Potential Use of Recycled Asphalt Pavement (RAP) in Hot MixAsphalt

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ABSTRACT:
The objective of the present paper is to examine the effect of Recycled Asphalt Pavement (RAP) on marshall properties and indirect tensile strength of HMA through experimental investigation. A mixture with 0% RAP was used as a control mix to evaluate the properties of mixes with 5%, 10%, and 15% RAP. One type of RAP was brought from Bab Al-moadam's road in Baghdad for this purpose. The experimental testing program included Marshall and Indirect Tensile Strength tests. The results indicated that the bulk density, flow and VFA increase with the increasing of the percentage of RAP, while increasing in RAP results decreases in VTM and VMA values. Furthermore, the stability is changed from 10.1 kN for the control mix to12, 13.6 and 11.7 kN for mixes with 5%, 10% and 15% RAP respectively. The results reveal that the inclusion of RAP into HMA mixtures increases the indirect tensile strength and decreases the values of ITS with the increasing of the test temperature. The results also indicated that increasing the percentage of RAP produces an increasing in temperature susceptibility value. The results of marshall properties and IDT test indicate that the amount of new binder that needs to be added to the RAP mixture can be reduced without significant effects on the quality of the produced mix.

Keywords: recycled asphalt pavement (RAP), marshall properties, indirect tensile strength old aggregate, and old asphalt.

أمكانية استخدام التبليط الاسفلتي المعاد تدويره في الخلطات الاسفلتية

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الخلاصة:
الهدف من البحث الحالي هو التحري عن تأثير الخرسانة الاسفلتية المعاد تدويرها على خواص مارشال و قوة الشد غير المباشر للخلطة الاسفلتية من خلال التحريات المختبرية. تم اعتماد خلطة بنسبة 0% من الخرسانة الاسفلتية المعاد تدويرها استخدمت كخلطة قياسية لتقييم خواص خلطات تم اعدادها مع نسب 5%، 10% و 15% من الخرسانة الاسفلتية المعاد تدويرها. تم توفير نوع واحد من الخرسانة الاسفلتية المعاد تدويرها من منطقة باب المعظم في بغداد لهذا الغرض. تضمن برنامج الفحوصات: فحوصات مارشال و فحوصات قوة الشد غير المباشر. النتائج اشارت الى ان الكثافة و الانسياب و الفراغات المملوءة بالأسفلت تزداد مع الزيادة بنسبة الخرسانة الاسفلتية المعاد تدويرها، بينما الزيادة في نسبة الخرسانة الاسفلتية المعاد تدويرها تنتج نقصان في نسبة الفراغات الهوائية والفراغات بين حبيبات الركام. علاوة على ذلك، الثبوتية تتغير من 10.1 كيلو نيوتن للخلطة القياسية الى 12، 13.6 و 11.7 كيلو نيوتن للخلطات التي تم اعدادها مع نسب: 5%، 10% و 15% من خرسانة إسفلتية معاد تدويرها وعلى التوالي. بينت النتائج بأن تضمين الخرسانة الاسفلتية المعاد تدويرها بالخرسانة الإسفلتية يزيد من قوة الشد غير المباشر والذي يقل مع زيادة درجة حرارة الفحص. كما اشارت النتائج بأن زيادة نسبة الخرسانة الاسفلتية المعاد تدويرها ينتج زيادة التأثر بدرجة الحرارة. وبينت نتائج فحوصات مارشال وفحص (IDT) الى ان مقدار الأسفلت المضاف للخلطة المحضرة مع خرسانة اسفلتية معاد تدويرها من الممكن أن يقلل من دون التأثير على نوعية الخلطة المنتجة.
الكلمات الرئيسية:التبليط الاسفلتي المعاد تدويره،خصائص مارشال،مقاومة الشد الغير مباشر،الركام القديم، الاسفلت القديم.

