Effect of Rejuvenating Agent on the Mixtures Containing High Percent of Reclaimed Asphalt Pavement

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Abstract: Due to economic reasons or need for environmental conservatism or also preserve the natural resources; there has been an increasing shift towards the use of reclaimed asphalt pavement (RAP) materials in the pavement construction industry. Therefore, use the Reclaimed Asphalt Pavement (RAP) has been enormously increased in pavement construction and has become common practice in many countries. Nevertheless, this is a relatively new concept in Iraq, and has to be remarked that is not used RAP in the production of HMA and this valuable material is mostly degraded. For this purpose, the reclaimed materials were collected from deteriorated pavement segments. The components of asphalt mixtures consist of: two asphalt penetration grades (40-50 and 85-100) brought from Daurah refinery. The aggregate gradation consists of (19) mm maximum size with limestone dust as a mineral filler. This work involved using the waste engine oil as a rejuvenating agent. All the types of tests result demonstrated that all mixtures, which contain RAP, have good properties compared with the virgin mixture. This demonstrated that mixtures with high RAP content could be successfully designed to meet the local volumetric and performance-specification requirements.

Keywords: HMA, Reclaimed Asphalt Pavement, Marshall Properties, Indirect Tensile Test, Moisture Damage.

1. Introduction
The history of asphalt pavement recycling dates back to the early 1900s. Recycling asphalt pavements first became common in the U.S. in the 1970s during the oil embargo when the cost of crude oil skyrocketed. The recycling asphalt pavements can be seen as a sustainable option, as it is a production process with environmental and economic benefits [1]. When the pavement surface reaches to the end of its service life then this pavement needs to milled up or ripped off the roadway for reconstruction and these materials is known as Reclaimed Asphalt Pavement (RAP) may be disposed or recycled. The using Reclaimed Asphalt Pavement (RAP) in the construction of new hot mix asphalt (HMA) pavement become a useful option to virgin materials because it preserves the natural resources by decrease the amount of use the virgin aggregate and asphalt binder required [2]. The most significant characteristic of RAP materials that influence on the properties of recycled mixtures especial at the high percentage of RAP is ageing of bitumen, which covers the RAP. Therefore, the methods for compensating of aged, hard bitumen and ensuring the adequate of pavement performance include the use of rejuvenating or softening additives or used softer virgin asphalt grade [3]. There are no agreements whether the hot asphalt mixture that contains RAP presents any different compared to hot asphalt mixture without RAP. Therefore, it is a necessity for the study on mechanistic evaluation of mixture that contains RAP with or without the use of rejuvenating agents. Among all the recycling
techniques, hot mix recycling techniques have a large number of advantages and are well suited for Iraq conditions. Some studies indicate that use of certain percentage of RAP increases the performance properties of mixes and some studies indicate that incorporating certain percentages of RAP there are no significant changes in the performance of mixes [4]. Therefore, the durability of the mixtures with RAP to resist moisture damage has studied and assessed by a number of researchers by water sensitivity tests. In their study [5] summarize his work that the mixtures which contain RAP for wearing layer shown non-susceptibility to moisture damage, even at high percentages of RAP such as 30% and 50 %. Another study by [6] also showed that mixtures which contain (30%) RAP has better resistance to the action of water than the virgin mixture. Overall, as indicated from prior studies, it can be concluded that the mixtures, which contain RAP, perform better than virgin mixtures in resisting the harmful action of water. The reason for this had been reported by a many of researchers [7]. They proposed that the aged asphalt binder tends to stick to the RAP aggregates, declining absorption of water when RAP materials are used as their aggregates are covered with a thick layer of asphalt binder. However, a number of researchers have pointed out that using RAP increased stiffness that leads to increase the stability of mixture compared with virgin mixture [3, 6].

2. Objective
The goal of this work studies the feasibility of using waste engine oil as an asphalt rejuvenator to improve the recyclability asphalt pavements and study the change in mechanical properties of the mixture, which contain the high percent of RAP when the aged asphalt binder is mixed with waste engine oil.

