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EVALUATION OF HOT MIX ASPHALT CONTAINING RECLAIMED ASPHALT PAVEMENT TO RESIST MOISTURE DAMAGE

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Abstract: Due to increasing cost of asphalt binder, significant economic savings can be realized by using the amount from reclaimed asphalt pavement (RAP) in the production of new hot mix asphalt (HMA). Moreover, this is an environmentally friendly option as it reduces the demand for virgin materials. It has to be remarked that in Iraq RAP is not used in the production of HMA and this valuable material is mostly degraded for use in lower value applications. Four mixtures were designed, which contains three different percent RAP, it is (0%, 5%, 15%) with asphalt grade (40-50) and (25%) with asphalt grade (60-70), it has been changed the grade of asphalt when adding RAP (25%) to compensate for the aged binder in the RAP when adding to mixture. All types of tests result demonstrated that all mixtures have good properties compared with the virgin mixture. This demonstrated that mixtures with RAP content could be successfully designed to meet the local volumetric and performance-specification requirements.

Keywords: *Reclaimed Asphalt Pavement, Marshall Properties, Indirect Tensile Test, Index of Retained Strength, Double Punching shear, Moisture Damage.*

تقييم الخلطة الإسفلتية الساخنة التي تحتوي على تبليط قديم لمقاومة ضرر الرطوبة

الخلاصة: بسبب زيادة تكلفة مادة الإسفلت، يمكن تحقيق موارد اقتصادية كبيرة باستخدام كميه من التبليط الاسفلتي القديم (RAP) في إنتاج الأسفلت الساخن الجديد (HMA). علاوة على ذلك، هذا هو الاخيار صديق للبيئة لأنه يقلل من الحاجة إلى المواد جديده. يجب ملاحظة أنه لا يتم استخدام RAP في العراق في إنتاج HMA وأن هذه المادة القيمة تتدهور في الغالب للاستخدام في التطبيقات ذات القيمة المنخفضة. تم تصميم أربعة خلطات، والتي تحتوي على ثلاث نسب مختلفة من (RAP)، وهي (0 ٪، 5 ٪، 15 ٪) مع درجة الإسفلت (40-50) و (25 ٪) مع درجة الإسفلت (60-70) استخدم اسفلت ذات درجه اختراق اعلى وذلك للتعويض عن الاسفلت القديم في التبليط المعاد تدويره عند اضافته الى الخلطة. أثبتت جميع أنواع الاختبارات أن جميع الخلطات التي تحتوي على (RAP) خصائص جيدة مقارنة مع الخلطة المرجعية. وهذا يثبت أن المزائج مع محتوى RAP يمكن تصميمها بنجاح للوفاء بمتطلبات الحجمية المحلية ومتطلبات الأداء .

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1. Introduction

The recycling of asphalt pavement dates back to the early 20th century. Recycling asphalt pavements first became common in the U.S. in the 1970s during the oil embargo when the cost of crude oil skyrocketed. Now, the two important factors that influence the use of reclaimed asphalt pavement (RAP) in the construction of new asphaltic pavements are economic savings and environmental benefits (Newcomb et al. 2007). RAP is a useful alternative for the virgin materials because it reduces the amount of aggregate and asphalt binder demanded in the production of hot mix asphalt (Copeland 2011). The most significant characteristic of RAP materials that affected on the properties and performance of recycled mixtures is the ageing of asphalt binder. Therefore, the methods for compensating for the ageing asphalt binder and ensuring adequate pavement performance include the use of rejuvenating or softening additives (Zaumanis 2014).

There is no agreement whether HMA, which contains RAP, improved or not compared to HMA without RAP. Therefore, the durability of recycled mixes to resist moisture damage has been studied and evaluated by many researchers by water sensitivity tests. In their study, (Tabakovic et al., 2006) concluded that moisture damage was not a problem for the mixtures containing 0%, 10% and 20% RAP. However, a number of researchers have pointed out that using RAP increased stiffness that leads to improve the stability of mixture compared with virgin mixture (McDaniel and Shah, 2002, Zaumanis 2014, and Al-Qadi et al., 2012).

2. Objective

This work focused on producing the HMA, which contain RAP similar to the virgin HMA, and then study the effect of addition RAP to HMA on the volumetric properties and performance to resist moisture damage and other properties.

3. Material and Methods

3.1. Virgin Binder

Essentially, all of the asphalt binder materials were assiduously brought from locally sourced. Concerning the asphalt cement binder, it was originally brought from Al-Daurah and Al-Nasiriyah refinery and have (40/50) and (60/70) penetration grade respectively. The common test results are summarized in Table (1).

3.2. Virgin Aggregate

The materials were used in this work are locally available in Iraq and used in roadwork's. The source for the coarse and fine aggregate was Al-Nibaee quarry at Al-Taji, north of Baghdad while Karbala factory was the exporter of limestone dust that was used as the mineral filler. The physical and chemical properties of the aggregate are shown in Tables (2) and Table (3) respectively. The gradation for aggregate used in this work is followed the mid-point gradation of Iraq specification (SCRB, R/9 2003) with nominal maximum size (12.5mm) type AIII, which is suitable for surface layer pavement and shown in Table (4) and Figure (1).

Table 1. Physical Properties of Asphalt Cement

Property	ASTM Designation 2010	Penetration Grade 40-50		Penetration Grade 60-70	
		Test Results	SCRB Specification 2003	Test Results	SCRB Specification 2003
Penetration @ 25C°, 100 gm., 5sec. (0.1mm).	D-5	46	40-50	63	60-70
Kinematics Viscosity, cSt @ 135◦C°.	D-2170	410	…….	370	…..
Softening Point (Ring and Ball). (C°).	D-36	51	……	46	…..
Ductility @ 25C°, 5cm/min, (cm).	D-113	130	>100	130	>100
Flash Point, (C°).	D-92	272	>232	251	>232
Specific Gravity (gm/mm³).	D-70	1.04	…..	1.03	…..

* The tests were done in Al-Mustainsriya University laboratories and Department of building research.

Table 2. Physical Properties of Al-Nibaee Aggregates

Property	Coarse Aggregate		Fine Aggregate	
	ASTM 2010	Result	ASTM 2010	Result
Bulk Specific Gravity (gm/cm³).	C-127	2.603	C-128	2.651
Apparent Specific Gravity (gm/cm³)	C-127	2.658	C-128	2.692
Percent Water Absorption (%).	C-127	0.453	C-128	0.733
Percent Wear (loss angels abrasion) (%)	C-131	18.3	------	------

* The tests were done in Al-Mustainsriya University laboratories.

