Comparative evaluation for the effect of particles size of reclaimed asphalt pavement (RAP) on the properties of HMA

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Abstract. The construction of highway pavement usually consumes a huge amount of aggregate and binder, and at the same time, big quantities of these materials are removed from the old and damaged roads. The disposal of these materials is costing money and effort. The current study aims to investigate the effect of particle size of RAP on the volumetric and mechanical properties of Hot Mix Asphalt (HMA). The study involved replacement of coarse aggregate and fine in wearing layer of the pavement by different percentages up to 40%. The mechanical tests (Marshall Test and indirect tensile strength test) were conducted to assess the mechanical properties of the obtained mixes. Also, the economical evaluation was conducted to explain the effect of using RAP on the total cost of HMA. The results of the study showed that the replacement of fine aggregate with RAP can be adopted up to 20% of the total aggregate, while the replacement of coarse aggregate is conducted up to 40% which represents the most coarse aggregate quantity in the mix. Also, the use of RAP in HMA can significantly reduce the cost of obtained HMA compared with that produces with virgin materials.

Keywords. Hot mix asphalt, Reclaimed asphalt pavement, Marshall test, Indirect tensile strength test, Economical study.

1. Introduction

The construction of road pavement (flexible or rigid) therefore the save of natural resources of these materials is an important issue [1-3]. Reclaimed asphalt pavement (RAP) is constructed from milled or milled asphalt ripped off the old asphalt surface. It is generally collected loosely granular shape as a pavement rehabilitation or restoration by-product and is commonly used as a new pavement of asphalt course base/subbase course if pulverized or extra hot recycling or cold recycling aggregate[4]. The incorporation of RAP mixtures of pavement has increased recently, since, it reduces the demand for new virgin materials (aggregate and asphalt binder) this is, in turn, reduces the cost of construction and protects the natural resources. On other hand, the use of RAP in Hot Mix Asphalt (HMA) reduces the cost of disposal of waste material of old pavement. The inclusion of RAP in HMA has become more common recently worldwide due to previously mentioned aspects. The assessment of mechanical properties and performance of HMA containing RAP was a part of many studies in the literature. The focus has been given to the advantages and disadvantages of incorporation of RAP in HMA and investigation of optimum ratios of recycling [5].
Many studies have been conducted to explore the impact of the addition of RAP to HMA in terms of mechanical and volumetric properties of such mixes [4-6]. Daniel and Lachance [7] their study showed that the volumetric properties of asphalt mixture containing RAP were increased in the VMA and VFA of the mixture, and the asphalt mixture's quality depends on how well the virgin interacts with RAP binder, especially in laboratory applications samples containing RAP binders produced. R. Izaksa et al. [8] showed that RAP does not significantly influence mechanical and volumetric properties of the recycled hot mix asphalt in terms of stability and flow of Marshall. Valdes et al. [9] studied the mechanical response of bituminous blends with high rates of RAP 40% and 60% for a surface layer. Their results show that high levels of recycled material can usually be incorporated in new mixes after RAP treatments for homogenization and characterization, and found that the obtained mixtures with RAP content of 10% and 30% have similar characteristics as conventional mixes.

Colbert and You. [10] examined the effect of fractionated RAP materials on the performance of asphalt mixture that contained varying proportions of RAP at 30%, 50%, 70% and 100%. Their results indicated that increase concentration of RAP and other aging conditions lead to increased viscosity of RAP asphalt mixtures and make the mixture stiffer. MirA et al. [11] studied the mechanical properties of the mixtures involved high RAP percentages and low penetration grade of asphalt. Their study included the replacing of sieves coarse and fine gradation of aggregate with different percentages of RAP 15%, 30% and 50%. The designed mix was used as a wearing layer and base layer of pavement. Their studies have shown that the mechanical properties of the mixture involved RAP replacement at levels 50% to produce HMA achieved satisfactory performance. Mogawer et al. [12] the study showed that the asphalt layer containing minimal RAP quantities less than 30 percent performed similarly to those asphalt mixtures made of virgin materials. Arshad et al. [13] evaluated mechanical properties in many mixtures containing various amounts of RAP (0%, 15%, 25%, and 35%). The new blend was employed as a pavement surface layer. The results showed the mixtures of asphalt containing RAP may behave similarly or better manner as Colbert and You. [14] investigated the adding of RAP to HMA, their study involved the replacing of sieves No. 12.5, No.9.5, No.4.75, No.2.36, No.1.18, No.0.6, No.0.3 and No.0.15 with ratios of RAP 15%, 35% and 50%. The new mix was used as a surface layer of pavement. Their results showed an increase of the dynamic module, decreasing the resilient modulus and more resistant mixtures for rutting with a high percentage of RAP. Tabakovic et al. [15] They were focused on evaluating the mechanical properties of a bituminous mixture containing several percentages of RAP 10%, 20% and 30%. The new mix was used as a binder course of pavement. Replacing the fine and coarse aggregate in the HMA. Their results showed an improvement in mechanical properties of mixes contained RAP compared with conventional mixes prepared as binder course.