1- INTRODUCTION

The most frequently used by-product in hot mix asphalt is recycled or reclaimed asphalt pavement (RAP) and the most recycled material in the United States. The use of RAP in hot-mix asphalt projects has economic and environmental benefits. The economic benefits from use of RAP materials can provide a great boost to the highway industry by freeing funds for additional highway construction, rehabilitation, preservation, and maintenance. In recent years, the incentive to recycle has grown stronger because of concerns about the environment and sustainability. The use of RAP can result in sustainable development and cost savings by reducing the amount of virgin materials required in the production of the new asphalt mixture (Behnia B. et al., 2011). Most states in the United States have established a limit of 10% to 50% RAP that can be used as part of their regular asphalt concrete (AC) designs. The Virginia Department of Transportation (Virginia DOT) recently increased the threshold of allowable RAP for Superpave mixtures from 20% to 30%. As in Virginia, AC mixtures produced in other parts of the United States may contain up to 30% or more RAP. The effect, therefore, of RAP on pavement performance is of tremendous importance and is receiving much attention as evidenced by numerous recent publications on the subject (Apeagyei A. K. et al., 2011).

A study by Jo Sias Daniel and Aaron Lachance (2005) showed that the voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) of the RAP mixtures increased at the 25% and 40% levels, and there was also an influence of preheating time on the volumetric properties**.**

Shu X. et al., (2008) conducted a laboratory study to evaluate fatigue characteristics of hot-mix asphalt (HMA) mixtures. In this study, the HMA mixtures containing 0%, 10%, 20%, and 30% of recycled asphalt pavement (RAP) were plant prepared with one source of aggregate, limestone, and one type of binder, PG 64–22. The results from this study indicated that both indirect tensile strength IDT and beam fatigue tests agreed with each other in ranking the fatigue resistance of mixtures when proper procedures were followed. An experimental study by Valdés G. et al., (2011) to characterize the mechanical behavior of bituminous mixtures containing high rates of reclaimed asphalt pavement (RAP). Two semi-dense mixtures of 12 and 20 mm maximum aggregate size and containing 40% and 60% RAP. Results show that the mixtures with RAP, have very similar values of indirect tensile strength, which are considerably higher than that of the conventional mixture.

Tran b. T. and Hassan R. A., (2011) conducted an experimental program to design and assess the properties of recycled hot dense graded asphalt mixes, the RAP contents in the recycled mixes were 10%, 20%, and 30%. The results from this experimental program proved to be successful in producing recycled mixes with up to 20% RAP that meet specification requirements. Results also indicate that the addition of RAP leads to reduction in required binder content to achieve 4% air voids content, also a reduction in the value of voids in mineral aggregate, voids filled with binder, and film index. Further, the addition of RAP results in a stiffer mix, and this effect increases with increasing RAP content. Intisar M. J., (2011) concluded that RAP materials are not suitable to be used in cold mix alone as base materials without certain processs o treatment to improve their characteristics.

2- OBJECTIVES

The objective of the present paper is to evaluate RAP's role and its effect on; bulk density, stability, flow, volumetric properties and the tensile strength of HMA through experimental investigation.

3- MATERIALS AND METHODS OF TESTING

3-1 Materials

Materials used in this study are locally available and selected from the currently materials used in roads construction in Iraq.

3-1-1 Asphalt Cement

One type of asphalt cement is used, (40-50) Penetration grade from Daurah Refinery. The physical properties for the asphalt cement are presented in **Table 1**.

3-1-2 Aggregate

The aggregate used in this work was crushed quartz obtained from Al-Nibaie quarry in Taji, north of Baghdad. This aggregate is widely used in Baghdad city for asphaltic mixes. The coarse and fine aggregates used in this work were sieved and recombined in the proper proportions to meet the wearing course gradation as required by SCRB specification (SCRB, R/9 2003).The gradation for the aggregate is shown in **Table (2)** and **Fig1**. Routine tests were performed on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the SCRB are summarized in **Table (3)**. Tests results show that the chosen aggregate met the SCRB specifications.

3-1-3 Mineral Filler

One type of mineral filler is used: ordinary Portland cement was brought from local market. It is thoroughly dry and free from lumps or aggregations of fine particles. The physical properties are shown in **Table (4)**.

3-1-4 Recycled Asphalt Pavement (RAP)

Recycled asphalt pavement (RAP) was taken from Bab Al-moadam's road in Baghdad. The top 50 mm of the asphalt layer was removed and gathered from the damaged pavement, which represents the surface layer. The gathered RAP was milled, sieved and recombined in predetermined percent with new aggregate and new asphalt grade (40-50). **Table (5)** represented the physical properties of recycled asphalt pavement used in the study. **Plate (1)** shows samples of Recycled Asphalt pavement.

