Influence of Recycled Asphalt Pavements on the Performance of Kuwait Asphalt Concrete Mixtures

إعادة استخدام الرصف القديم في دولة الكويت

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الملخص العربى:

الخلطة الأسفلتية الساخنة تتكون من الركام الخشن والركام الناعم والبودرة بالإضافة إلى مادة الأسفلت التى تربط تلك المواد مع بعضها. ولقد تزايد الطلب على تلك المواد فى الفترة الأخيرة نظرا للتوسع فى إنشاء عدة طرق تدعم الشبكة الحالية بالإضافة إلى عمل صيانة للطرق الموجودة أصلا. وقد يؤدى الطلب المتزايد على مواد الرصف أن تقل المواد الخام أو قد تنضب من بعض البلاد ولذا كان من الضرورى التفكير فى إيجاد حلول لتلك المشكلة. ويهدف هذا البحث إلى دراسة إمكانية استخدام المواد ناتج الرصف القديم فى إنشاء بلاطات أسفلتية جديدة فى دولة الكويت مع تحديد النسبة المثلى المناسبة من المواد المعاد استخدامها.

لذا تم تصميم برنامج معملى لتلك الدراسة تم فيه إختيار المواد محل الدراسة وهى الركام الخشن والناعم والبودرة والأسفلت بالاضافة إلى مصدر المواد المعاد استخدامها. وبعد ذلك تم إجراء اختبارات الصلاحية على تلك المواد للتأكد من مناسبة استخدامها فى الخلطة الأسفلتية. وبعد ذلك تم عمل خلطة تصميمية باستخدام الركام البكر بطريقة مارشال تحدد فيها نسبة الاسفلت المثلى وخصائص الخلطة المناظرة. وبعد ذلك تم عمل خلطات أخرى تم اختيار نسبة الركام المعاد استخدامه فيها ليكون ١٥% ، ٢٥%، ٣٥%، ٥٠% بالاضافة إلى الخلطة القياسية وذلك حتى يمكن تحديد النسبة المثلى الملائمة وفى كل خلطة تم تحديد نسبت الأسفلت المثلى والخصائص المناظرة للخلطة.

وأخيرا تم عمل بعض الاختبارات الخاصة والتى تقيس سلوك الخلطة تحت الأحمال وشملت تلك الاختبارات إختبار العجلة الترددية لقياس مدى مقاومة الخلطات المختبرة للتحدد تحت الأحمال وكذلك تم عمل اختبار الشد الغير مباشر على نفس الخلطات وذلك لقياس مدى مقاومة الخلطات المختبرة للشروخ وكل العينات تم عملها عند نسبة الأسفلت المثلى الناتجة من إختبار مارشال.

وقد أظهرت نتائج الدراسة أن خصائص الخلطة الأسفلتية لا تتأثر كثيرا بإضافة أسفلت معاد حتى نسبة ٢٥% بناء على خصائص مارشال وقد وجد أن تلك النسبة تكون فى حدود (١٥ – ٢٠%) وذلك لضمان افضل اداء للرصف عند الاستخدام وذلك باعتبار نتائج جميع الاختبارات المستخدمة وأخيرا أوصت الدراسة بعمل بحث شامل على عينات أكثر وفى ظروف متعددة

ABSTRACT

Currently, many countries are facing a dangerous challenge due to shortage in the virgin materials used in highway construction. This problem increases with time as a result of constructing new roads as well as maintaining the existing road network. In addition, construction costs, and oil and fuel prices escalates tremendously in the last few decades. Thus, reusing old pavement materials (reclaimed asphalt pavement, RAP) in new construction gains the attention of researchers and practitioners. Although pavement recycling is widely practiced in the advanced countries, it is still relatively new in the developed countries. One of the major advantages of using the recycled asphalt pavement is that, it decreases both the quantity of aggregate and the quantity of asphalt required.

The main purpose of this research was to investigate the influence of using reclaimed asphalt pavement (RAP) materials on the performance of asphalt concrete mixtures containing RAP. Another objective of this study was to determine the maximum RAP

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percentage that can be added to a new Hot-mix asphalt (HMA) mixture without a significant effect on the mixture performance. A total of five asphalt mixtures containing different percentages of RAP from old pavements in Kuwait were investigated. Marshall tests were conducted on these mixtures to determine the optimum asphalt content according to Kuwait specifications. Asphalt concrete specimens were then prepared at the optimum asphalt content resulted from Marshall tests to investigate the influence of the percentage of RAP in the mixtures on the cracking and rutting resistance through the indirect tensile test and the wheel tracking test. Results showed that, using up to 25% RAP yields about 3.6% reduction in the optimum asphalt content as well as saving in the virgin aggregate without a significant influence on the mixture performance. Furthermore, using more than 25% RAP in the asphalt concrete mixture yields a significant reduction in the mixture performance (resistance to rutting, cracking, stability and flow).