3. Materials and Methods
To simulate, as possible as the actual behavior of asphalt pavement in the field with laboratory environment. Therefore, all the materials using in this experimental work have been brought locally available such as asphalt cement, aggregate, waste oil engine, and reclaimed asphalt pavement. The main properties of selected materials are presented in this section and which was divided into two part and they are:

1. Virgin materials, which include: asphalt cement, coarse aggregate, fine aggregate and filler (limestone dust).
2. Recycle materials, which include: Reclaimed Asphalt Pavement (RAP) and waste engine oil.

3.1. Virgin Materials
The materials used in this work are consisted of:

3.1.1. 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 properties of the aggregate are shown in Tables (1). The gradation for aggregate used in this work is followed the mid-point gradation of specification SCRB [8] with nominal maximum size (12.5mm) type AIII, which is suitable for wearing course pavement and shown in Table (2) and Figure (1).

3.1.2. Virgin Binder. Essentially, all of the asphalt mixtures materials were assiduously brought from locally well-known sources. Concerning the asphalt cement binder, it was originally brought from Al-Daurah and have (40/50) and (85/100) penetration grade respectively. The common test results are summarized in Table (3).
Table 1. Physical Properties of Al-Nibaee Aggregates

| Property                                      | Coarse Aggregate | Fine Aggregate |
|-----------------------------------------------|------------------|----------------|
|                                               | ASTM NO. | Result | ASTM NO. | 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     | 2.269  |
| Percent Water Absorption (%)                  | C-127     | 0.463  | C-128     | 0.733  |
| Percent Wear (loss angels abrasion) (%)       | C-131     | 18.3   | -----     | ------  |

Table 2. Gradation of Aggregate for Surface Course

| 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                    |

Figure 1. Specification Limits and Selected Mid-Point Gradation of (SCRB) for Surface Layer
3.2. Recycle Materials
The materials used in this work are consisted of:

3.2.1. Reclaimed Asphalt Pavement. The reclaimed asphalt pavement (RAP) was obtained from Baghdad-Hillah 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 5cm. When the percent of RAP used in the HMA pavement exceeds 25%, the mix design process takes into account the amount of bitumen in RAP materials [9]. The first and common significant step in the design of recycled HMA is to determine the properties of RAP material. The necessarily required characterization of RAP materials are asphalt content and sieve analysis of aggregates. Ten samples have been chosen randomly from the milling RAP material in the stockpile and subjected to extraction test to isolate asphalt binder from aggregate according to specification ASTM [10] procedure to obtain asphalt binder, filler content, gradation and properties of aggregate. The properties of reclaimed asphalt pavement after extraction as shown in Table (4) and gradation of RAP before and after extraction shown in the Table (5) and Figure (2). Prior to mix this RAP was crushed and fractionated to sieve no 4.75mm to coarse and fine. The weight of dry RAP (coarse and fine) calculated from the following equation:

\[
M_{\text{dry RAP}} = \frac{M_{\text{RAPagg}}}{(100 - Pb)} \times 100
\]

Where \( M_{\text{dry RAP}} \) is mass of dry RAP, \( M_{\text{RAP agg}} \) is mass of RAP aggregate, and \( Pb \) is RAP binder content.
3.2.2. Recycling Agent. Recycling agent was described as an organic material with physical and chemical properties chosen to restore the aged asphalt binder in RAP to required specifications. The recycling agent can be divided into softening and rejuvenating agents. Softening agents is lower the viscosity of the aged asphalt binder while rejuvenating agents restore its physical and chemical characteristics [11]. Examples of softening agents include flux oil, slurry oil, and soft bitumen while rejuvenating agents consist of lubricating and extender oils, which contain a high proportion of maltenes constituents [12]. The major significant in the choice the rejuvenating agent is to be compatible with the aged asphalt binder. Rejuvenating agents with low saturate content and high aromatic content are usually compatible with the aged asphalt binder [13]. In this work used waste oil engine as rejuvenating agent and asphalt grade (85-100) as softening agent to improve the properties of agent asphalt binder and to compensate for the maltene lost in the aged binder over time.