3- 2RAP Variability

In order to minimize the RAP aggregate variability, especially in gradation, the RAP aggregate was milled and sieved on standard sieve and the amount of RAP aggregate retained on each sieve was separated.

3-3 Mix Design

The Marshall Mix design method was employed to determine the optimum asphalt content (O.A.C) for the mix with zero RAP percent. The optimum asphalt content for HMA mixture with 0%RAP was found to be 4.9%.

3-4 SPECIMENS PREPARATION

New aggregate is heated to a temperature of 175 ^{0}C to 190^{0}C, the compaction mold assembly and rammer are cleaned and kept pre-heated to a temperature of 100^{0}C to 145^{0}C. The bitumen is heated to a temperature of 121^{0}C to 138^{0}C. In case of mixture with RAP, the RAP is heated in special oven at 120°C for 60 minutes, before mixing with new aggregate and new asphalt cement. The mixture of new aggregate and new asphalt cement (40-50) and RAP (in case of preparation the mixture with recycled asphalt pavement) is then placed in mixing bowl and mix rapidly until the new aggregates are thoroughly coated. The mix is placed in standard mold and compacted with number of blows specified on each face.

3-5 TEST METHODS

3-5-1 Resistance to Plastic Flow of Asphalt Mixture (Marshall Test Method)

This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixtures loaded on the lateral surface by means of the Marshall apparatus according to ASTM (D 1559).This method includes preparation of cylindrical specimens which are 4 inch (101.6 mm) in diameter and 2.5 ±0.05 inch (63.5 ±1.27 mm) in height.

The Marshall Mold, spatula, and compaction hammer are heated on a hot plate to a temperature between (120-150 ˚C). The asphalt mixture is placed in the preheated mold and it is then spaded vigorously with the heated spatula 15 times around the perimeter and 10 times in the interior.

The temperature of the mixture immediately prior to compaction is between (142-146˚C) (ASTM D-1559). Then, 75 blows on the top and bottom of the specimen are applied with a compaction hammer of 4.535 kg sliding weight, and a free fall in 18 inch (457.2 mm).The specimen in mold is left to cool at room temperature for 24 hours and then it is removed from the mold.

Marshall stability and flow tests are performed on each specimen. The cylindrical specimen is placed in water bath at 60 ˚C for 30 to 40 minutes, and then compressed on the lateral surface at constant rate of 2in/min. (50.8mm/min) until the maximum load (failure) is reached.

The maximum load resistance and the corresponding flow value are recorded. Three specimens for each combination are prepared and the average results are reported.

The bulk specific gravity and density ASTM (D 2726), theoretical (maximum) specific gravity of voidless mixture is determined in accordance with ASTM (D 2041). The percent of air voids is then calculated.

3-5-2 Indirect Tensile Strength

Specimens are prepared by Marshall method and tested for indirect tensile strength according to ASTM (D 4123). The prepared specimens are cooled at room temperature for 24 hours, immersed in a water bath at different test temperatures (5, 25, and 40 ˚C) for 30 minutes, then tested by Versa-Tester using a 1/2 in. (12.5mm) wide curved, stainless steel loading strip on both the top and bottom, running parallel to the axis of the cylindrical specimen which are loaded diametrically at a constant rate of 2 in/min. (50.8 mm/min.) until reaching the ultimate loading resistance. Three specimens for each mix combination are tested and the average results are reported. The indirect tensile strength (I.T.S) is calculated, as follows:

$$I.T.S = 2\,P_{ult} / \pi\, t\, D \qquad \text{(eq.1)}$$

where:

P_{ult} = Ultimate load upto failure (N). t = Thickness of specimen (mm), and D = Diameter of specimen (mm).

The temperature susceptibility is calculated, as below:

$$TS = [(I.T.S)_{t0} - (I.T.S)_{t1}] / (t_1 - t_0) \qquad \text{(eq.2)}$$

where:

$(I.T.S)_{t0}$ = Indirect tensile strength at t_0 (˚C) $(I.T.S)_{t1}$ = Indirect tensile strength at t_1 (˚C) t_0 = 25˚C, t_1 = 40 ˚C.