Key Words: Recycling - RAP – Marshall - Indirect tensile strength - Wheel tracking test - Rutting – Cracking.

BACKGROUND

With time and traffic pavements deteriorate, and consequently rehabilitation will be needed at some point of the pavement age. There are different methods for flexible pavement rehabilitation depending on the severity of the deterioration and the available funding. These methods are: overlaying, recycling, and reconstruction. In the recycling process reclaimed asphalt pavement (RAP) is partially or fully reused in new construction [1]. Inflation in construction cost and oil price was one of the important reasons led to an increase in recycling the old deteriorated pavements. Other advantages associated with pavement recycling are shorter user delay, conservation of energy, preservation of environment, and conservation of natural resources (aggregate and binder) [2]. Long-term pavement performance and detailed evaluations show that recycled HMA that is designed and controlled during production will perform comparably to conventional HMA and can improve materials properties of the existing pavement layer [3]. However, recycling of asphalt pavement is not yet a common practice in the developed countries such as Kuwait and Egypt. On the other hand, in advanced countries, bituminous materials are the most recycled materials in the construction industry. In USA, about 73 million tons out of 91 million tons of reclaimed asphalt pavements are used per year for recycling purposes. This represents about 80% of the total amount of RAP collected from old bituminous pavements [4]. In addition, 20 million tons of recycled hot mix was produced in Japan in 1995 [5]. This represents about 30% of the total HMA production. One disadvantage of the RAP material is that it includes aged asphalt which may lead to premature cracking compared to fresh mixtures. Thus, the process of recycling recommends mixing of the RAP with new bitumen and virgin aggregate by certain proportions [6].

Recycling Methods

The primary pavement recycling methods are central plant recycling and in-situ recycling [7]. Moreover, if heat is used in the recycling process, it is then called hot-mix recycling. On the other hand, if a recycling agent (such as emulsion) is used instead of heat, the process is then called, cold-mix recycling. Another recycling method is the full-depth reclamation. In this process, all of the asphalt pavement section and a portion of the underlying materials are processed and used as a stabilized base course after introducing additives.

OBJECTIVES

The specific purpose of this research is to investigate the influence of using reclaimed asphalt pavement materials on the performance of HMA mixtures containing RAP. Another objective of this study is to determine the maximum amount of RAP to be added to a fresh HMA mixture, without a significant effect on the performance, based on investigated mixtures typically used in highway construction projects in Kuwait.

MATERIALS AND METHODS

The materials investigated in this research effort are virgin aggregate, virgin binder, and RAP. The virgin aggregate and binder are commonly used in pavement construction in Kuwait. The RAP material was milled from old pavements in Kuwait and stored in a landfill. After checking the material quality acceptance according to the Kuwaiti specifications, five different mixtures were prepared. Each mixture was prepared with different amount of RAP as follows:

- Mix M1: 0% RAP + 100% Virgin Mix

- Mix M2: 15% RAP + 85% Virgin Mix
- Mix M3: 25% RAP + 75% Virgin Mix
- Mix M4: 35% RAP + 65% Virgin Mix
- Mix M5: 50% RAP + 50% Virgin Mix

Mix M1 which does not have any RAP represents the control mix. No additives or recycling agents were added to the investigated mixtures. The laboratory testing program outlined in Figure 1 was conducted on the investigated materials and mixtures. Acceptance/qualification tests were conducted on the virgin aggregate, RAP, and binder. Marshall samples were prepared from each mixture group and tested in order to determine the optimum asphalt content (OAC) for each mixture based on the mixture volumetric properties as well as Marshal stability and flow. Because the investigated mixtures contain different percentages of RAP, which of course contains aged asphalt, it was important to assess the influence of the RAP amount, in the mixture, on the cracking and rutting development. Thus, the indirect tensile tests (IDT) as well as the wheel tracking tests (WTT) were performed on these mixtures for cracking and rutting evaluation, respectively.