Kodippily et al. [16] assessed the effects of adding RAP and polymer-modified asphalt on performance HMA, their study involved the preparation of six mixtures contained a different percentage of RAP and polymer-modified asphalt. They replaced aggregate by RAP at percentages of (0%, 15% and 30%) from sieves 9.5, 6.7, 4.75 and 2.36mm. Their results showed that the mixture has a high contained of RAP and polymer-modified bitumen meet requirements of mechanical properties and sustainability resistance of the development of highways in New Zealand. Shen et al.[17]evaluated volumetric properties and ITS of 12 asphalt blends of which ten contain recycled materials, two are a combination of new materials. Using two types of rejuvenating agents including one type of oil commercially available in the US and liquid asphalt with low viscosity. The replacing of aggregate by RAP from coarse and fine gradation. Their results showed that the volumetric criterion of recycled mixes were satisfied and ITS meet specifications of the recycled mixtures.

Widyatmoko. [18] studied the effect of adding the RAP to an asphalt concrete surface course and a base course that both contained RAP at 10%, 30% and 50% by mechanical characteristics and durability. It was found that the mixes containing RAP have performed at least equivalent or better than those of the control mix without RAP. Cong et al. [19] examined the effects of the replaced asphalt and rejuvenating agent SBS on mixtures performance. The combination designs included a control mixture of 0% RAP and three asphalt mixtures, 15% RAP, 25% RAP, and 30% RAP. Their study involved the replacing of sieves 16, 13.2, 9.5, 4.75, 2.36, 1.18, 0.6, 0.3 and 0.075mm. The results showed that the loss of indirect tensile
strength is within the 20 percent loss limit stated in the Superpave requirement. The results indicated that (ITS) loss could meet those demands, but rejuvenating agents can achieve better moisture resistance of the RAP-containing asphalt blend. The current research aims to optimize the best technique for adding RAP to HMA by investigating the effect of particle sizes of aggregate in RAP on volumetric and mechanical properties of HMA. Although, there are many studies deal with using RAP in HMA, a limited studies were focused on the effect of particles size of RAP on HMA performance. Most of previous studies focused on replacement percentages from all sieves or percentages from specific sieves for aggregate gradation used in HMA. The work involved comparison the replacement from coarse aggregate and fine aggregate. The HMA was designed as a wearing layer of pavement involving different percentages of RAP.

2. Materials

2.1. Asphalt
The asphalt binder used in this research was AC 40-50 grade asphalt binder provided from Al-Nasiriya refinery, southeast of Baghdad city. The physical properties of the binder were tested and evaluated as summarized in Table 1.

Table 1. Physical properties of asphalt binder.

| Test type                        | ASTM Designation | result | SCRB specification |
|----------------------------------|------------------|--------|--------------------|
| Penetration (25°C, 100 gm, 5 sec)| D-5              | 44     | (40-50)            |
| Ductility (25 °C, 5 cm/min), (cm)| D-113            | 123    | >100               |
| Flash point (Cleveland open cup), (°C)| D-92     | 300    | Min.232            |
| Softening point, (°C)            | D-36            | 53     | --------           |
| Specific gravity at 25 °C        | D-70            | 1.03   | --------           |

2.2. Aggregates
The crushed aggregates (coarse and fine aggregate) used in this research were obtained from local sources (Badra quarries) in eastern Iraq. The physical characteristics of the aggregates were examined experimentally and the results are listed in Table 2.