4- RESULTS AND DISCUSSION

4-1 Marshall Test Results

The results of Marshall Tests show typical relationships between Marshall Properties and control mix (0% RAP), mixes with 5% RAP, 10% RAP and 15% RAP. **Fig (2A)** shows the bulk density values for various mixtures as a function of RAP content. In this Fig, the bulk density increases with the increase in RAP content, this indicates that; with the presence of RAP more dense mixes will be produced as compared with no RAP mixes and this effect appears clearly with the increasing in RAP content. **Fig (2B)** shows the Marshall Stability values. It indicates that, stability values for various mixes follow the typical trend in the presence of RAP. Where, the stability values increase with the increase in RAP content until a maximum value is reached after which stability tends to decrease.

This can be attributed to the increase in the stiffness of asphalt by incorporating more RAP which gives high cohesive strength while maintaining the interlocking between coarse crushed aggregate. The decrease in stability after certain RAP content is due to an increase in the thickness of asphalt film coating the coarse aggregate particles, which lower the internal friction. The decrease in internal friction is also associated with the increased lubrication, which is believed to be the reason for the continuous increase in Marshall Flow values, as shown in **Fig (2C).**

Fig (2D) shows the relationship between the percent of air voids and RAP content. It can be noticed that percent of air voids decreases with the increase in percent of RAP content. This is an indication that the old asphalt in the RAP aggregate do not act as black rock and the old asphalt in the RAP contributed with new asphalt cement (AC) and result in increasing the asphalt percentage in the produced mix. And this leads to a reduction in percent of air voids for compacted specimen and consequently the bulk density of specimen increases.

Fig (2E) shows voids in mineral aggregate (VMA) against RAP content. It can be noticed that percent of (VMA) decreases with the increase of RAP content. This reduction in (% VMA) due to the decrease percent of air voids.

Fig (2F) shows the values of voids filled with asphalt (VFA) percent against RAP content. It can be noticed that percent of (VFA) increase with the increase of RAP content, and this is prove that the old binder in the RAP contributed with new asphalt cement and increasing the percentage of asphalt in the mix. The (VFA) values are within the S.C.R.B specified limit (70-85) %.

Fig (3) shows the effect of RAP content for various mixes on Marshall Stiffness. Marshall Stiffness is defined as the ratio between the Marshall stability and Marshall Flow. The high Marshall Stiffness (stability /flow) means that asphalt mixture has good resistance to plastic flow resulting from traffic loading when this mix is used in pavement. Also, high value of stability of asphalt mixes does not mean that good resistance of plastic flow can be gained from this mix because high flow value will lead to low Marshall Stiffness. This indicates that, stiffness values for various mixes follow the typical trend in their relation with asphalt content where these values increase with the increase in the percent of RAP content until a maximum value is reached after which stiffness tends to decrease.

4 -2 Indirect Tensile Strength Test Results

The evaluation of tensile strength for asphaltic concrete mixture used in construction of pavement becomes increasingly more important. This is partially due to the fact that pavements during service will be exposed to various traffic loading and climatic conditions. These conditions may cause tensile stresses to be developed within the pavement, and as a result, two types of cracks may be exhibited: one resulting from traffic loading, called fatigue cracking and the other type of crack resulting from climatic conditions and called thermal or shrinkage cracking. The indirect tensile test IDT has been used to evaluate the mixture resistance to low temperature cracking.

In order to evaluate the mixture resistance to variation in temperatures, three different testing temperatures are used (5°C, 25°C and 40°C), at the selected optimum asphalt content (O.A.C) which are obtained previously.

The mechanical responses for four mixtures at three temperatures (5°c, 25°c and 40°c) during the indirect tensile strength tests are shown in **Fig (4).** The results indicate that, the presence of recycled asphalt pavement (RAP) in a mixture tends to increase the indirect tensile strength of the mix as compared to a mixture without RAP. This may be related to the hardness of the old asphalt in the RAP as compared to the new asphalt cement (40-50) which result in increasing the viscosity of the mix. The results reveal that the values of IDT strength decreases with increase the temperature of the test. At the highest temperature (40°C), the asphalt mixture is more ductile and has a lower peak tensile strength and the high temperature diminish the difference between the four mixes. At the lowest temperature (5°C), the material is brittle and has a higher peak tensile strength. At 25°C, the mixture exhibits an intermediate response. Test results also confirm the significance of temperature on the mixture indirect tensile strength, since indirect tensile strength increased as temperature decreased.