Table 4. The properties of Reclaimed Asphalt Pavement after Extraction

| Material                   | Property                                   | ASTM NO. | 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  |
Table 5. RAP Gradation Before and After Extraction Test and Limitation of SCR/B/R9 for Surface Layer

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

3.2.3. Waste Oil Engine (WOE). Waste oil engine WOE is described as any petroleum-based or synthetic oil that has become unsuitable for its original purpose due to the presence of impurities or loss of original properties was used as a recycling agent and obtained from waste of motor vehicle oils used. The important concern in the selection of the rejuvenating agent is to be compatible with the aged binder in RAP. Therefore, used six different percent of waste oil engine (1%, 2%, 3%, 4%, 5% and 6%) from the weight of asphalt binder by trail was find the 4% of WOE is the suitable percent for recycling agent for RAP. The physical waste engine oil properties were shown in Table (6).
4. Mix Design

The aim of a design of recycled HMA is to optimize RAP content and find the asphalt grade and asphalt content required which will be added to mixtures contain RAP for produce a mix with good properties in resistance to moisture damage, temperature susceptibility and double punch shear. Further, the mixture has to meet the required volumetric properties including air voids, voids in mineral aggregates (VMA), voids filled with asphalt (VFA) [14]. Mixtures were designed using the Marshall method according to specification ASTM [10], and gradation of aggregate according to the Iraq road specifications SORB [8]. Marshall mix design procedure was used for the determination of the optimal bitumen content for the reference mixture for asphalt grade (40/50) and (85/100), considering the mixture test results for Marshall stability and flow, as well as the volumetric values: air voids (V), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB). All mixtures which contain RAP were designed according to specification AASHTO [15] and 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 using equation (2) and that depends on the percent of RAP additive to the mixture

\[
\text{Binder Replacement, } % = \frac{(A \times B)}{C} * 100
\]  

Where A, B, and C are RAP percent binder content, RAP percent in mixture, and total percent binder content in mixture respectively.

5. Methods

5.1. Preparing Marshall Specimens

All specimens were prepared with optimum asphalt content for reference specimens and the percent of binder replacement from the optimum asphalt content used for mixture contains RAP depend on the percent of RAP. These specimens were prepared for Marshall Test, indirect tensile test, temperature susceptibility, indirect tensile strength ratio, and double punching shear strength, and prepared by using impact compactor according to specification ASTM [10] with 75 blows of the hammer on each face and to obtain air voids (4%). Asphalt grade (40/50) is used with the reference mixture (zero RAP content) and (35%, 45%, and 55%) RAP content used with asphalt grade (85/100) then the same percent of RAP used with (40-50+waste oil) according to specification AASHTO [15]. Thus, to obtain air voids (7%) in specimens require to change the number of blows then by using a various 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. Thus, prepared specimens with air void (7%) for used in indirect tensile test and tensile strength ratio test. The specimens are shown in the plate (2).
5.2. Indirect Tensile Strength and Temperature Susceptibility Test

The indirect tensile strength is determined according to the method illustrated by specification ASTM [10] that was used to find the indirect tensile strength and temperature susceptibility of asphalt mixtures. The results can be used to measure the quality and strength of materials used in the asphalt mixture, and the main principles for specimen test by applies a compressive load across the diametric axis of a cylindrical specimen. The specimens were prepared accordance with specification ASTM [10], after the preparation, the specimen was placed to cool at the room temperature for 24 hours then extraction. After that place the specimens for the minimum (30 minutes) in the water bath at three different temperatures of (25°C, 40°C, and 40°C) and then the specimen is centered on the vertical diametrical plane between the two parallel loading strips. Vertical compressive load at rate of (50.8 mm/min) by master loader machine was applied until the digital reader reached the maximum load resistance, this value was recorded. Plate (3) presents the specimens and indirect tensile test. The indirect tensile strength is calculated by using equation (3). The temperature susceptibility is calculated by using equation (4), [16].

\[
ITS = \frac{2000 + P}{\pi D T}
\]  
(3)

Where \(ITS\) is Indirect Tensile Strength (kPa), \(P\) is Maximum load resistance at failure (N), \(D\) is Diameter of specimen (mm), and \(T\) is Thickness of specimen immediately before test (mm).

\[
TS = \frac{(ITS)_{t1} - (ITS)_{t2}}{t2 - t1}
\]  
(4)

Where \(TS\) is Temperature susceptibility (kPa / °C), \((ITS)_{t1}\) is Indirect tensile strength at \(t1\), \(t1 = 25°C\), and \((ITS)_{t2}\) is Indirect tensile strength at \(t2\), \(t2 = 40°C\).