Table 2. Physical properties of coarse and fine aggregates

| Property                               | ASTM Designation | Coarse Aggregate | Fine Aggregate | SCRB Specification |
|----------------------------------------|------------------|------------------|----------------|--------------------|
| Bulk Specific Gravity                  | C127, 128        | 2.560            | 2.496          | --------           |
| Apparent Specific Gravity              | C127, 128        | 2.672            | 2.595          | --------           |
| Percent Water Absorption               | C127, 128        | 1.63             | 1.52           | --------           |
| Percent Wear (Loss Angeles Abrasion)   | C131             | 20.7%            | ------         | 30% max.          |

2.3. Mineral Filler
One type of mineral filler was utilized in this research which is limestone dust and was supplied from Fallujah city, Table 3 shows the chemical properties of limestone dust.

2.4. RAP material
The first major step in the design of HMA containing RAP is the determination of the properties of the RAP aggregate and asphalt binder content in RAP. The contents of the asphalt and the RAP material gradation were tested according to ASTM D2172[20] after extracting its asphalt binder. Table 4 and Figure1 present the physical properties and gradation of the RAP materials after asphalt binder extraction. The RAP material used in this research was obtained from the milling a surface layer with average depth(5cm) which were collected from an old pavement of Al-Diwaynah and Najaf highway.

Table 3. Chemical properties of limestone

| Chemical compound             | % Content |
|-------------------------------|-----------|
| Silica oxide, SiO₂            | 4.19      |
| Lime oxide, CaO               | 43.7      |
| Sulfuric Anhydride, SO₃       | 2.08      |
| Magnesia, MgO                 | 0.036     |
| R₂O₃(Aluminum oxide Al₂O₃, Ferricoxide) | 1.01 |
| Loss on Ignition%             | 41.39     |
| Non-soluble substances        | 4.62      |

Table 4. Physical properties of Reclaimed Asphalt Pavement (RAP) after Extraction Test.

| Marital Property | Property              | Test results | ASTM designation |
|------------------|-----------------------|--------------|------------------|
| Coarse aggregate | Bulk Specific Gravity | 2.524        | C-127            |
|                  | Apparent Specific     | 2.572        | C-127            |
|                  | Gravity               | 1.2          | C-127            |
|                  | Percent Water         | 1.63         | C-128            |
|                  | Absorption            |              |                  |
| Fine aggregate   | Bulk Specific Gravity | 2.472        | C-128            |
|                  | Apparent Specific     | 2.576        | C-128            |
|                  | Gravity               | 1.63         | C-128            |
|                  | Percent Water         |              |                  |
|                  | Absorption            |              |                  |
| Asphalt cement   | Asphalt content%      | 2.92         | D2172            |

Figure 1. Gradation with SCRB/R9 of recycled aggregate surface course limitations
3. Methodology

The research was conducted in three stages. The first stage of the study comprised of the characterization of the materials, involving aggregates, asphalt, and RAP (i.e., gradation and asphalt content calculation in the RAP). The second stage involved implementing Marshall Procedure according to AASHTO T245 [21] to determine the optimum asphalt binder. The last stage involved testing and prediction of mechanical and volumetric properties of obtained HMA mixture that contained different percentages of RAP. Second strategies were adopted in producing the HMA contain. RAP, the first strategy includes replacing the fine aggregate in HMA with different percentages of RAP, the second strategy involves replacing the coarse aggregate in HMA with different percentages of RAP. The replacement in the first and second strategies was up to 40% of the total weight of aggregate in the increment of 10%. The 40% of total aggregate approximately represents all amount of total aggregate used in the mix. The mixes designed to be used in the wearing layer of pavement with a nominal maximum size of 12.5 mm.

3.1. Mix Design and preparation of samples

The first step of the mix design was the selection of the aggregate gradation curve. Based on the aggregate gradation specified for the dense-graded, mid of specification ASTM D3515 [22] was selected as shown in Figure 2.

![Figure 2.](image)

Marshall mix-design method was used to find the optimum asphalt content OAC; three samples were prepared for five different asphalt binder contents (4, 4.5, 5, 5.5 and 6) as a percent by total weight of the mixture. Once the newly compacted specimens take off the mold, the bulk specific gravity for each specimen was calculated according to ASTM D2726 [23]. The stability and flow of each test specimen were calculated according to ASTM D6927 [24]. The optimum asphalt content (OAC) is calculated and found to be equal to 4.7% by weight of the total mix. The control mixture was prepared with OAC to be a reference for other mixes in this research.

