Assessment of Durability Properties of Reclaimed Asphalt Pavement Using Two Rejuvenators: Waste Engine Oil and Asphalt Cement (60-70) Penetration Grade

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Abstract. The production of asphalt pavements using Reclaim Asphalt Pavement (RAP) has achieved economic and environmental benefits. However, one of the main challenges when using untreated RAP in pavement construction is the hardness of the binder due to aging. The purpose of this study is to recycle and restore damaged asphalt using two types of regenerative agents: Waste Engine Oil (WEO) and Asphalt Cement (AC (60-70)) Penetration Grade. Five ratios (1, 1.5, 2, 2.5 and 3) % of both types of regenerators were added to the RAP, separately, for the purpose of regeneration. Marshall Test was performed on the regenerated samples in order to obtain the optimum ratios for the regenerative additives, which will be adopted in subsequent tests, which include; indirect tensile strength (ITS), tensile strength Ratio (TSR) and Duplex Punch Shear Strength Test (DPSST) to evaluate the performance of regenerated RAP mixes and compare them with the original RAP. The results indicated that (1.5 and 3) % are the optimal ratios for (WEO and AC (60-70)), respectively. In addition, the results of the performance tests indicated that the regenerated RAP mixes are better than the original RAP in terms of cracking resistance, stripping resistance and resistance to moisture damage, as well as achieving the specification requirements for the surface course. It can be concluded that rap recycling using (WEO and AC (60-70)) is an effective process that reduces paving costs, reduces environmental pollution and leads to gain sustainable paving.

1. Introduction
Asphalt mixture is the most widely used road surfacing material. Aggregates give the structural stability, while bitumen binds them together [1]. The properties of the binder, which is the single most important factor to asphalt mixtures performance, are not constant over time, which affects the pavement performance and the occurrence of distresses, as it is subjected to oxidation and loss of volatiles in a process called ageing [2]. After many years of exposure to climate change and traffic loads, the road would suffer from aging and diminution in the performance of asphalt binder. Asphalt aging results in an increase in binder stiffness and furthermore affects its physiochemical properties. Therefore, aged binder becomes more brittle and causes a decline in pavement strength with a
reduction in pavement service life and in this case the surfaces of pavement can be removed which is called as reclaimed asphalt pavement (RAP) [3]. The asphalt paving industry was very successful in recycling old asphalt at the beginning of the twentieth century, and therefore this success in the manufacture of asphalt surfaces for road made of obsolete asphalt (RAP) reduced the amount of virgin asphalt and the required aggregate, and this indicates sustainability in the paving industry and conservation of resources natural. However, one of the main challenges when using RAP in road construction is the rigidity of RAP. Using unmodified RAP can make the mix too stiff and difficult to compact, which can lead to premature road failure [4]. In order to be able to use RAP in road construction, the lost properties of oxidized asphalt have to be restored using a practical rejuvenation technique. There are several techniques for overcoming the stiffness of RAP, including using softer asphalt [5]. Asphalt cement (60-70) penetration grade is available in Iraqi refineries, but it is not used in roads' construction, especially in middle and southern regions of Iraq as it is soft and out of Iraqi specifications, therefore, the application of AC (60-70) in the rejuvenation of RAP is considered as a valid method for utilizing this binder.

Investigators are constantly induced to investigate the probability of utilizing different kinds of waste materials as bitumen modifiers/rejuvenators in hot mix asphalt industry (HMA). The fact that the conventional bitumen is relatively expensive besides the massive regulations of the environmental authorities formed some serious motivations for them. Furthermore, the illegal disposal of waste oils formed another challenge to the investigators to consider their recycling in HMA industry. Waste oils have become a major environmental pollutant as they can be treated as a potential rivers and land resources contaminators [6]. Moreover, a possible locally waste that can be used to rejuvenate the RAP is motor oil for cars and trucks (WEO). The structure of WEO is similar to the molecular structures of asphalt with sufficient aromatic content, which leads to a cohesive bond by modifying the components and rejuvenating aged asphalt [7].

The purpose of this study is to investigate the possibility of recycling the RAP for the purpose of reusing in paving works by renewing it using two types of regenerators: Waste Engine Oils and Asphalt cement (60-70) penetration grade and clarifying the effect of these renewable additives on different properties of RAP.