One may be seen that the IDT strength values did not follow a definitive trend at 5°c with 5% RAP, so the behavior of HMA with low RAP percent (less than 15%) at low temperature, need more laboratory investigation.

Fig. (5) shows the values of temperature susceptibility for four mixes. The results indicates that any increasing in RAP percent produce increasing in temperature susceptibility value. This may be related to the fact that the old (aged) asphalt cement in the RAP aggregate changes the physical properties of new asphalt cement (40-50) and make it more susceptible to change in temperature.

5- SUMMARY AND CONCLUSIONS

A laboratory study was conducted to evaluate RAP's role and its effect on bulk density, stability, flow, volumetric properties and the tensile strength of HMA using marshall test method and ITS. The HMA were prepared with one source of aggregate, Portland cement and one type of asphalt cement (40-50), containing 0%, 5%, 10%, and 15% of RAP.

Based on the findings of this study, the following conclusions can be put forward:

1- Marshall stability increases with the increasing of RAP content until a maximum value is reached after which stability tends to decrease.
2- Increasing of the percent of RAP content produces decreasing of air voids and VMA. This increasing in RAP would produce an increase in bulk density, flow and VFA with the same increment in RAP content.
3- Stiffness of mixes increase with the increasing of the percentage of RAP until a certain value is reached and it then tends to decrease.
4- The inclusions of RAP into HMA mixtures (in general) increases the tensile strength, while the values of ITS are decreased with the increasing of temperature test.
5- The results indicate that increasing in RAP content produces an increasing in temperature susceptibility.
6- Results of marshall properties indicate that the amount of new binder in the RAP mixture can be reduced without any effect on the quality of the produced mixes.
7- Finally and based on the tests results , it appeared that 5% of RAP can be recognized as optimal percentage to be added to the HMA of wearing course layer for local pavement within the study limitation. Keeping in mind comprehensive lab and field tests need to be carried out to confirm or revise the mentioned percentage.

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Table (1): Physical Properties of Asphalt Cement.

Property	ASTM Designation (ASTM,2000)	Penetration Grade 40-50	
		Test Results	SCRB(*) Specification
1-Penetration at 25°C,100 gm,5 sec, (0.1mm)	D-5	41	40-50
2- Softening Point, (°C)	D-36	50	……
3-Ductility at 25 °C, 5cm/min,(cm)	D-113	>100	>100
4-Flash Point, (°C)	D-92	288	Min.232
5-Specific Gravity	D-70	1.041	……
6- Residue from thin film oven test	D-1754		
- Retained penetration,% of original	D-5	60	55+
- Ductility at 25°C , 5cm/min,(cm)	D-113	80	25^+

(*): State Commission of Roads and Bridges

Table (2): Combined Gradation of Aggregate and Mineral Filler.

Sieve Size	Sieve Opening (mm)	Percentage Passing by Weight of Total Aggregate	
		Surface or Wearing Course	
		Specification Limit (SCRB)	Selected Gradation
3/4"	19	100	100
1/2"	12.5	90-100	96
3/8"	9.5	76-90	82
No.4	4.75	44-74	56
No.8	2.36	28-58	36
No.50	0.3	5-21	12
No.200	0.075	4-10	6

Table (3): Physical Properties of Aggregate

Property	ASTM designation	Test results	SCRB specification
Coarse aggregate			
1. Bulk specific gravity	C-127	2.611	……
2. Apparent specific gravity		2.687	……
3. Water absorption,%		0.447	……
4. Percent wear by Los Angeles abrasion ,%	C-131	19.0	30 Max
5. Soundness loss by sodium sulfate solution,%	C-88	3.2	10 Max
6. Fractured pieces, %		96	95 Min
Fine aggregate			
1. Bulk specific gravity	C-127	2.62	……
2. Apparent specific gravity		2.69	……
3. Water absorption,%		0.720	……
4. Sand equivalent,%	D-2419	55	45 Min.

Table (4): Physical Properties of Mineral Filler.

Property	Test results
% Passing Sieve No. 200	100
Specific Gravity	3.13

Table (5): Physical Properties of Recycled Asphalt Pavement.