Indirect Tensile Test

This test is considered an important measure for the ability of the HMA to resist cracking. The indirect tensile strength test was conducted on asphalt concrete samples prepared at the optimum asphalt content obtained from Marshall testing results. The test was conducted by applying a compressive load parallel to and along the vertical diametral plane of a cylindrical specimen of 4 in. diameter and 0.5 in. curved loading strip. The reason for this loading configuration is to impose a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametral plane which causes a split failure of the specimen along its vertical diameter. The following relationship is used for calculating the indirect tensile strength at failure [8]:

$$\sigma_x = 2P / \pi t D \qquad (1)$$

where,

σ_x = Horizontal tensile stress at center of specimen at failure (tensile strength), psi;

P = Total compressive load at failure, lb;

D = Diameter of specimen; in.; and

t = Height of specimen; in.

Wheel Tracking Test

The Wheel Tracking Test (WTT) was run on the investigated mixtures to simulate rutting in the field. The test was conducted on asphalt concrete samples prepared at the optimum asphalt content obtained from Marshall testing results. This test has been in use for several decades and its results have been shown to correlate with rutting of in-service pavements [9]. This test consists of a small loaded wheel, which bears on a sample of a HMA mixture (30.5×30.5×5.1cm) held in a moving table. The table moves over a distance of 23.1cm at a rate of 42 passes per minute. A solid rubber-tired wheel, bearing a total load of 53.5 kg which is equivalent to a stress level of 5.3 kg/cm^2, indents a straight track in the specimen. The rate of the permanent deformation at the mid-point of the wheel track under the wheel is monitored during testing for up to 45 minutes. This test was run at a temperature of 60^{0}C. The conventional tracking rate (TR), or the rate of increase of track depth, is determined from the last third of the deformation/time curve, which is approximately linear. It can be computed with the help of Equation (2). The TR (expressed in 0.001 in/min) is used to express the rutting resistance of bituminous mixes.