2. Used Material

2.1. Reclaimed Asphalt Pavement (RAP)

The reclaimed asphalt mixture was obtained by the rubblization of the asphalt concrete (surface course) from highway in Wasit- Iraq. RAP sample was heated after sampling, three samples were subjected to an ignition test according to procedure (AASHTOT308) [8]. Table (1) presents the properties of pure RAP before recycling process.

| Property          | Value | Specification limit |
|-------------------|-------|---------------------|
| Asphalt content   | 4.5%  | 4.9%                |
| Stability (KN)    | 7.4   | 8min                |
| Flow (mm)         | 4.8   | 2-4                 |
| Density (Kg/cm3)  | 2.187 | -----               |
| Air void (%)      | 12    | 3-5                 |
| Gmm               | 2.479 | -----               |

2.2. Asphalt Cement (AC (60-70))

In this study, asphalt cement of penetration grade (60-70) was used as one rejuvenator. This asphalt was obtained from Al-Dora Refinery, south of Baghdad in Iraq. Table (2) shows physical properties of asphalt binder according to ASTM (D5, D36, D113, D92, D70 and D1754) [9, 10, 11, 12, 13 and 14] respectively.
Table 2. Physical properties of AC (60-70)

| Property                        | Results | SCRB specification |
|---------------------------------|---------|--------------------|
| Penetration (0.1mm)             | 67      | 60-70              |
| Softening point (cm)            | 46      | 47-54              |
| Ductility (cm)                  | >130    | 100                |
| Viscosity (mPa s) at 135°C      | 347     | >300               |
| Specific gravity                | 1.04    | 1.01-1.05          |
| Flash and fire point (°C)       | 298-306 | 260                |
| %Loss of weight after (TFOT)    | 0.03    | 0.2                |
| Retained penetration of residue % | 88%    | 75                 |
| Ductility of Residue (cm)       | >110    | 55                 |

2.3. Waste Engine Oil (WEO)

Waste engine oil was obtained from cars workshops and WEO was sieved through a No. 200 sieve to remove any particles, and tested for viscosity, specific gravity and water content as shown in Table 3. The tests were carried out by the general company for food products-Baghdad, by using a Brookfield viscometer for viscosity, a KERN moisture analyzer for water content and a Bingham pycnometer for specific gravity.

Table 3. Properties of waste Engine oil (WEO)

| Test               | WEO |
|--------------------|-----|
| Viscosity (CP)     | 167 |
| Specific Gravity   | 0.95|
| Water content (%)  | 0.28|

3. Laboratory Work

3.1. Sample Preparation

Samples were prepared for the old mixture of 100% pure RAP according to (ASTM D1559, 2015) [15] after being heated in the oven at (140-160) °C for (1-2) hours to increase the workability of the old mixture. Samples prepared for the Marshall test were subjected to the properties of the mixture (average of three samples). On the other hand, other Marshall samples were prepared for recycled mixtures of (RAP) with regenerative factors (WEO, AC (60-70)) at 1%, 1.5%, 2%, 2.5%, and 3% of the total weight of the mixture, taking into account the heating of the components separately before mixing at a temperature (130-160) °C, after which they are mixed together for two minutes to ensure a good coating of the aggregates, depending on the visual inspection of the components during the mixing period. Moreover, Marshall samples are manufactured from recycling using regenerative agents, to find the optimum content for these generators based on the Marshall surface course properties. Finally, samples of recycled mixtures with the optimum content of regenerative agents will be subjected to other tests such as (Indirect tensile strength at (25, 40 and 60) °C, moisture damage and double punch shear strength test).

3.2. Tests

3.2.1. Marshall Test

In this test, firstly the bulk specific gravity of each specimen, theoretical specific gravity (maximum) and percentage of air void according to ASTM (D2726-08, D2041-03 and D3203-05) [16, 17and 18] respectively, were calculated. Also, Marshall stability and flow were performed for each sample according to (ASTM D1559, 2015) [15] in order to finding optimum content for regenerating agents. Secondly, the optimal content of the regenerative agents in this study use to prepare new Marshall specimens and subject them to other the tests.
3.2.2. Indirect Tensile Strength Test (ITS).
To assess the indirect tensile strength of recycled mixtures using the optimum content of regenerative agents (WEO and AC (60-70)) specified in this paper according to procedure (ASTM D6931-07) [19]. The final test value of the samples results from the average of three samples per temperature (25, 40 and 60) °C. Figure 1 illustrates the test mechanism.