Table 3. Chemical Composition of Al-Nibaay Aggregates

Chemicals Compound	Results%
Loss on Ignition (L.O.I)	6.55
Silica (SiO_2)	82.52
Lime(CaO)	5.37
Magnesia (MgO)	0.78
Sulfuric Anhydride (SO_3)	2.7
Ferric Oxide (Fe_2O_3)	0.69
Alumina (Al_2O_3)	0.48
TOTAL	99.09
Mineral Composition	
Quartz	80.3
Calcite	10.92

* The tests were done in Al-Mustainsriya University laboratories and Department of building research.

Table 4. Gradation of Aggregate for Surface Layer Type AIII

Sieve size	Sieve opening (mm)	Percentage Passing by Weight of Total Aggregate	
		Specification limits (S.C.R.B)	Mid-point Gradation
3/4"	19	100	100
1/2"	12.5	90-100	95
3/8"	9.5	76-90	83
No.4	4.75	44-76	59
No.8	2.36	28-58	43
No.50	0.3	5-21	13
No.200	0.075	4-10	7

* The tests were done in Al-Mustainsriya University laboratories.

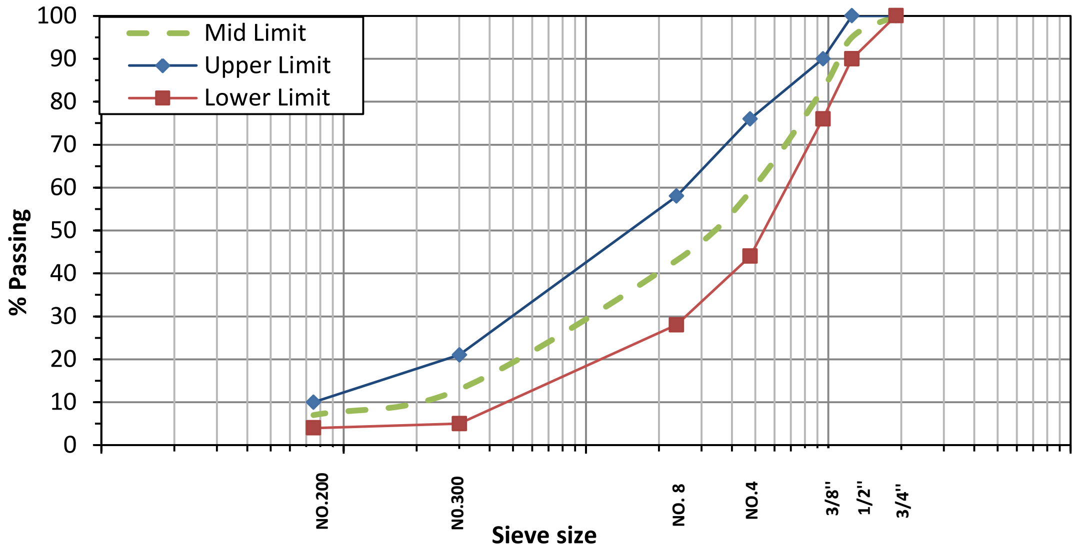

Figure 1. Specification Limits and Selected Mid-Point Gradation of (SCRB) for Surface Layer Type AIII

3.3. RAP Material

The reclaimed asphalt pavement (RAP) was obtained from Baghdad-Babylon highway as shown in plat (1) after the pavement was heavily deteriorated with various cracks and ruts existing on the pavement surface, the milling depth from the roadway was 5 cm. The first important step in the design of recycled HMA was determined the properties of RAP material. The basic required properties of RAP materials are asphalt content and sieve analysis of aggregates. Ten samples have been selected randomly from the milled RAP material and these samples were subjected to extraction test to isolate asphalt binder from aggregate according to (ASTM D-2172) procedure to obtain asphalt binder, filler content, gradation and properties of aggregate. It observes that the percent of passing aggregates are increased after extraction because the RAP-aggregate before extraction is coated with a layer from asphalt and filler material, and this prevents some aggregate particles to pass, hence after extraction get rid of this layer lead to an increase in the percent of aggregates passing. The asphalt content is calculated by difference from the weight of extracted aggregates. The properties of reclaimed asphalt pavement after extraction as shown in

Table (5) and gradation of RAP before and after extraction shown in the Table (6) and Figure (2). Prior to recycling this RAP was crushed and fractionated to sieve No4.

Table 5. The properties of Reclaimed Asphalt Pavement after Extraction

Material	Property	ASTM 2010	Result
RAP Mixture Marshall properties	Stability (kN).	D-1559	11.9
	Flow (mm).	D-1559	3.6
	Bulk Density (gm/cm³).	D-2726	2.336
	Air Void (%).	D-2726	4.29
Binder Asphalt	Binder Content After Extraction (%).	D-2172	3.8
Coarse Aggregate	Bulk Specific Gravity (gm/cm³).	C-127	2.621
	Apparent Specific Gravity (gm/cm³).	C-127	2.632
	Percent Water Absorption (%).	C-127	0.213
Fine Aggregate	Bulk Specific Gravity (gm/cm³).	C-128	2.654
	Apparent Specific Gravity (gm/cm³).	C-128	2.694
	Percent Water Absorption (%).	C-128	0.663

* The tests were done in Al-Mustainsriya University laboratories and Department of building research.

Table 6. RAP Gradation Before and After Extraction Test and Limitation of SCRB/R9 for Surface Layer

Sieve Size	Sieve Opening (mm)	Percentage Passing by Weight of Total RAP Aggregate		
		Before Extraction	After Extraction	Specification Limits (S.C.R.B)
3/4"	19	100	100	100
1/2"	12.5	91.6	94.9	90-100
3/8"	9.5	78.5	83.3	76-90
No.4	4.75	53.3	58.7	44-76
No.8	2.36	36.1	41.9	28-58
No.50	0.3	6.3	11.7	5-21
No.200	0.075	4.3	5.2	4-10

* The tests were done in Al-Mustainsriya University laboratories and Department of building research.

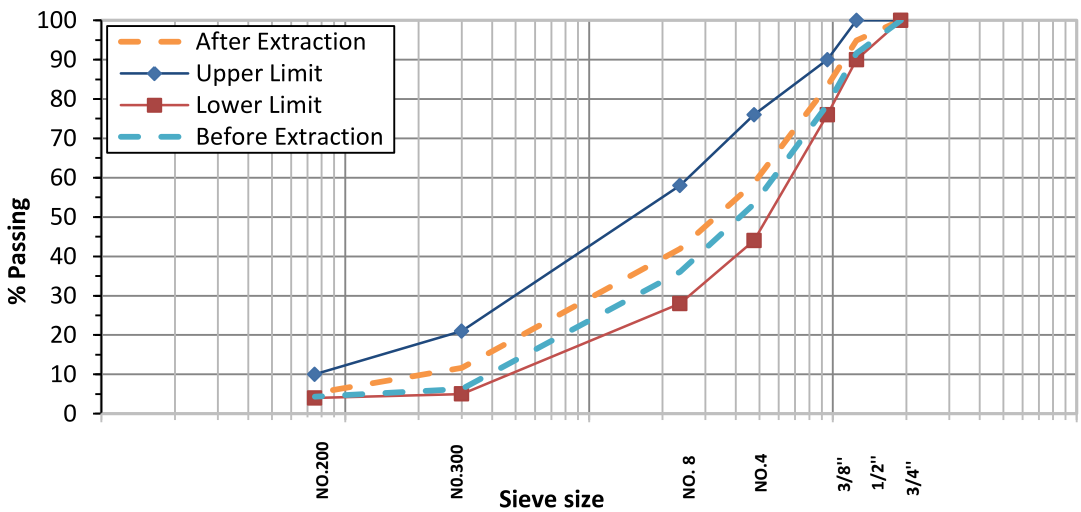

Figure 2. RAP Gradation Before and After Extraction Test and Limitation of SCRB/R9 for Surface Layer