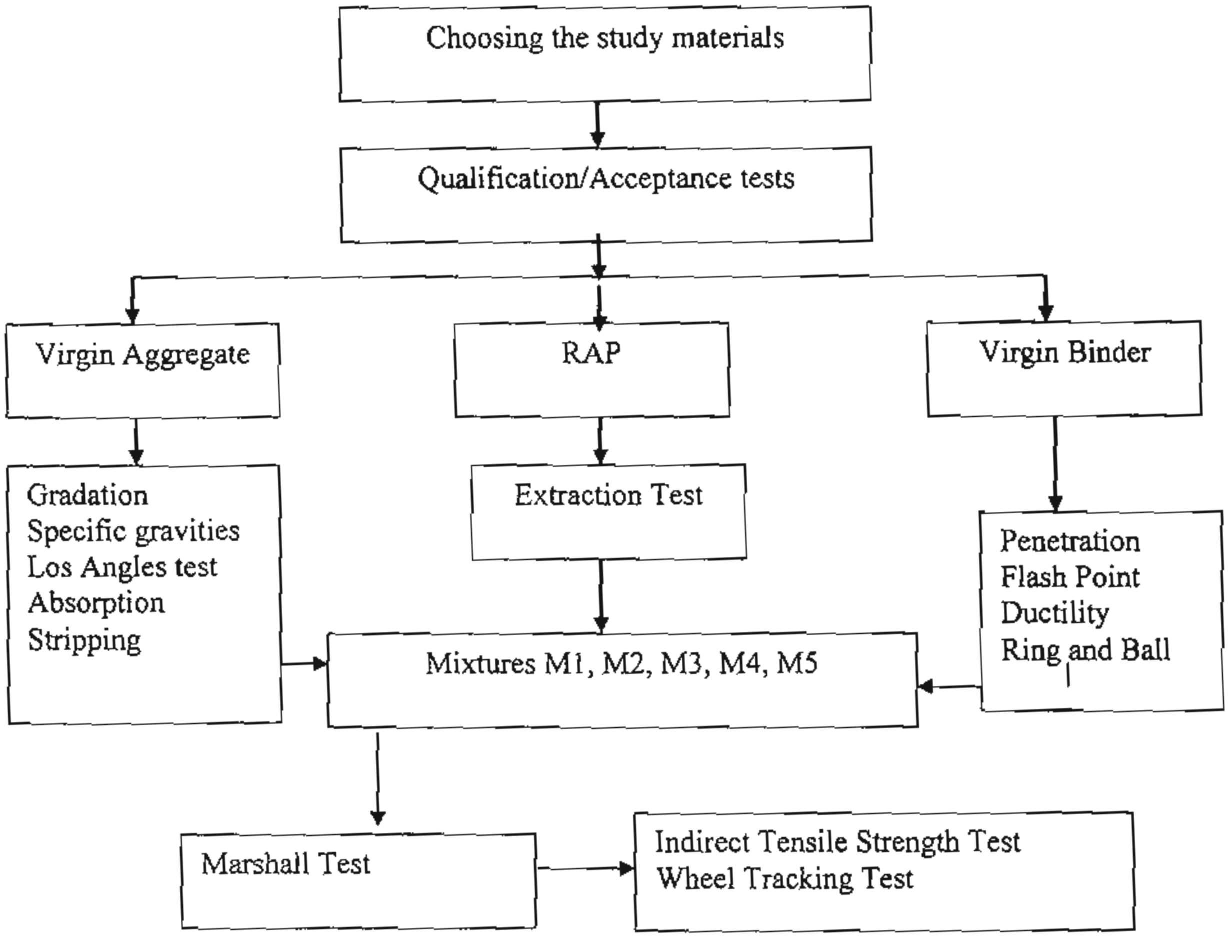


Figure 1 Experimental Program Design

$$TR = 10.16 \times 10^{-2} (TD_{45} - TD_{30}) \qquad (2)$$

where,

TR = Conventional tracking rate, mm/hour;

TD_{30} = Track depth after 30 min., 0.001 in., and

TD_{45} = Track depth after 45 min., 0.001 in.

Another measure of the rutting resistance that can be computed form the wheel tracking test is the Dynamic Stability (DS). The DS was also determined in this research. It is defined as the number of wheel passes that produces a rut depth of one mm, and given by the following formula:

$$DS = \frac{N_{60}}{CTR} \qquad (3)$$

$$CTR = 1.524\, b \qquad (4)$$

or

$$DS = \frac{2520}{1.524\, b} \qquad (5)$$

where,

N_{60} = Number of passes per hour = 2520 (60 min, about 42 pass/min);
CTR = Comprehensive tracking rate, mm/hour;
b = Slope of track depth/time regression line, 0.001 in/min.

RESULTS AND ANALYSIS

The results of the physical properties of the virgin aggregate and binder used in this study as well as the specification limits for each property are shown in Tables 1 and 2, respectively. The asphalt used in the investigated mixtures has a penetration grade of 60-70 as required by Kuwait specifications. To identify the properties of the reclaimed asphalt pavement materials, extraction tests were conducted on three different samples selected randomly from a stockpile of RAP milled from old pavements in Kuwait. Table 3 presents the results of the extraction tests of the RAP as well as the specifications of the standard gradation for the original mixture. The data in the table shows that the gradation of all samples complies with the standard gradation, except for the sample number 3 at sieve number 200. However, the average gradation of the three samples produces an aggregate that totally falls within the specification limits. It is generally noticed that the results of the extraction test tend to be closer to the upper limit of the specifications (finer gradation). This observation is rational and of course one can surmise that, it occurred because of the abrasion of the aggregate particles a result of the several passages of the heavy equipments during the construction stage as well as the traffic movement during the pavement service life. On the other hand the average asphalt content of the RAP from the extraction test was found to be 4.4%. This asphalt content was found to be lower than the optimum design value by about 1%. This loss is probably due to aging of the asphalt which leads to an evaporation of some constituents as well as losses due to bleeding of asphalt as a result of high temperature in Kuwait. It may be also due to hardening of asphalt in the aggregate pores. For these reasons the RAP asphalt binder may be considered inefficient when designing a new asphalt mix.

The gradations of the five mixtures illustrated above were selected to conform to mix type III (wearing course) as specified by the general specification of Kuwait [10]. The gradation of these mixtures follows the specification limits shown in Table 3.

