber, it have to increase the contacting surface area by sustain good adhesion between the asphalt binder and the fiber. This prevents concentrations of stress.

5. Recommendation

- It is recommended that use low percentage of RAP in asphalt mixture not exceeded 25%RAP without modifier Bitumen but it is favored that using higher percentage of RAP with modifier bitumen after checking it by tests such as Indirect tensile strength and wheel Track Test till it accepted from concerned authority. This result met with the previous research such as [19].
- It is recommended to study the effect of other types of binder grade and modified binder on the asphalt mix properties especially when will be used high percentages of RAP in bituminous mixture.

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تقييم الخلطة الاسفلتية المعاد تدويرها فنيا واقتصاديا

الملخص

لقد اصبح استخدام الاسفلت المعاد استخدامه أمرا لا غنى عنه فى معظم دول العالم نظرا لفوائده العديدة ومنها تقليل التكاليف والحفاظ على البيئة . كان للعديد من العوامل مثل الركام ومحتوى الاسفلت وتوافر الاسفلت المستصلح ولزوجة الاسفلت وايضا مدى تدهوره دورا مهما فى التأثير على النسبة المثلى للاسفلت المعاد تدويره.

والهدف الرئيسى من هذه الدراسة هو دراسة تأثير استخدام المواد المعاد تدويرها وكذلك دراسة تأثير استخدام المضاف على خصائص الخلطة الاسفلتية وتحديد النسبة المثلى من الاسفلت المعاد تدويره لتحقيق هدف الدراسة.

أهداف البحث

1. التحقق من استخدام (RAP) فى عملية انشاء الطرق وتحديد النسبة المثلى التى تضاف الى الخلطة الاسفلتية عن طريق اجراء الفحوصات المختبرية ومنها فحص مارشال.
2. دراسة تأثير استخدام المواد المضافة (glass fiber) اي استخدام الاسفلت المعدل على خصائص خلطة الخرسانة الاسفلتية وتأثيره على محتوى ال(RAP) فى انتاج الخلطات الجديدة.

لقد لوحظ من الابحاث السابقة أن النسبة المئوية المثلى لاستخدام الاسفلت المستصلح ليست محددة وتختلف من مشروع لأخر. لذلك تم اضافة نسب مختلفة من الاسفلت المعاد تدويره (0%, 25%, 50%, 75%, 100%) من وزن الركام بالاضافة الى استخدام الالياف الزجاجية عند النسبة المثلى للاسفلت.

لقد بينت الدراسة ان الاسفلت المعاد تدويره عند نسبة 100% اعطت نتائج غير جيدة غير صالحه للاستخدام كخلطه بيتومينية. وكذلك نسبة 25% من الاسفلت المعاد تدويره اعطت نفس خصائص واداء الخلطة الاسفلتية الاعتيادية.

ومن نتائج البحث تبين ان استخدام 50% من الاسفلت المعاد تدويره كحد أقصى اعطت افضل النتائج عند اضافتها الى الالياف الزجاجية بنسبة 0.26%.

وأشارة النتائج الى ان استخدام نسبة 25% من الاسفلت المعاد تدويره عند خلط الالياف الزجاجيه لها بنسبة 0.26% حققت متطلبات المواصفات واعطت اداء افضل ومن حيث التقييم الاقتصادى لها حيث انها وفرت حوالى 21% من التكلفة.