Plate 3. Indirect Strength Ratio (A): Specimens (B): Test
5.3. **Double Punching Shear Strength Test**

The procedure test was developed at the University of Arizona [17] to measure the stripping of the asphalt binder from the aggregates; there is much research on this test [18]. The specimens were prepared in accordance with specification ASTM [10], and then set the specimens in the water bath at (60°C) for (30 min). The test was begun by central loading the cylindrical specimen is set vertically between the loading platens of the test machine and compressed by two steel punches the diameter of steel punch is 1in (25.4mm) located concentrically on the top and bottom surfaces of the cylinder and loaded at a rate of 1in/min (25.4 mm/min) until failure. Recording the maximum load resistance from the digital reader in the multi-speed device. Plate (4) shows the double punch test. The punching strength is computed by the equation (5) [19]:

\[
\sigma_t = \frac{P}{\pi(1.2bh-a^2)}
\]  

Where \( \sigma_t \), \( P \), \( a \), \( b \), and \( h \) are Punching stress (Pa), Maximum load (N), Radius of punch (mm), Radius of specimen (mm), and Height of specimen (mm).

![Plate 4. Double Punching Shear Strength Test](image)

5.4. **Indirect Tensile Strength Ratio Test**

The final step in the mix design process is to evaluate the moisture sensitivity for asphalt pavement and this relates to the ability of the pavement to withstand freeze-thaw cycles when moisture has penetrated into the asphalt concrete. This step is accomplished by performing moisture damage testing that was described in specification AASHTO [15] and the specimens were prepared by Marshall design Method for air voids (4%) at (75 blow) according to Iraq specification SCRB[8] and (7%) at (50 blow) according to specification AASHTO [15]. The specimens prepared was divided into two groups. The first subset of three specimens is considered control specimens was placed in a water bath for (30min at 25°C), and it is expressed (ITS Sunc). The second subset of three specimens is the conditioned subset. The conditioned subset is subjected to partial vacuum saturation at pressure (10-26 in.Hg) followed by an optional freeze cycle (16h at -18±3°C), followed by a 24 hour thaw at 60°C then finally removed and placed in water bath for 1h at 25°C, and it is expressed (ITS Sc). All specimens are tested to determine their indirect tensile strengths as shown in plate (5).
The moisture sensitivity is determined as a ratio of the average tensile strengths of the conditioned subset divided by the average tensile strengths of the control subset, as shown in equation (6). The criterion for tensile strength ratio 80% minimum.

\[
ISR = \frac{ITSC}{ITSCn}
\]

(6)

6. Results and Discussion

6.1. Marshall Properties Results

All mixtures meet the minimum stability criteria of (8kN) for high traffic intensity roads 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 Figures above explains the behavior of Marshall properties for the asphalt mixture that contains a high percentage of RAP and how influenced by the rejuvenator agent type and compared with the reference mixture. Therefore, it concluded that the stability and bulk density increased with RAP and then decreased at (55%) RAP, at the same time, the flow reduces by increasing the percentage of RAP, additionally; the air-voids reduce with increase RAP percent and then increased regardless type of rejuvenator compared with reference mixture. However, the stability, flow, and bulk density of rejuvenator agent type (40-50+ waste oil) is higher than using asphalt grade (85-100) and air-void the opposite.

![Figure 3. Marshall Stability Values](image1)

![Figure 4. Marshall Flow Values](image2)
6.2. Effect of the Different Percent of RAP Content on Indirect Tensile Strength Test

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 used the three different testing temperatures (25, 40, and 60°C) for each type of virgin mixture and mixtures which contain RAP with the optimum percent for rejuvenator agent type content and different mixing ratios of old and virgin materials, with various asphalt binder types. Figure (7) shows the effect of ITS for the mixture contains the high percentage of RAP by rejuvenator agent then, it observed that the ITS when used (40-50+ waste oil) better than from the asphalt grade (85-100) at 25°C. Figure (8) and Figure (9) observed that the ITS, when used (40-50+waste oil), is influenced by temperature more than used asphalt grade (85-100) that was mean the ITS for asphalt grade (85-100) more than (40-50+waste oil). From the figure above, it observed that the ITS increased with the percentage of RAP increasing until (45%) then decreased in (55%) RAP content at 25°C but the ITS for temperature (40°C and 60°C) increase continuously with increased percent of RAP. It is worth mentioning, it observed that the ITS decreased with increasing temperature, and also, that the ITS for mixture contains RAP when using (40-50+waste oil) and asphalt grade (85-100) better than reference mixture for all temperature.