Test Method	ASTM designation	Coarse RAP	Fine RAP
Bulk specific gravity	C- 127& C- 128	2.311	2.078
water absorption, %	C- 127& C- 128	3.811	7.981

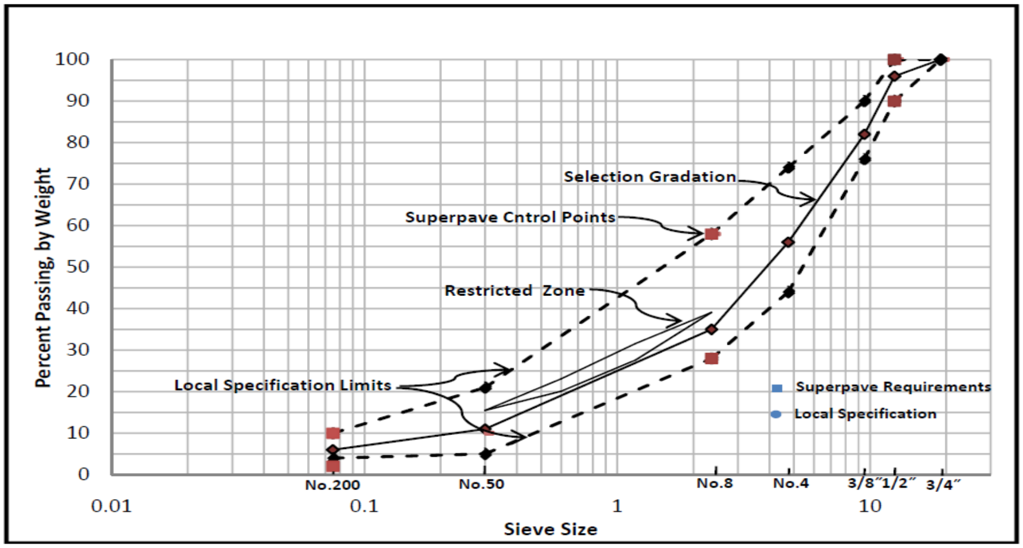

Fig (1): Aggregate Gradation Curve.

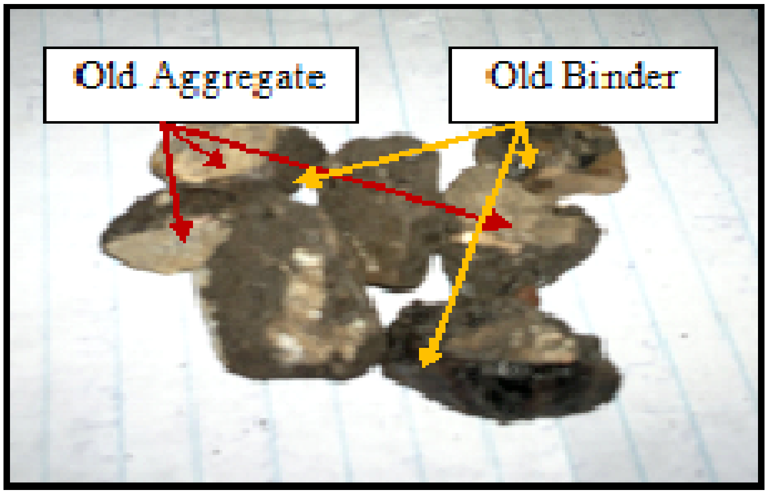

Plate (1): Samples of Recycled Asphalt Pavement (RAP).

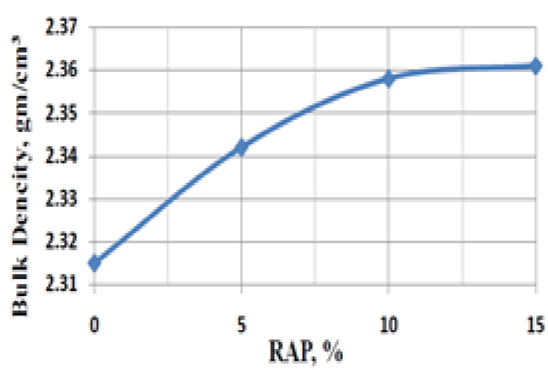

Figure (2A): Relationship between RAP Percent and Bulk Density.