Test	Designation	Result	Specification Limits
Specific gravity:			
Bulk	AASHTO T-85	2.609	-
Saturated, surface-dry	AASHTO T-85	2.659	-
Apparent	AASHTO T-85	2.748	-
Water absorption (%)	AASHTO T-85	1.5	≤ 5
Los Angeles abrasion, 500 revolutions (%)	AASHTO T-96	21	≤ 40
Stripping (%)	AASHTO T-182	>95	>95

Table 1 Physical Properties of Coarse Aggregates

Table 2 Physical Properties of the Asphalt Cement

Test	Designation	Result	Specification Limits
Penetration (0.1mm, 25°C, 100 gm, 5 sec.)	AASHTO T-49	63	60-70
Kinematic viscosity (centistokes, 135°C)	AASHTO T-201	346	≥ 300
Flash point (°C)	AASHTO T-48	+270	≥ 232
Softening point (ring and ball test, °C)	AASHTO T-53	52	45-55
Ductility, cm.	AASHTO T-51	+100	≥50

Table 3 RAP Gradation

% Passing Sieve Size	RAP Gradation			Average	Specification Limits
	Sample 1	Sample 2	Sample 3		
3/4"	100	100	100	100	100
1/2"	91	95	93	93	66-95
3/8"	82	79	86	82	54-88
No. 4	62	68	64	65	37-70
No. 8	45	43	47	45	26-52
No. 16	36	32	37	35	18-40
No. 30	24	26	26	25	13-30
No. 50	21	19	23	21	8-23
No. 100	11	12	13	12	6-16
No. 200	8.4	7.4	10.5	8.8	4-10
Asphalt Content, %	4.1	4.5	4.6	4.4	-

Influence of the Amount of RAP on Marshall Properties

The influence of the amount of RAP on Marshall properties is illustrated in Figures 2-a through 2-f. Figure 2-a shows a decrease in the optimum asphalt content with an increase in the amount of RAP, which is rational as the RAP contains old asphalt. This figure also shows that, the relationship between the amount of RAP and the OAC follows a 2nd degree polynomial with an excellent coefficient of determination (R^2 = 0.98). Furthermore, increasing the RAP percentage from zero to 25% results in a reduction in the optimum asphalt content from 5.6% to 5.4%. This means a saving in asphalt content by about 3.6%. This saving in asphalt content may be due to the old asphalt filled the reclaimed aggregate pores. Moreover, an increase in the amount of RAP causes a linear reduction in the mix unit weight as shown in Figure 2-b.

Mix stability and flow are very important indicator s of the HMA resistance to distresses. Figure 2-c shows a linear reduction in Marshall stability with the increase in the RAP amount. On the other hand, the flow was found to increase with an increase in the RAP percentage. Both stability and flow were found to have strong linear relationships with the percentage of RAP as illustrated in the figures. Although there is a reduction in the stability of the mix and increase in the flow, with the increase in the percentage of RAP, all mixes were within the specification limits regarding the stability and flow.

The mix air voids is an important factor that must be considered when designing HMA. The air voids limits for the mix type III considered in this research should be 3% to 5% of the total mix volume. Increasing the RAP amount was found to be accompanied by a reduction in the air voids as shown in Figure 2-e. It can also be seen form Figure 2-e that mixtures containing more than 25% RAP were found to have air voids outside the specification limits. Thus, it is not recommended to use amount of RAP higher than 25%. This recommendation is very important to avoid asphalt bleeding after construction especially in hot climatic conditions like that of Kuwait weather. Finally, there is linear increase in the voids in mineral aggregate (VMA) with the increase in the amount of RAP in the mix. This is of course due to the old asphalt in the RAP.

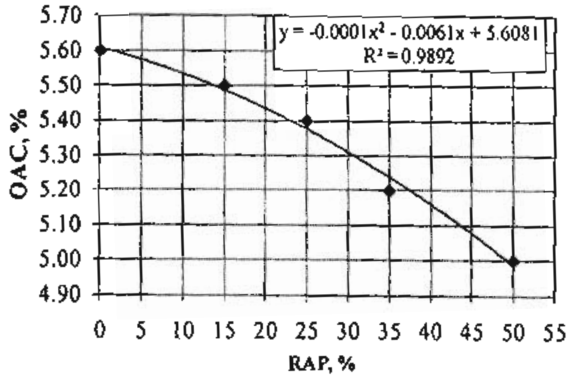
Influence of the Amount of RAP on the Indirect Tensile Test Results

The results of the indirect tensile strength test are presented in Figure 3. It is clear from this figure that, there is a decrease in the indirect tensile strength with an increase in the RAP percentage. This figure also shows that, mixtures containing 50% RAP may lose about a 60% of their original indirect tensile strength. On the other hand, mixtures containing up to 25 percent RAP may lead to only about 20% reduction in their tensile strength. Although a linear trend was found to fit the data shown in Figure 3, in fact the figure shows a bilinear trend. The first three mixtures congaing up to 25% RAP show a smaller rate in the reduction of the tensile strength, while mixtures with more than 25% RAP show a higher rate in the tensile strength reduction. This phenomenon occurred as the RAP contains aged asphalt. Thus, with increase in the RAP percentage, HMA mixtures lose their flexibility and become stiffer, hence a decrease in the tensile strength occurs.