![Figure 1. ITS test devise](image)

3.2.3 Indirect Tensile Strength Ratio Test (TSR)
Moisture resistance test has been performed according to (ASTM D4867, 2015) [20] for recycled mixtures and compared to the old mixture (pure RAP). A group of six samples was prepared for each regeneration agent, where samples are divided and subjected to different conditions. Three samples are subjected to the indirect tensile strength test after storing them in a water bath at a temperature of (25) °C for a period of (60-120) minutes, and calculating the average of the three specimens exposed to the test (ITS) and coding them (SI that mean average ITS for unconditions specimens). On the other hand, the remaining three samples are adapted by placing them in a volumetric container (4000ml) of heavy glass and filled with water to cover the specimens with a temperature (25) °C, with running the vacuum with a capacity of 3.74 kPa (28 Mm Hg) for a period of (5-10) minutes to obtain the saturation level (55-80) %. The saturated samples are subjected to deep freezing at (-18) °C for a period (16) hour, followed by storing the samples in a water bath at a temperature of 60°C for a period of 24 hours according to the test requirements. Before the test is carried out, the samples are placed in another water bath at a temperature of 25°C for an hour. Finally, the samples are tested to find indirect tensile strength of the samples and calculate the average value, symbolized by (SII, average ITS for moisture-condition specimens). Figure 2 shows the steps for examining the samples.
3.2.4. Double Punch Shear Test (DPS)
This test procedure was previously developed by the University of Arizona (Jimenez 1974) [21]. The Scientist Jimenez used this test to measure the stripping of binder. Three Marshall samples (per each regenerative additive) were used in this test and adjusted by placing them in a water bath at 60 °C for 30 minutes. The test was carried out by centrally loading the cylindrical sample with two cylindrical punches located at the top and bottom of the sample, with the sample centered between the two punches (2.54 cm diameter) and perfectly aligned and then loaded at a speed of 2.54 cm / min until it broke as shown in figure 3. Meter reading is recorded at the highest load resistance till the specimen fails. Several studies have reported this test [22, 23, 24, and 25].

4. Result and discussion
The prepared Marshall samples were added from adding the optimum content ratios that were calculated from the Marshall Test in Item (3.1 and 3.2) where they were (1.5% and 3%) for the
renewals (WEO, AC (60-70)), respectively, and which were decided in this The study, therefore, to purposes obtain the results, discuss them and compare them with the original mixture (RAP) to clarify the effect of recycling of mixtures using the rejuvenators.

4.1. Marshall Properties

4.1.1 Bulk density. Figure 4 shows the bulk density of recycled mixtures and the old mixture (pure RAP). The low density of the old mixture at (2.18 g / cc) indicates the lower operability of the mixture due to the high viscosity resulting from the asphalt aging in (RAP), which reduces the susceptibility of the samples to compaction, in addition to increasing the percentage of air voids inside the mixture. Whereas, recycled mixtures using regenerative additives (WEO and AC (60-70) showed an increase in bulk density by (8.3% and 6.5%) for regenerative additives (WEO and AC (60-70)) respectively, compared to the aging mixture. The reason for this may be due to the restoration of the equilibrium ratio (asphaltenes/ maltenes) in recycled mixtures, unlike the aging mixture.

![Figure 4. Bulk density results for aged and recycled mixtures](image)

4.1.2 Marshall Stability. Figure 5 shows that the stability value resulting from test the aged mixture samples is less than the stability value of the recycled mixture due to the aging of the bonding and the increase in the air void ratio in the RAP, while the regenerators played a positive role in restoring the properties of the binder thereby increasing the workability and adhesion of mixture components. The stability value of the aged mixture was low at (7.42 KN), but it increased by (19.9% and 67.4%) for the mixtures recycled with (WEO, and AC (60-70)) respectively, compared to the aged mixture. This result agrees well with [26].

![Figure 5. Marshall Stability results for aged and recycled mixtures](image)
4.1.3. Marshall Flow. Figure 6 shows the results of the flow property of recycled mixtures using regenerative additives and aging mixture (pure RAP), and as shown in Figure, there is a decrease in the value of Marshall flow of recycled mixtures compared to the old mixture. Moreover, all types of recycled mixtures meet the flow parameters of the surface layer at (2-4) mm. On the other hand, it was noted that recycling using the regenerative agent (AC (60-70)) gave the highest flow rate of WEO-Rejuvenated RAP, indicating a difference in viscosity between regenerating additives and its role in the recycled mixture.