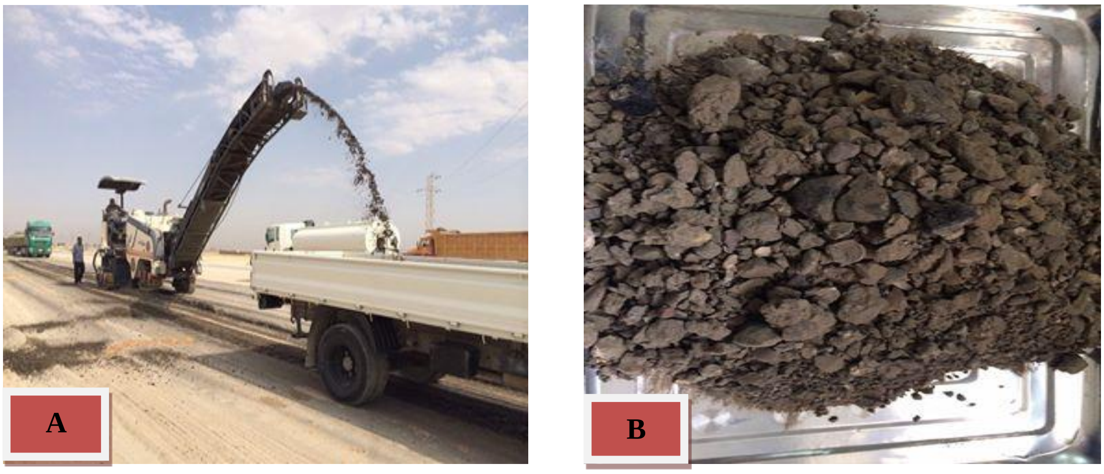

Plate 1. Compilation of Reclaimed Asphalt Pavement (A): During Compilation (B): After Compilation

4. Mix Design

Marshall mix design procedure was used to determine the optimum asphalt content for the virgin mixture, considering the mixture test results for Marshall stability, flow and bulk density , as well as the volumetric values: air voids (Va), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) and determined the optimum asphalt content equal to (4.8%) for asphalt grade (40/50) and (4.7%) for asphalt grade (60/70). The details of Marshall Test properties and volumetric mix properties (for two type of asphalt) at each percent of asphalt content for surface layer type AШ are shown in Table (7) and Table (8). Virgin mixture, which does not have RAP used asphalt grade (40/50) and prepared at optimum asphalt content (4.8%). The aim of the design of recycled HMA was to find the asphalt grade and asphalt content required that will be used and added to mixtures containing RAP by depended on (AASHTO M-323) and produce a mix with good performance in durability (resistance to moisture damage). Further, the mixture has to meet the required volumetric properties (AL- Qadi et al. 2007). All recycled asphalt mixtures were designed depending on (AASHTO M-323) with optimal binder content and the (AASHTO M-323) recommend when used RAP up to (15) percent there is no change in asphalt binder grade and when used RAP (16) percent or more used asphalt binder one grade softer than that normally specified. As known as when used RAP materials to produce HMA which leads to reduce the optimum of asphalt binder add to mixture and which can be calculated the percent of asphalt binder replacement from the optimum asphalt content by the following equation and that depends on the percent of RAP additive to the mixture as shown in Table (9).

$$\text{Binder Replacement, \%} = \frac{(A*B)}{C} * 100 \qquad (1)$$

Where:

A = RAP percent in mixture,
B = RAP percent binder content, obtains from extraction test,
C = total percent binder content in mixture.

Table 7. Marshall Result for Asphalt Grade (40-50)

Asphalt content %(40-50)	3.75%	4.25%	4.75%	5.25%	5.75%
Marshall Stability (kN)	10.752	11.7	13	11.6	10.2
Flow (mm)	2.75	3.15	3.51	3.83	4.09
Bulk density (gm/mm³)	2.317	2.341	2.349	2.345	2.337
Air voids (%)	6.48%	4.83%	3.83%	3.31%	2.97%
Percent voids in mineral aggregate (VMA)%	16.52%	16.09%	16.25%	16.83%	17.55%
Percent Voids Filled with Asphalt (VFA)%	60.76%	69.96%	76.43%	80.31%	83.10%

Table 8. Marshall Result for Asphalt Grade (60-70)

Asphalt content %(60-70)	3.75%	4.25%	4.75%	5.25%	5.75%
Marshall Stability (kN)	9.8	10.447	11.3	10.368	9.888
Flow (mm)	2.89	3.34	3.6	3.87	4.2
Bulk density (gm/mm³)	2.301	2.334	2.342	2.339	2.329
Air voids (%)	7.26%	5.24%	4.22%	3.66%	3.38%
Percent voids in mineral aggregate (VMA)%	17.10%	16.34%	16.49%	17.04%	17.83%
Percent Voids Filled with Asphalt (VFA)%	57.55%	67.95%	74.40%	78.55%	81.04%

Table 9. Percent of Binder Replacement from O.A.C

Percent of RAP (A)	Asphalt in RAP (B)	O.A.C on Virgin Mixture (C)	Binder Replacement From O.A.C
0%	3.8%	4.8%	0%
5%	3.8%	4.8%	4%
15%	3.8%	4.8%	11.9%
%	3.8%	4.7%	20.2%

5. Methods

5.1. Marshall Specimens Preparing

All mixtures were designed with optimum asphalt content for reference (virgin) specimens, and the percent of binder replacement from the optimum asphalt content used for mixture contains RAP as shown in plate (2). The specimens were prepared for the Marshall test, indirect tensile test, temperature susceptibility, indirect tensile strength ratio (moisture damage), and double punching shear strength, therefore, these specimens prepared by using Marshall compactor according to (ASTM D-1159) with 75 blows of the hammer for each face to achieve air voids (4%) according to Iraq specification (SCRB, R/9 2003). Asphalt grade (40/50) is used with the virgin mixture and (5% and 15%) RAP content then (25%) RAP content used with asphalt grade (60/70), the grade of asphalt change when used (25%) RAP depended on recommending in (AASHTO M-323). In addition, according to the (ASTM D-4867 or

AASHTO T-283) prepared specimens for use in the indirect tensile strength ratio test (moisture damage) with air voids (7%). To achieve this air voids need to change the number of blows by using a different number of blows; and it is (75, 65, 55, 45, and 35) and measured the Gmm and bulk density for each change in the number of blows then calculated the air voids. The number of blows which given air voids (7%) is 50 blow.