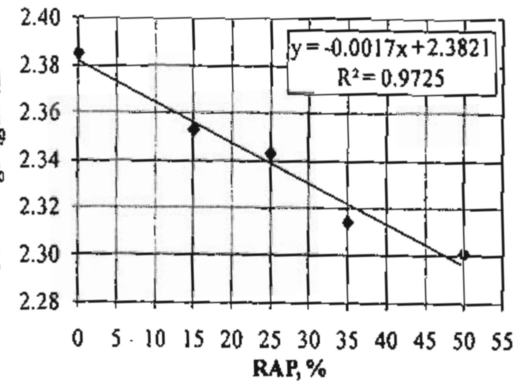
Influence of the Amount of RAP on the Wheel Tracking Test Results

The relationship between time and the measured track depth is presented in Figure 4. This figure clearly shows an increase in the track depth with time (number of passes of the wheel), achieving the highest track depth at the end of the test time. It is also clear from this figure that the rate of the track depth is the highest during the first zero to10 minutes. After that, it decreases with time as the voids reduced and the mix densificates. Furthermore, the first two mixes (M1 and M2) achieved closer values and approximately parallel relationships, i.e., equal slope. On the other hand, the last two mixes (M4 and M5) showed higher values of tracking rate. This reflects lower rutting resistance for mixes containing more than 25% RAP. The last two mixes (M4 and M5) showed no significant difference in the tracking rate. This may indicates that after some amount of RAP, the mix starts to gain stiffness as it contains more aged asphalt from the RAP. This is also supported by the increase of the rate of losing the tensile strength shown in Figure 3.

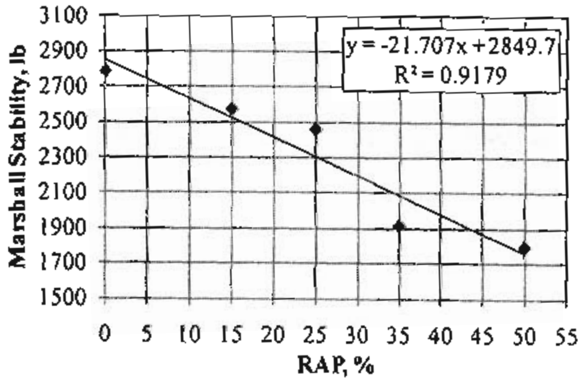
The wheel tracking test parameters are summarized in Table 4. These parameters are the conventional tracking rate, comprehensive tracking rate, slope of the tracking rate, and dynamic stability. These parameters were computed by equations 2 through 5 previously presented. The dynamic stability is considered the main indicator of mixtures resistance to rutting. Referring to Figure 5 it can be noticed that the dynamic stability decreases with an increase in the amount of RAP. This indicates a lower rutting resistance for mixtures containing higher percentages of RAP.