![Figure 6. Marshall Flow results for aged and recycled mixtures](image)

4.1.4 Percent air voids. Figure 7 shows the percentage of air voids for the recycled mixtures and the aging mixture. As shown in the figure, there is a significant decrease in the percentage of voids at (66% and 66.3%) for regeneration additives (WEO and AC (60-70)), respectively, compared with the old mixture. This indicates that the recycling process has a prominent role in enhancing the volumetric properties of the rejuvenated aged mixture using the additives established in this paper. This corresponds well with a number of researchers [27, 28, and 29].

![Figure 7. Air void results for aged and recycled mixtures](image)

4.2. Effect of renewals agent types on indirect tensile strength (ITS)

The mixtures were subjected to the indirect tensile strength test at (25, 40 and 60) °C according to (ASTAM D6931, 2015) [19]. Where three samples were tested for each mixture type using regenerative additives at (optimum content), and the mean values were calculated to represent the indirect tensile strength of the mixture types at the specified temperature. The recycling process by the fine AC of the aging mixture also revealed an increase in the value of the indirect tensile strength (ITS) at a temperature of 25 °C. The value of the increase in the mixtures recycled using (RAP + AC
(60-70)) by (175%), while the regenerated mixtures with oils (WEO) gave the lowest value to (ITS) at 25 °C at (32.5%) compared with the mixture Pure rap. This can be attributed to the low viscosity of the regenerative additive (WEO) and the low content in the mix. Besides, the aging mixture (pure rap) was not influenced significantly by temperature at 25 °C as shown in Figure (8).

At 40 °C, as shown in Figure 9, the value of (ITS) for mixtures recycled using WEO is 46.5% less than the old mixture, due to the lower content of the regeneration additive, low viscosity of higher temperature and other properties of the oil, while the value of (ITS) for the old mixture (pure rap) was lower compared to the indirect tensile strength of the recycled mixture using (AC (60-70)) by (137.9%), and this decrease is due to the increase in the ratio of air voids in the old mixture, lower apparent density and gradual increase at temperature, therefore, the aging mixture does not have sufficient resistance to withstand the force applied. Figure 9 shows the (ITS) value of the age and recycled mixtures.

Moreover, the value of the decrease in the value of (ITS) for recycled mixtures with (WEO) was about (43%) compared to the old mixture, as shown in figure 10 below at (60 °C). Whereas, the recycled mixtures with (AC) revealed the highest value of indirect tensile strength compared to other recycled mixtures and the old mixture.
4.3. Effect of renewals agent types on tensile strength ratio (TSR)
Results of the tensile strength ratio test showed that regenerated mixtures using regenerating agents (WEO and AC) had a high resistance to moisture damage since the TSR values for these mixtures were greater than (80%) which represents the minimum specifications requirements as shown in Figure 11. As can be seen from Figure 11 the values (TSR) of the regenerated mixtures with (WEO, AC (60-70)) at the optimum ratios above the value (TSR) of the pure rap mixture. It is possible to explain the reason for this increase in the resistance to moisture damage after the regeneration process to the decrease in the percentage of air voids and the improvement of aggregate coating in addition to increasing the cohesion and adhesion between the components of the mixture and obtaining a well-compacted mixture, and thus a high density of the recycled mixture, and this is similar to my results obtained by a number From researchers [26, 27, 29 and 30].

![Figure 10. ITS results for aged and recycled mixtures at 60 °C](image)

4.4. Effect of renewals agent types on double punching shear strength (PSS)
Figure 12 shows the results of a double shear strength test for the aging mixture and the regenerated mixtures using (WEO and AC(60-70)). As can be seen from Figure 12, the value (PSS) of the aging mixture is less than recycled mixtures. This may be due to the low density and the increased air voids resulting in less consistency of ingredients for the pure rap mixture. It was also noticed that the recycled mixture with fine asphalt showed a higher value (PSS) compared to the old mix (pure RAP). The increase rate was about (149%) for the soft AC regeneration additive (60-70), while the results of the double-punch strength of the recycled mixture using oil waste confirmed a slight increase
compared to the aging mixture, but less than the values resulting from recycling using soft asphalt, Where the increase rate was at (13%), and therefore, these results showed the positive impact of the recycling process on old materials, and this leads to economic and environmental benefits, in addition to preparing promising future programs for the renewal processes.