Plate 2. Specimens Prepared by Marshall

5.2. *Indirect Tensile Strength Test and Temperature Susceptibility*

The indirect tensile strength is determined according to the method described by (ASTM D-6931) that used to find the indirect tensile strength and temperature susceptibility of asphalt mixtures. The results can be used to evaluate the quality and strength of materials used in mixture, and the main principles for a cylindrical test specimen is loaded on two diametrically opposite sides. This induces a tensile stress in the test specimen. The test is performed with a constant deformation speed until failure. The maximum load is recorded and used to calculate the indirect tensile strength. The specimens are prepared in accordance with (ASTM D-1559), after the preparation, the specimens were left to cool at the room temperature for 24 hours. Then place the specimens for the minimum (30 minutes) in the water bath at two different temperatures of (25Cº and 40Cº) and the specimen was centered on the vertical diametrical plane between the two parallel loading strips. The strip width (12.7 mm), specimen diameter (101.6mm) and the height of the specimen (63.5±1.27mm). Vertical compressive load at the rate of (50.8 mm/min) by the master loader machine was applied until the digital reader reading reached the maximum load resistance, this value was recorded. Plate (3) presents the indirect tensile specimens and test. The indirect tensile strength (ITS) is calculated by using equation (2). The temperature susceptibility (TS) is calculated by using equation (3), (Husham, 1999).

$$ITS = \frac{2000*P}{\pi*D*T} \quad (2)$$

Where:

ITS = Indirect Tensile Strength, kPa

P = Maximum load resistance at failure, N
D = Diameter of specimen, mm
T = Thickness of specimen immediately before test, mm

$$TS = \frac{(ITS)t1-(ITS)t2}{t2-t1} \qquad (3)$$

Where:
TS = Temperature susceptibility (kPa / ºC)
(ITS) t1 = Indirect tensile strength at t 1, and t1 = 25ºC
(ITS) t2 = Indirect tensile strength at t 2, and t2 =40º.

Plate 3. Indirect Tensile (A): Specimens (B): Test

5.3. Moisture Susceptibility

A key durability issue associated with the ability of asphalt pavement to resist the effects of water, without significant deterioration in the pavement. The moisture damage is commonly referred to as loss of the adhesion bond at the asphalt-aggregate interface or loss of the cohesion of asphalt binder. Two stages are considered to be the major elements of the water damage mechanism (Caro et al., 2008, and Scholz, 1995):

1. Moisture transport: the process by which the moisture comes to the asphalt-aggregate interface in a state of liquid or vapor via infiltrating the asphalt binder.
2. System response: changes in the internal structure contributing to a lack of load carrying capacity of the material.

To evaluate this, laboratory testing is done and the principle followed in such testing includes the determination of the strength ratio of the conditioned specimen and the unconditioned specimen, prepared as per mix design and comparing with the minimum acceptable strength ratio as given in the specifications.

5.3.1. Compressive Strength Specimens Test

The dimension for cylindrical specimens is (4 inches, 101.6 mm) in diameter and (4 inches, 101.6 mm) in height. It was prepared and then compacted by compression machine according to the (ASTM D-1074). Compress the mixture under an initial load of 1 MPa (150 psi) for (1min) then applied load about 20.7 MPa (3000 psi) for (2min) on the mixture in the mold. After removal, the specimen from the mold will be placed the specimens in oven cure for 24hrs at 60C° (140F) then the specimens become ready for the test as shown in the plate (4). This test is conducted as per (ASTM D-1075) specifications in this test, a set of six specimens are prepared for each percent of RAP and divided the specimen into two group. The first group placed the specimens in the water bath for 24hrs at 60C° then for 2hrs at 25C°, and after that tested for compressive strength value (wet specimens S1). The second group placed the specimens in the air bath for 4hrs at 25C° and after that tested for compressive strength value (dry specimens S2) then calculated the index of retained strength (IRS) from the following equation:

$$IRS = \frac{S1}{S2} \quad (4)$$

Plate 4. Compressive Strength Specimens

5.3.2. Indirect Tensile Strength Ratio Test

The specimens were prepared by Marshall design method for air voids (4%) at (75 blow) and (7%) at (50 blow). The test procedures start, firstly, by measuring the conditioned and unconditioned ITS of the specimens according to the (ASTM D-4867 or AASHTO T-283) to measure the water sensitivity test and used the two methods mention in this specification, they are:

1. First method: The specimens prepared was divided into two groups; the first group are soaked in the water bath at 60C° for 24hrs then placed in the water bath at 25C° for 1hrs, and it is expressed (ITS Sc).
2. Second method: The specimens prepared was divided into two groups, the first group place the specimens in vacuum saturation and subjected to pressure about (10-26 in.Hg) followed by a freeze for a minimum (16h at -18±3C°) and then thaw by soaked the specimen in water bath for 24hr at 60C° then finally remove and placed in water bath for 1h at 25C°, and it is expressed (ITS Sc).

The second group for the two methods above is placed in a water bath for (30min at 25C°), and it is expressed (ITS Sun) and the indirect tensile strength specimens and test shown in the plate (5). The tensile strength of each group is determined by the equation (2). The Indirect Tensile Strength Ratio (ISR) found for each method and for two type of air voids percent (4%) and (7%) by the equation (5).

$$ISR = \frac{ITS\ Sc}{ITS\ Sun} \tag{5}$$

Plate 5. Indirect Strength Ratio (A): Specimens (B): Test

5.4. Double Punching Shear Strength Specimens Preparing

Jimenez (1974) developed this procedure test at the University of Arizona for measuring the stripping of the asphalt binder from the aggregates, there are many studies for this test such as (Solaimanian, 2004, Turos, 2010, and Mashkoor, 2015). The specimens are prepared in accordance with ASTM D-1559 and placing them in the water bath at 60ºC for 30 min. The test was conducted by centrally loading the cylindrical specimen is placed vertically between the loading platens of the test machine and compressed by two steel punches the diameter of steel punch 1in/mint (25.4mm/mint) located concentrically on the top and bottom surfaces of the cylinder and loaded at a rate of 1in/mint (25.4 mm/min) until failure. Recording the maximum load resistance from the digital reader in the multi-speed device. Plate (6) shows the double punch test. The punching strength is computed by the equation (6) (Farouki, and Rolt, 1985):

$$\sigma t = \frac{P}{\pi(1.2bh - a^2)} \tag{6}$$

Where:
σt = Punching stress, Pa
P= Maximum load, N,
a= Radius of punch, mm,
b=Radius of specimen, mm,
h=Height of specimen, mm.