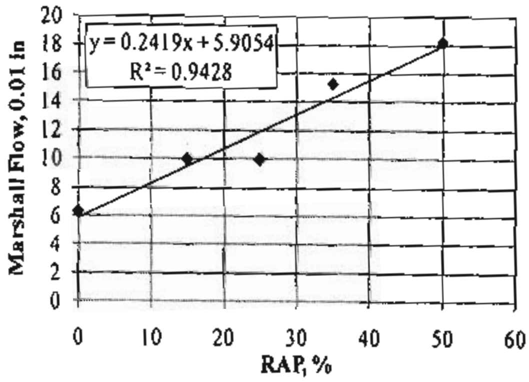
a) OAC



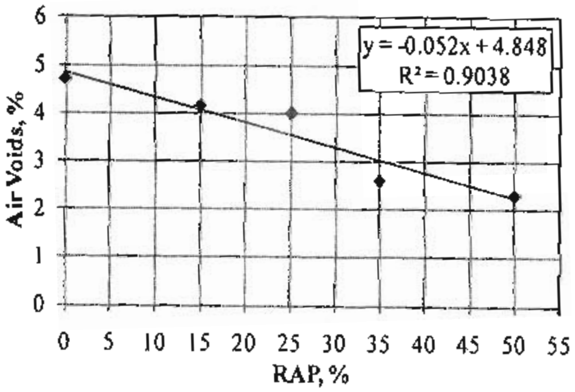
b) Unit Weight



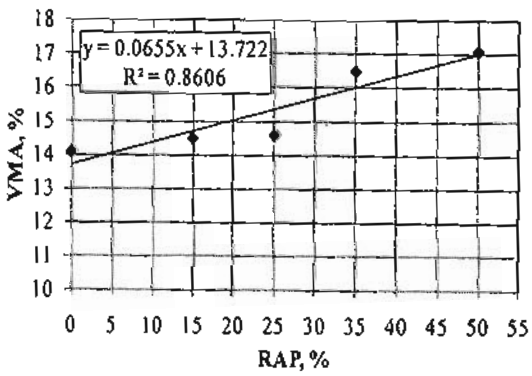
c) Stability



d) Flow



e) Total Air Voids



f) Voids in Mineral Aggregate

Figure 2 Influence of Amount of RAP on Marshall Properties

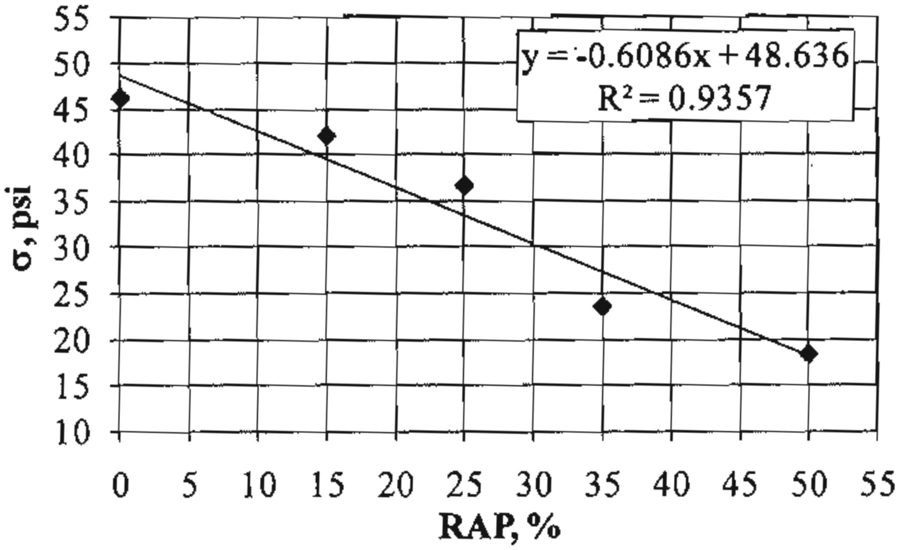


Figure 3 Influence of the Amount of RAP on the Indirect Tensile Strength

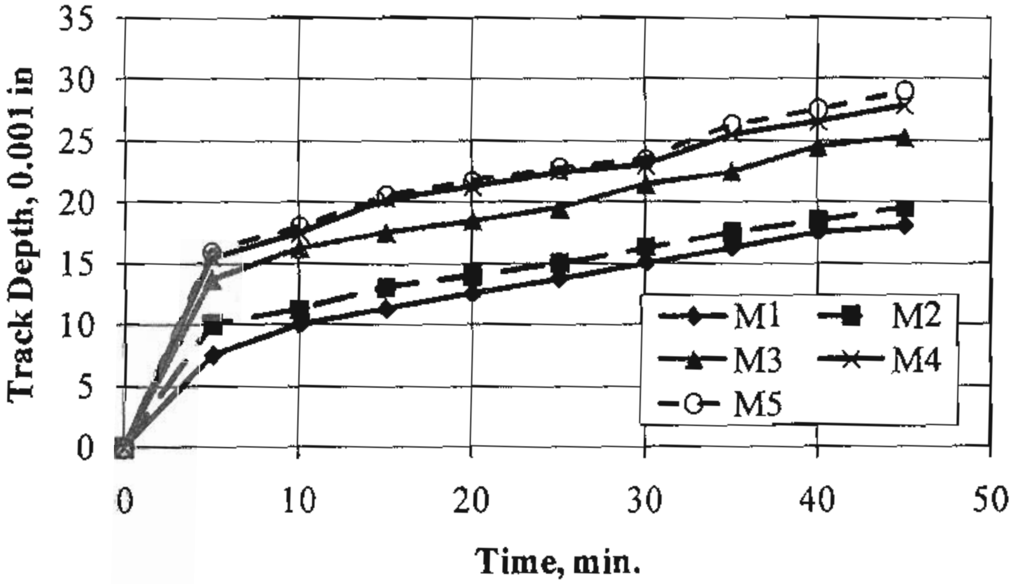


Figure 4 Observed Track Depth for the Investigated Mixes

Table 4 Wheel Tracking Test Parameters

Mix	b*	$TD_{45} - TD_{30}$	TR, mm/hr.($x10^{-2}$)	CTR, mm/hr. ($x10^{-2}$)	D.S, Pass/min
M1	0.3343	0.60	30.48	50.94	4947
M2	0.3360	0.65	33.02	51.21	4921
M3	0.4203	0.75	38.10	64.05	3935
M4	0.4561	0.95	48.26	69.51	3625
M5	0.4761	1.10	55.88	72.56	3473

*b = slope of the regression line correlating time with track depth

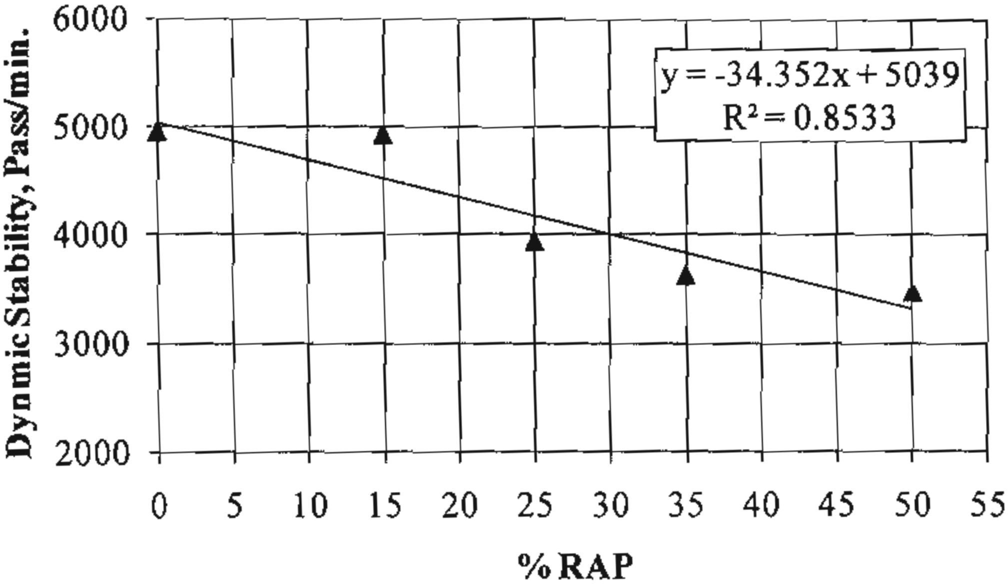


Figure 5 Relationship between Dynamic Stability and RAP Percentage

CONCLUSIONS AND RECOMMENDATIONS

This paper investigated the influence of mixing reclaimed asphalt pavements from older pavements in Kuwait with fresh aggregate and binder on the Marshall properties as well as the tensile strength and the permanent deformation resistance of such mixtures. Based on the analysis of conducted laboratory testing program results, the following conclusions were found:

1. As the amount of RAP increases, Marshall stability, unit weight, and total air voids decreases linearly. On the other hand, Marshall flow and VMA were found to increase linearly with an increase in the amount of RAP. Thus, the mix performance decreases with the increase in the RAP amount. However, mixtures with amount of RAP not exceeding 25% of the total mix weight still follow the specification limits. In addition, the reduction in mix performance is not overly significant when the amount of RAP is less than to 25%.
2. As expected, there was a nonlinear decrease in the optimum asphalt content with an increase in the amount of RAP, Furthermore, increasing the RAP percentage from zero to 25% yielded a decrease in the optimum asphalt content from 5.6% to 5.4%. This means a saving in the asphalt (which is the most expensive component in the mixture) by about 3.6%.
3. Both rutting as well as cracking resistance of the mixtures containing RAP decrease with an increase in the RAP amount. However, the reduction in rutting and cracking resistance is more significant when the amour of RAP is higher than 25%.
4. Based on the previous discussion, and considering all the investigated parameters and conditions, it can be recommended that up to 25 percentage of the total mix weight can be RAP materials to ensure good field performance for the asphalt concrete mixtures. However for the pavements exposed to high axle loads which may resulted in high distresses, the percentage of RAP should be less than 25% to sustain such higher loads and limit pavement distresses.

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