Figure 5. Bulk Density Values

Figure 6. Air Voids Flow Values

Figure 7. Influence ITS at (25°C) for Mixtures Contain RAP by Rejuvenator Agent
6.3. Effect of RAP on Temperature Susceptibility

Temperature susceptibility for each mixture was obtained from the results of the indirect tensile strength test at (25°C and 40°C) successively. Results revealed that temperature susceptibility decreased when the content of RAP materials into hot asphalt mixture increased regardless of any type of rejuvenator agent, 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. Therefore, RAP binder is subjected to ageing during the service life of the pavement then the binder has become stiffer, which lead to less influence by temperature variation. Figure (10) show the effect of rejuvenator agent type on the temperature susceptibility for the mixtures that containing the high percentage of RAP. The results for mixtures that containing the high percentage of RAP when used rejuvenator agent type (40-50+waste oil) was more influenced by temperature than asphalt grade (85-100). Because the inclusion of waste oil in recycling agent reduced the tensile strength slightly and effect by high temperature, which corresponds with the findings [20].
6.4 Moisture Damage Resistance Evaluation

The modified specification AASHTO [15] test procedure 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. Usually, damage by moisture is described as the loss in the cohesion of the mix or loss of adhesion between asphalt binder and aggregate interface. Hence, the moisture damage mechanism occurs by infiltration of moisture, in either liquid or vapor state, through the asphalt binder generally. 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 is the tensile strength ratio (TSR) and the higher the tensile strength ratio (TSR) the less susceptible the mixture is to moisture damage. Minimum TSR for asphalt mixtures in AASHTO [15] is 80%; the mixture is unacceptable if the minimum requirement is not met. The moisture damage test is a protocol used to determine the susceptibility of asphalt mixture to water by measuring the loss in ITS after conditioning in water. Generally, Figure (11), Figure (12), Figure (13), and Figure (14) show the effect of rejuvenator agent type for mixture contains the high percentage of RAP (35%, 45%, and 55%) on ITS for dry and wet specimens at air void (4%) and (7%). It concluded that ITS for (40-50+ waste oil) more than the ITS for asphalt grade (85-100) in dry samples, but the ITS is that opposite completely for the wet condition specimens for air-voids (4%) and (7%) at them same time, it remarked the ITS for dry and wet specimens at air voids (4%) more than (7%). Figure (15) and Figure (16) illustrates the effect of rejuvenator agent type on the ISR. It can be seen that mixture with asphalt grade (85-100) have higher ISR values than the mixture with (40-50+ waste oil) both for (4% and 7%) air voids. Generally, that the influence of moisture damage decreased with the increasing percentage of RAP for all cases and resistance to moisture damage for air void (4%) better than (7%). The loss in ISR when used (40-50+waste oil) this can be attributed to the points and it is: when waste oil is added to asphalt binder grade (40-50) lead to weakening the bond between the asphalt and the aggregate when subjected to specific conditions, or because of the RAP showed A weak adhesion between aggregate and asphalt binder, the problem is likely to reoccur if adhesion additives are not added to the new (re-made with RAP) HMA mixture. Thus, the moisture reaches to the aggregate-binder interface and displaces the asphalt binder from the aggregate surface. This leads to the reduction of the adhesive bond between the aggregate and binder, or breakage of the bond in severe conditions. Regard to the mixture, which contains the high percentage of RAP and used (40-50+waste oil) is better than the reference mixture for all case.
**Figure 11.** Effect of RAP Content on the ITS for (4%) Air Voids and Asphalt Grade (85-100)