Plate 6. Double Punching Shear Strength Test.

6. Results and Discussion

6.1. Marshall Stability and Flow Result

All mixtures meet the minimum stability criteria of 8kN for high traffic intensity roads for surface layer type AШ and satisfy the air voids and bulk density requirements. At the same time, all mixtures meet Marshall Flow criteria of 2-4mm. The stability, flow, bulk density, and air voids values for all mixtures are presented in Figure (3), Figure (4), Figure (5), and Figure (6).

The results show that increasing the RAP content in mixtures lead to increase the Marshall Stability and bulk density and reduce the flow and air voids compared with reference mixture. Those increasing in RAP maybe related to making the mixture stiffer than virgin mixture and may be related to the good interlocking offered by asphalt binder and aggregate particles and this lead to the reduction in the fluidity of the binder and increasing stabilities and improve other properties.

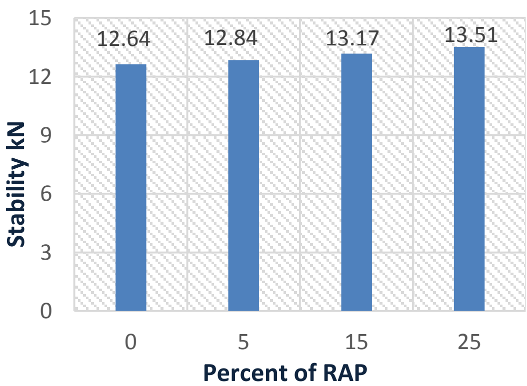

Figure 3. Marshall Stability Values

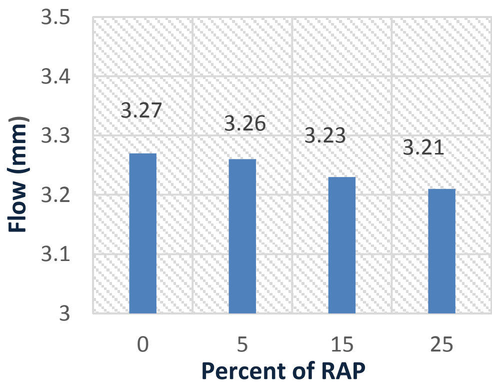

Figure 4. Marshall Flow Values

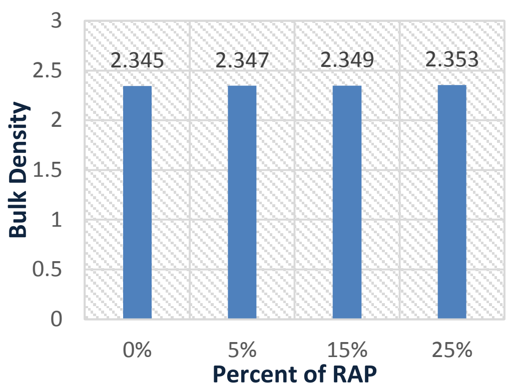

Figure 5. Bulk Density Values

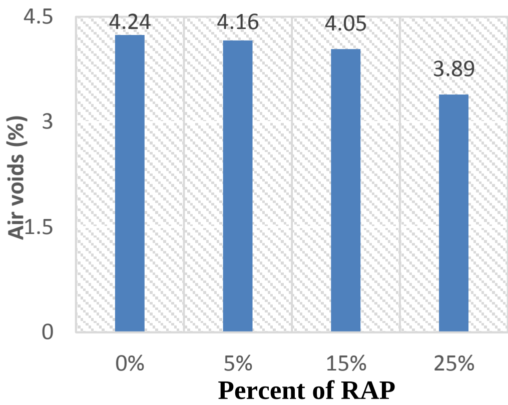

Figure 6. Air Voids Flow Values

6.2. Indirect Tensile Test Result

The indirect tensile strength test is used to determine the tensile properties of the HMA mixtures, which can be related to the cracking properties of the asphalt pavement. In order to evaluate the mixture resistance to variation in temperatures. It used two different testing temperatures (25C° and 40C°) for each type of mixture. Figure (7) illustrates the effected of RAP content on the ITS and influenced by temperature change, it observed that the ITS increased with increasing the percentage of RAP for (25C° and 40C°) compared with the virgin mixture, this indicates the improvement in tensile strength property after mixing the mixtures with RAP. It is worth mentioning, that the ITS decreased with increasing temperature. Temperature susceptibility for each mixture was obtained from the results of the indirect tensile strength test at (25C° and 40C°) successively by the applied equation (3), (Husham, 1999). Results revealed that temperature susceptibility decreased when the content of RAP materials into hot asphalt mixture increased, which means that the influence of temperature variation was less on mixtures that containing the high percentage of RAP materials, and this might be caused by the increasing content of aged asphalt binder for RAP, which corresponds with the findings of (Hasan, 2012). Therefore, RAP binder is subjected to ageing during the service life of the pavement then the binder has become harder, which lead to less influence by temperature variation and the temperature susceptibility results are presented in Figure (8).

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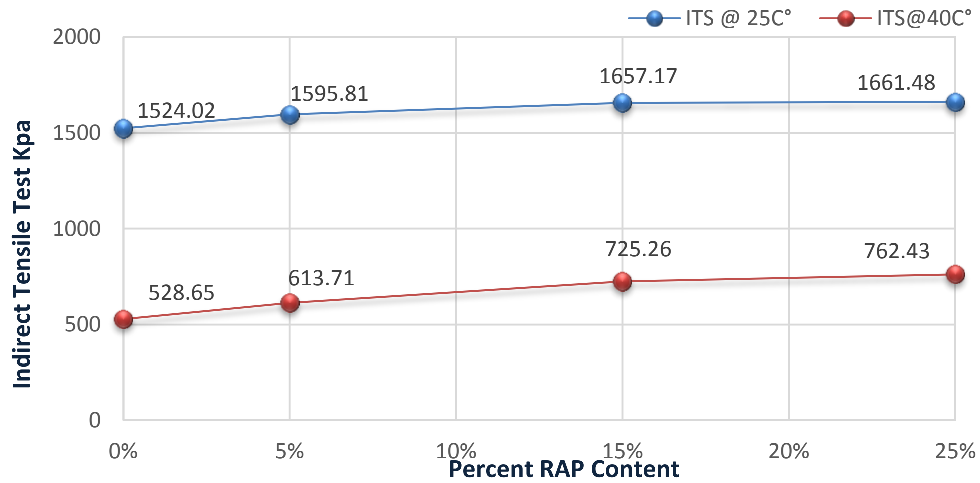