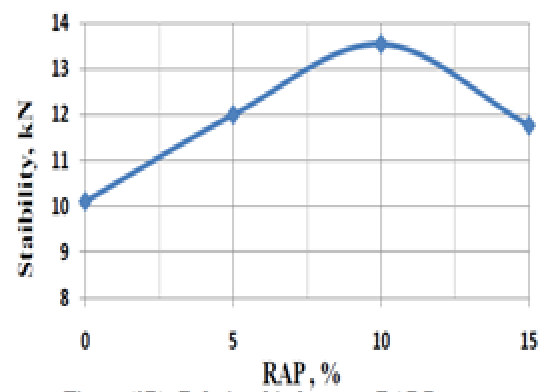

Figure (2B): Relationship between RAP Percent and Stability.

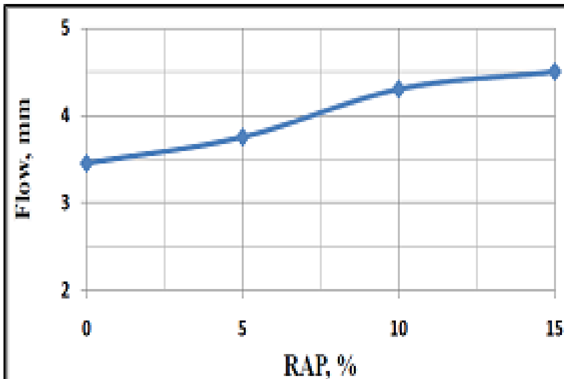

Figure (2C): Relationship between RAP Percent and Flow.

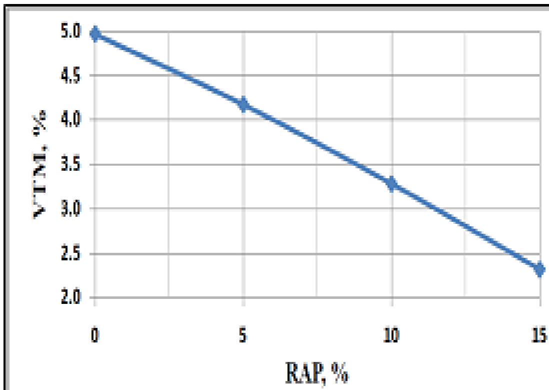

Figure (2D): Relationship between RAP percent and VTM.

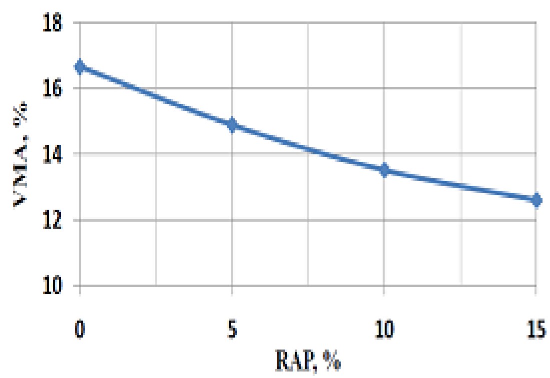

Figure (2E): Relationship between RAP Percent and VMA.

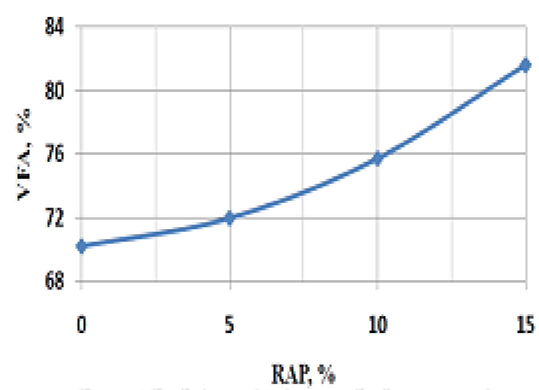

Figure (2F): Relationship between RAP percent and VFA.

Fig (2): Effect of RAP (%) on Marshall Properties.