![Double punch test results for aged and recycled mixtures](image)

**Figure 12.** Double punch test results for aged and recycled mixtures

5. Conclusions
The following conclusions were obtained from the current study results:
1- The optimum percentage of recycled (additive) content of different types was obtained in this study. Where the recycled mixtures are prepared from old materials (pure rap) at 100% with the optimum ratio of regenerative content at rates (1.5% and 3%) of the total weight of the mixture for regenerative additives (WE and AC (60-70)), respectively.
2-The optimum ratio of regenerative additive content (WEO) was lower compared to the value of the optimum content of regeneration additive (AC (60-70)), used in this study. This can be attributed to the properties of these wastes, which have a low viscosity, and therefore have an impact on the Marshall properties of the pure rap mixture when calculating the optimal content in addition to, restoring the properties of the aging binder, and giving results that meet the criteria for surface layer specifications at these ratios.
3-Outputs obtained from laboratory tests for this study, an increased improvement in Marshall's stability was observed for the properties of recycled mixtures using regenerative additives. The percentage increase in Marshall Stability was (20.3% and 40.8%) for (WEO and AC soft regenerators (60-70)), respectively.
4- The use of soft asphalt cements in the regeneration and recycling of old materials yielded better performance than other types of oil waste.
5-The results showed that recycling of Marshall Samples using WEO has good performance characteristics and this gives a promising scenario by presenting promising plans for recycling (RAP) using waste and comparing them with other materials of these oils.
6-The flow value of the soft asphalt additive at (2.4) mm was slightly higher than the value of the flow additive of oil waste at (2.1) mm and both were within the requirements of the standard specifications. While the flow of Marshall to pure rap mixture was higher than regenerated mixtures due to the increase in the ratio of air voids, low apparent density as well as a decrease in the value of Marshall Stability.
7-Based on the results, a sudden decrease was observed in the percentage of the volume of air voids of the recycled mixtures compared to the old mixture (pure rap). Thus the percentage of decline was (66%, 66.3%) for regenerative additives (WEO, and AC (60-70)), respectively.

8- By testing the indirect tensile strength at temperatures (25, 40 and 60) °C, it can be seen that the ITS value of regenerated mixtures using the soft asphalt compared to the aging mixture (pure rap) can be seen. Whereas, the value of (ITS) decreases for the regenerated mixture using (WEO), and therefore the value of the increase in the value of (ITS) was at 25 °C using soft asphalt by (175%). While it decreased slightly at (40 °C) at 137.9%, the decline in ITS value at 60 °C to (97.7%) continued due to the increase in temperature rise and its effect on soft asphalt. However, the ITS values for the mixture Regenerator using (soft asphalt) is higher compared to the aging mixture. On the other hand, there was an increase in the (ITS) value of the old mixture at the expense of regenerated mixtures using (WEO) at (25, 40 and 60) °C. The percentage increase in the (ITS) of the aging mixture at the expense of the glorified mixture using (WEO) was at 25 °C by (48%), and the value by (87%) was obtained when the test was conducted at 40 °C. Finally, the results of the (ITS) pure rap mixture at 60 °C were higher compared to the regenerated mixture using (WEO) approximately (75%).

9- Results of the tensile measurement ratio (TSR) showed that all recycled mixtures using regenerative additives have a high resistance to moisture damage and were in compliance with standards and specifications requirements (not less than 80%).

10-The results of the double-punch test for regenerated mixtures showed an almost higher value (13% and 149%) for regenerative additives (WEO and AC (60-70)), respectively compared to the aged mixture (pure rap), and it can be explained by the reason that these additives help to increase The workability (lower viscosity) of these mixtures reduces the percentage of air voids and increases the coating around the aggregates and increases the density after compaction, unlike the aging mixture with a high air gap ratio and low apparent density in addition to high flow and little Marshall stability value before recycling.

6. Recommendations
   1- Adopt other regenerative additives from waste oil and other grades (softer grades) of asphalt binder as the rejuvenator for RAP mixture.
   2- Perform other tests to evaluate performance characteristics such as fatigue and thermal cracks.
   3- Use warm additives to prepare recycled mixtures.
   4- This study relied on pure RAP from one source to measure performance characteristics. Therefore, it is necessary to study the effect of the use of (RAP) from various sources on the characteristics of Marshall and the performance of other tests.

7. Acknowledgments
   The researchers would like to thank the University of Technology, workers in the asphalt lab and the project management department in Wasit Governorate, Iraq.

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