Figure 7. Influence ITS for Mixtures Contain RAP by the Temperature

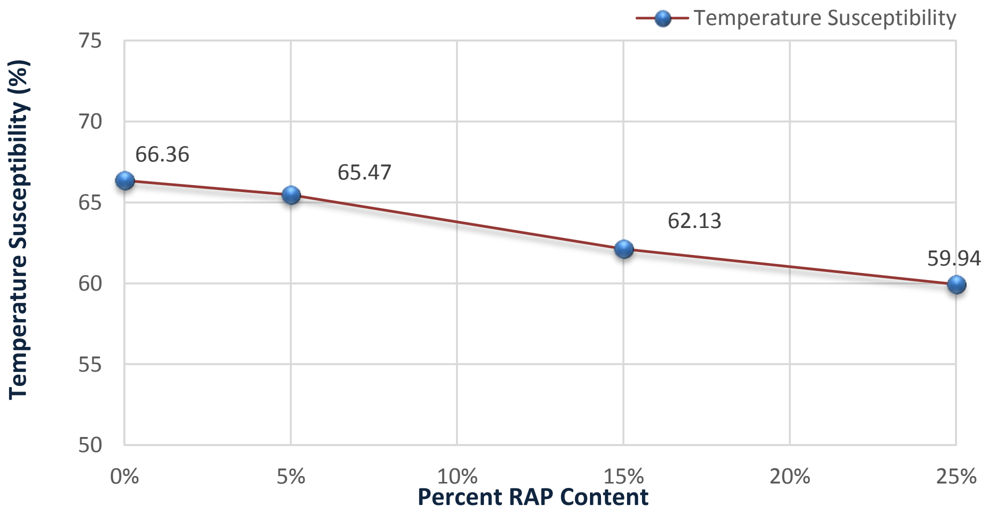

Figure 8. Effect of RAP Content on the Temperature Susceptibility

6.3. Moisture Susceptibility Result

6.3.1. Index of Retained Strength

Compressive strength results were shown that it has increased with increase percent of RAP content in the mixture at the same time the compressive strength values for dry specimens more than the compressive strength values for wet specimens as shown in Figure (9). Values obtained for 25 % RAP mixtures are higher as compared to the virgin mixture, which clearly indicates that mix made with RAP had high resistance to moisture damage. That could be explained by the work of the aged materials, which result into more stiff and hard mixture when the RAP materials content increased extensively, that the bonding between mixture particles is influenced and maybe lead into increase resistance to compressive force (Hasan, 2012). The moisture damage test is a protocol used to determine the susceptibility of asphalt mixture to resist the water by measuring the loss of compressive strength after and before conditioning in water. The results further confirm the increased resistance of mixes towards moisture damage with RAP percent increased as shown in Figure (10). The higher index of retained strength (IRS) is the less susceptible mixture for moisture damage. Minimum IRS for asphalt mixtures according to (ASTM D-1075) is 70%; the mixture is unacceptable if the minimum requirement is not met, and all the mixtures are satisfied requirements.

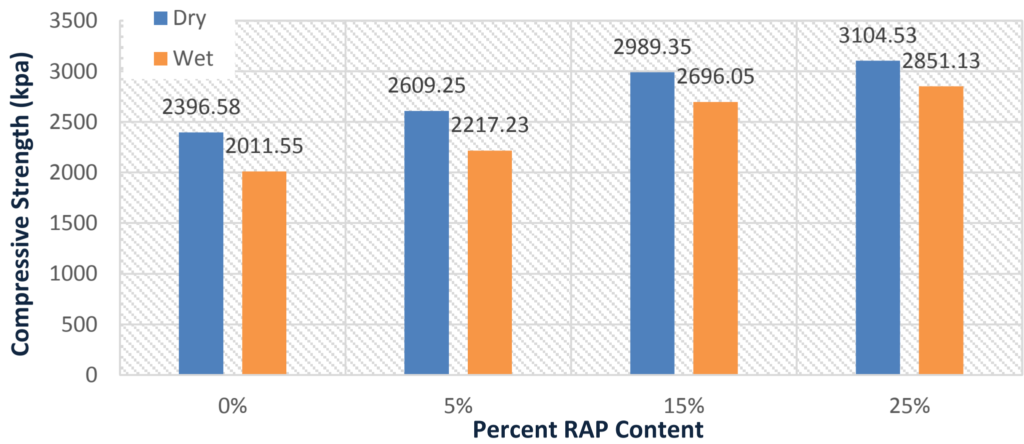

Figure 9. Effect of RAP on the Compressive Strength

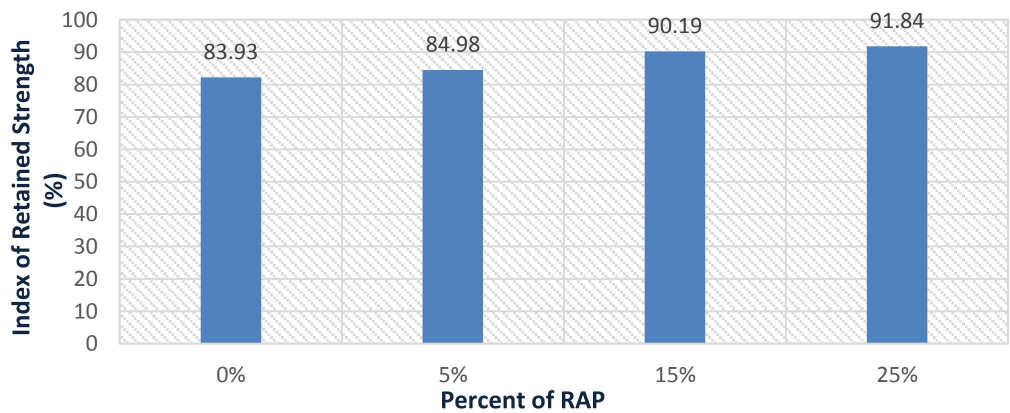

Figure 10. Effect of RAP on the Index of Retained Strength.

6.3.2. Tensile Strength Ratio

The modified (ASTM D-4867 or AASHTO T-283) test was used to evaluate the HMA performance against stripping phenomenon and study the resistance of the RAP mixtures to moisture damage. Therefore, that one of the significant factors influencing on the durability of asphalt mixtures is moisture damage. Two types of data were obtained from this test. The first was the indirect tensile strength (ITS) of the dry and wet specimens. The second was the tensile strength ratio (TSR), and it is generally evaluated by calculated the average tensile strength of conditioned specimens to the average tensile strength of unconditioned specimens and this represent the moisture susceptibility of the asphalt mixture. Figure (11) and Figure (12) show the ITS for all specimens (Dry, saturation condition, and saturation followed by the freeze and thaw conditions) for air voids (4%) according Iraq specification for surface layer type AШ and (7%) according to modified specification (ASTM D-4867 or AASHTO T-283).