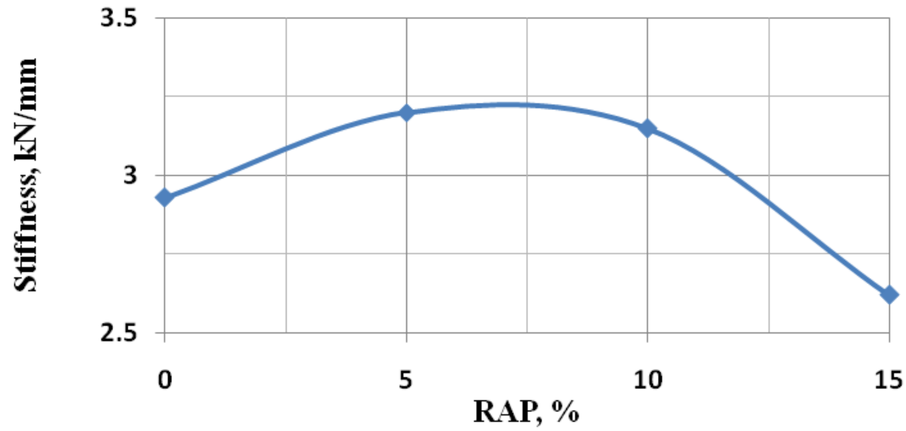

Figure (3): Relationship between RAP (%) and Marshall Stiffness.

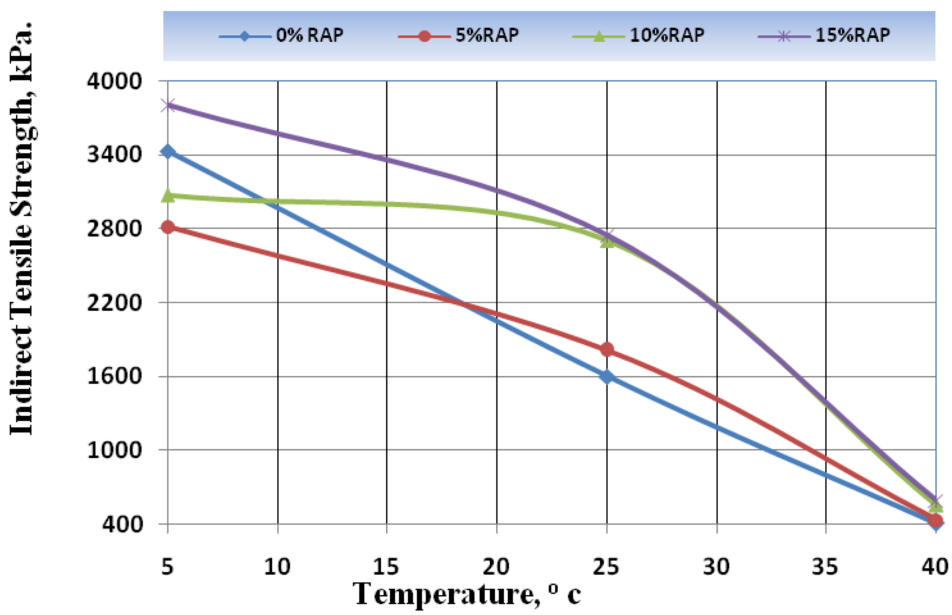

Figure (4): Relationship between RAP Percent and Indirect Tensile Strength.

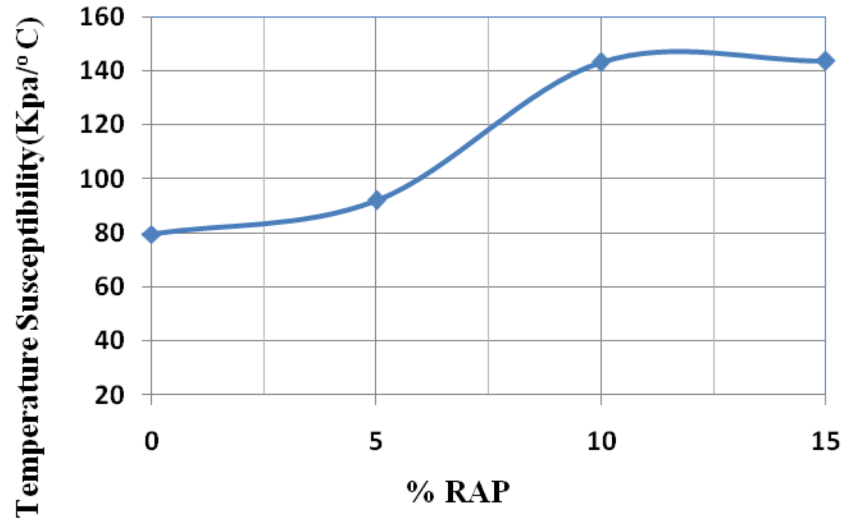

Figure (5): Relationship between RAP (%) and Temperature Susceptibility.