**Figure 12.** Effect of RAP Content on the ITS for (4%) Air Voids and Asphalt Grade (40-50+waste oil)

**Figure 13.** Effect of RAP Content on the ITS for (7%) Air Voids and Asphalt Grade (85-100)
Figure 14. Effect of RAP Content on the ITS for (7%) Air Voids and Asphalt Grade (40-50+waste oil)

Figure 15. Effect of RAP Content in Moisture Damage (4%) Air Voids

Figure 16. Effect of RAP Content in Moisture Damage (7%) Air Voids

6.5. Effect of RAP Materials on the Double Punch Shear Strength
Double punch shear test indicates mainly the shear resistance behavior between asphalt and aggregate. Double punch test results were proved that the mixtures, which contain the different percentage of
RAP materials given the performed well compared with the reference mixture. This might is related to the stiffness of mix, which is lower in the reference mix and higher in the RAP mix. Figure (17) presents double punch test results for both rejuvenator agent types when used the high percentage of RAP in mixtures. It can be seen that using (40-50+waste oil) had resistance to punching shear higher than using asphalt grade (85-100). Interestingly that the mixture, which used (40-50+waste oil) and asphalt grade (85-100) have punching shear more than a reference mixture.

![Figure 17. Effect of RAP on the Double Punching Shear](image)

### 7. Conclusions
The tests described above allow the following conclusions to be drawn regarding the ability of various used waste materials to improve the characteristics of HMA:

1. It was noticed that addition RAP improves all the properties of the asphalt mixtures. This indicates that mixtures with (45%) RAP would perform better than the reference mixtures under similar conditions. Based on the findings of the study, it is concluded that it is possible to design acceptable-quality bituminous mixes with the RAP that meets the required volumetric, mechanical properties and desired performance criteria. The mixtures with RAP were tended to have the higher stability than the virgin mixture when used (40-50+waste oil) about (26.3%), and asphalt grade (85-100) about (13.4%) at (45%) RAP content. It’s worth mention that the stability when used (40-50+waste oil) more than asphalt grade (85-100) about (11.4%) at (45%) RAP content also, it remarked that reduced the flow and air-void and bulk density increased with the increasing percentage of RAP regardless type of rejuvenator.

2. Mixtures with a (35%), (45%), and (55%) RAP given ITS better than the reference mixture and also the ITS when used (40-50+waste oil) more than used asphalt grade (85-100) about (8.2%) for (45%) RAP at (25°C). Beside this the ITS at (40C° and 60C°) when used asphalt grade (85-100) more than (40-50+waste oil) about (8.7%) and (6.3%) for (45%) RAP.

3. The change in ITS with the temperature is expressed temperature susceptibility, it is interesting that the temperature susceptibility is decreasing from the influence by increased the percent of RAP, such as reduction about (16%) when used asphalt grade (85-100) and about (0.24%) when used (40-50+waste oil) for (45%) RAP compared with the reference mixture. At the same time, the type of rejuvenator agent effect on temperature susceptibility such as temperature susceptibility for asphalt grade (85-100) better than (40-50+waste oil) about (15.8%) at (45%) RAP.

4. The inclusion of RAP in HMA mixtures appear the punching resistance strength value increased with increasing percentage of RAP when used (40-50+waste oil) about (118.4%), and asphalt grade (85-100) about (79.3%) at (45%) RAP content compared with the reference mixture. Besides this, the double punching shear is influenced by the types of rejuvenator and observed that the punching resistance for (40-50+waste oil) higher than asphalt grade (85-100) about (21.9%) for (45%) RAP.
5. The Modified Lottman test results indicated that as the percentage of RAP increased in the mixture, the Tensile Strength Ratio (TSR) increased compared with reference mixture, and the mixture with asphalt grade (85-100) performed better than the mixture with (40-50+waste oil) about (12.2%) and (11.5) at (4%) and (7%) respectively. Although, the durability is influenced by the types of rejuvenator agent whereas, resistance to moisture damage when used asphalt grade (85-100) about (16.1%) and (15.2%) and for (40-50+waste oil) about (2%) & (1.9%) for (45%) RAP at (4%) and (7%) compared with reference mixture respectively.

8. Reference

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