However, it is observed that the ITS is increased with increasing the percentage of RAP and it is worth mentioning that the ITS for air voids (4%) more than the ITS for (7%). It also remarked that the ITS for dry specimens more than the other specimens and at the same time the ITS for vacuum saturation specimens higher than ITS for saturation followed by the freeze and thaw condition specimens.

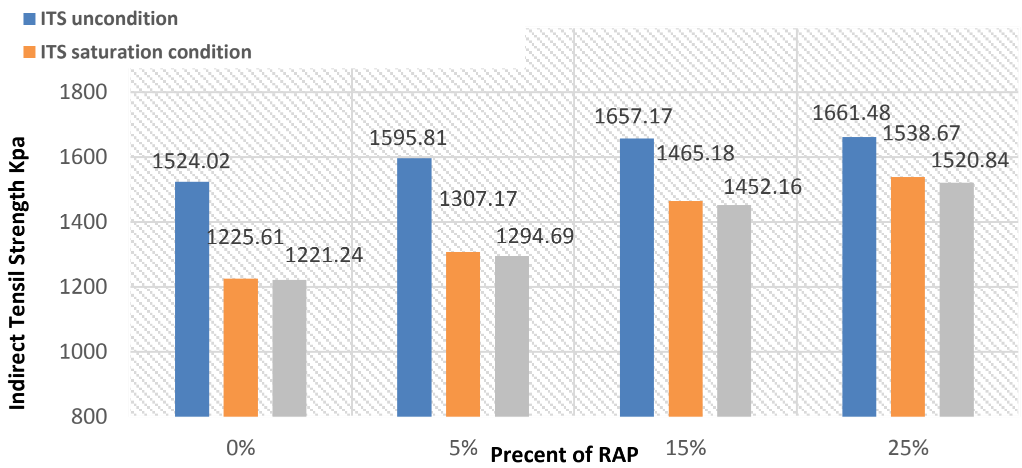

Figure 11. Effect of RAP Content on the ITS for (4%) Air Voids.

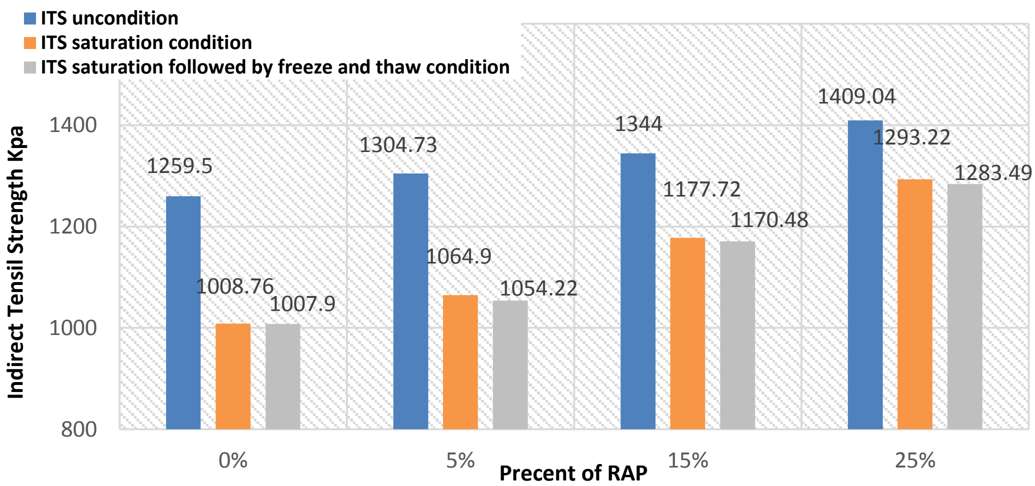

Figure 12. Effect of RAP Content on the ITS for (7%) Air Voids.

This Figure (13) and Figure (14) indicated the behavior of both RAP and virgin mixtures, then show the influence of increasing RAP content in the HMA and resistance to moisture damage thus, that the ISR is increased with increasing percentage of RAP. It is concluded from this work that the mixtures, which contain RAP have resistance to moisture damage by saturation condition more than saturation followed by the freeze and thaw condition and mixtures have air voids (4%) more than air voids (7%). It can be concluded that mixtures with RAP are expected to be less susceptible to moisture and perform better than virgin mixture in resisting the damage action of water. The reason for this has been described by a number of researchers. They proposed that the aged binder tends to stick to the RAP aggregates, and RAP is a material, which had already been exposed to ageing, thus the RAP binder becomes stiffer. Therefore, the bond between the aggregate and RAP binder becomes stronger, that it is reducing absorption of water when RAP materials are used and their aggregate is covered with a thick layer of asphalt binder (Karlsson and Isacsson, 2006 and Gregory and Tuncer, 2009). Minimum ISR for asphalt mixtures according to (ASTM D-4867 or AASHTO T-283) is 80%, and all the mixtures were satisfied requirements.

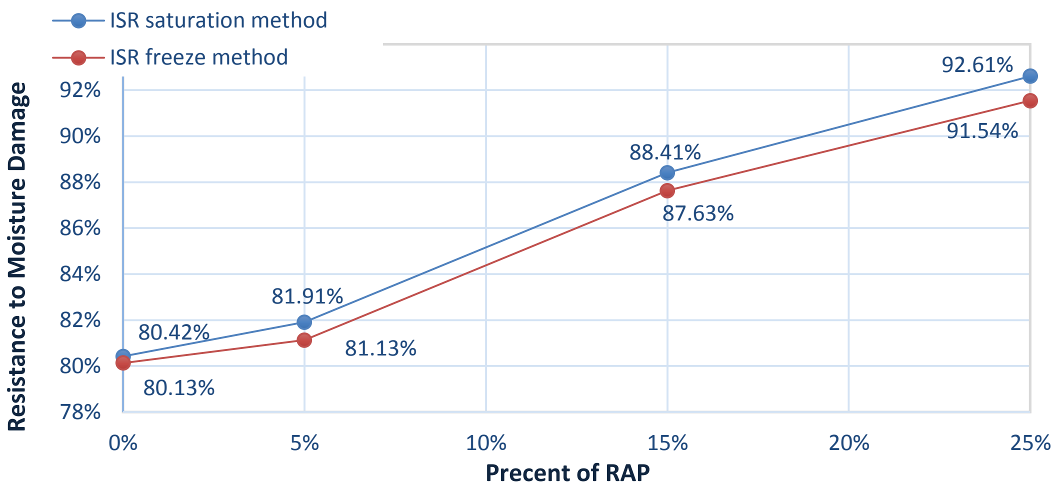

Figure 13. Effect of RAP Content in Moisture Damage (4%) Air Voids.

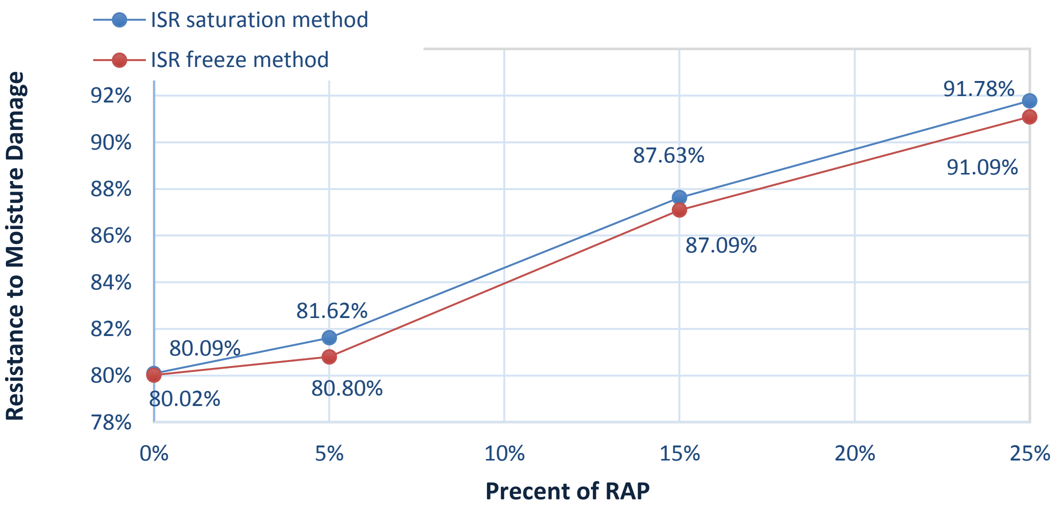

Figure 14. Effect of RAP Content in Moisture Damage (7%) Air Voids.

6.4. Double Punch Shear Strength Result

Double punch shear test indicates mainly the shear resistance behavior between asphalt binder and aggregate. Double punch test results were proved that the mixtures, which contain the different percentage of RAP materials give the performed well compared with the virgin mixture. Figure (15) show the influenced of double punching by increased the RAP materials in the hot asphalt mixture and concludes that the punching strength value for mixtures, which contain RAP, is increased with the increased percentage of RAP.

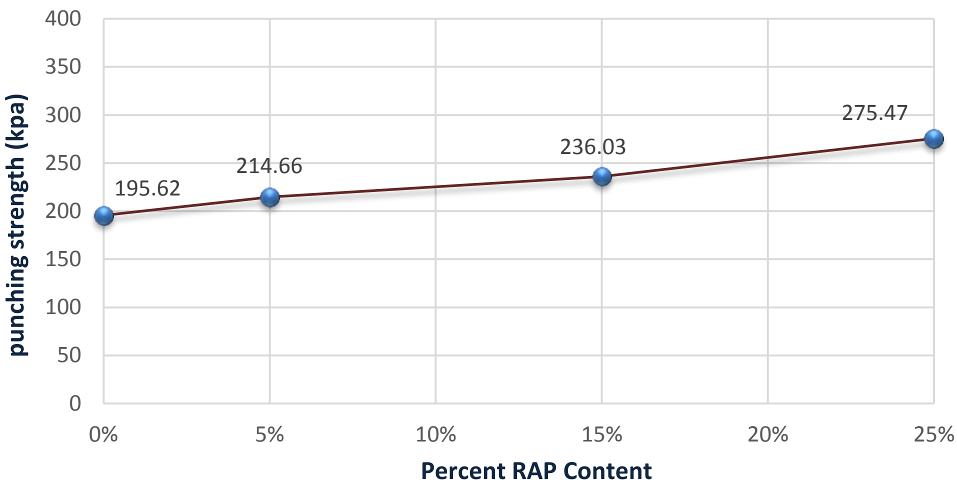

Figure 15. Effect of RAP on the Double Punching Shear.

7. Conclusions

Considering all results of the laboratory testing work carried out on virgin mixes and mixes with (5%, 15%, and 25%) RAP and analysis, the following conclusions are drawn:

1. It was found that addition RAP improves all the properties of the asphalt mixtures. This indicates that mixtures with 25 % RAP would perform better than the virgin mixtures under similar conditions. Based on the findings of the study, it is concluded that it is possible to design acceptable-quality asphaltic mixes with the RAP that meets the required volumetric, mechanical properties and desired performance criteria.
2. Mixtures containing various percentages of RAP contents (0% up to 25%) effect on volumetric properties of the mixture. It tended to have the higher stability than the virgin mixture about (1.6%), (4.19%), and (6.9%) for (5%), (15%), and (25%) RAP content. Flow value and air voids are continued to decrease with increased percent of RAP about (0.3%), (1.2%), and (1.8%) for flow value and about (1.9%), (4.7%), and (20%) for air voids and it is worth mention that the bulk density increased with the increasing percentage of RAP about (0.09%), (0.17%), and (0.34%) for (5%), (15%), and (25%) RAP content respectively compared with the virgin mixture.
3. The temperature affects the ITS, that lead to decrease the ITS when the temperature increase, at the same time the mixtures which contain RAP reduce the influence of temperature. Therefore, it observed the ITS at the temperature (25 and 40C°) increased with the increased percentage of RAP about (4.7%), (8.7%), and (9%) and about (16.1%), (37.2%), and (44.2%) for (5%), (15%), and (25%) RAP compared with the virgin mixture respectively. It is interesting that the temperature susceptibility decreases the influence by increasing the percent of RAP content about (1.3%), (6.4%), and (9.7%) for (5%), (15), and (25%) RAP compared with the virgin mixture.

4. The inclusion of RAP in HMA mixtures appear the punching resistance strength value increased with increasing percentage of RAP about (9.7%), (20.7%), and (40.8%) for (5%), (15), and (25%) RAP compared with the virgin mixture.
5. As a result of increasing the compressive strength value for the dry and wet specimens with increasing percent of RAP in HMA about (8.9%), (24.7%), and (29.5%) for dry and about (10.2%), (34%), and (41.7%) for wet at (5%), (15), and (25%) RAP compared with virgin mixture and this lead to improving the resist to moisture damage (index of retained strength) about (1.3%), (7.5%), and (9.4%) for (5%), (15), and (25%) RAP compared with the virgin mixture.
6. The durability of mixtures, which contain RAP to resist moisture damage, was assessed by the water sensitivity test. The results demonstrated that the mixtures, which contain RAP, were not susceptible to moisture damage and can resist the harmful action of water better than the virgin mixture for (25%) RAP at (4%) RAP about (15.2%) & (14.2%) and at (7%) RAP about (14.6%) & (13.8%) for saturation method & freeze and thaw method.

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