3.2. Characterization of recycled mixtures

RAP was tested to determine the aggregate gradation and percentage of asphalt binder to conduct the replacement process and determine the required asphalt binder substitution. This process involved firstly determine the percent of asphalt binder in RAP according to ASTM D2172 [20], then sieve analysis was carried out to determine the aggregate gradation according to ASTM D2172 [20]. In order to investigate the best replacement technique, three ways of replacement were adopted, the first involved replacement of the aggregates by RAP from retaining on sieves size 12.5, 9.5, and 4.75 mm (coarse gradation of aggregate) with percentages of 10%, 20%, 30% and 40% of RAP, the second way involved replacement of the aggregates by RAP from sieves size 2.36, 0.3, and 0.075 mm with percentages of 10%, 20%, 30%
and 40% of RAP. All recycled asphalt mixtures were designed with optimum asphalt content (4.7%) by the total weight of the mixture. This selection of OAC was adopted to explore the effect of RAP replacement and to limit the number of OAC determination to a possible limit since the determination of OAC for each percentage of replacement required a huge number of specimens. The percentage asphalt binder in RAP was determined as 2.92. This percentage is considered as a part of net binder in new mixes. The percentage of neat asphalt binder required to achieve the OAC in new HMA mixtures produced with RAP was determined as shown in Table 5 after considering the asphalt binder in RAP.

Table 5. Percentage of asphalt binder content added for each percentage of RAP replacement.

| % RAP | 10  | 20  | 30  | 40  |
|-------|-----|-----|-----|-----|
| %Asphalt content | 4.4 | 4.1 | 3.8 | 3.5 |

3.3. Assessment of volumetric and mechanical properties of HMA contain RAP.

Assessment of the effects of fine, coarse RAP particles on the volumetric properties (bulk specific gravity, VA%, VMA% and VFA%) and the mechanical properties of the HMA was carried out experimentally by conducting Marshall stability, flow and indirect tensile strength test.

3.3.1. Marshall stability and flow tests

The Marshall Test method is used in the design and evaluation of bituminous paving, which is commonly used in routine paving testing programs. The samples were prepared according to ASTM D6926 procedure (ASTM, 2010) [25]. The Marshall method of designing has two main features mixes, density-analysis of voids and stability-flow evaluation. Strength is measured in terms of the stability of the Marshall (ASTM D6927, 2010), known as the maximum load carried by the specimen at a normal test temperature of 60 °C. Flexibility of sample is calculated by the 'flow value' that is calculated by the change in the sample diameter direction of load application between loading start and time of loading to maximum load. Three replicated specimens were prepared for each test.

3.3.2. Indirect Tensile Strength Test (ITS)

The ITS test can give an indication for the tensile strength of mix and crack propagation. The tensile strength ratio (TSR) obtained from this test gives an indication of the moisture susceptibility of specimens. This test is conducted according to AASHTO T283 [26]. The load was applied diametrically to the specimen at a constant rate of 50.8mm/min and the force required to break the specimen down is determined. The indirect tensile strength (ITS) was determined using the equation (1). The tensile strength ratio (TSR) (i.e., the ratio of ITS of conditioned samples to the ITS of unconditioned samples) was calculated according to equation (2).

\[
ITS = \frac{2P}{\pi xtD}
\]  

(1)

\[
TSR = \frac{ITS_{conditioned}}{ITS_{unconditioned}}
\]  

(2)

Where:

\(\text{ITS} = \) Indirect tensile strength (Mpa)
\(\text{P} = \) Applied load at failure (N)
\(\text{t} = \) Thickness of specimen (mm)
\(\text{D} = \) Diameter of specimen (mm)
TSR = Tensile strength ratio
ITS conditioned = Indirect tensile strength of conditioned samples.
ITS unconditioned = Indirect tensile strength of unconditioned samples

4. Results and discussion

In this section, the results of volumetric and mechanical characterization HMA containing different percentages of RAP (according to work methodology) are presented.

4.1. Volumetric properties

The volumetric properties of the mixes were assessed according to the output of experimental work (i.e. bulk specific gravity and maximum specific gravity). These properties involve air void, voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA). For mixtures involved the replacement of fine gradation and coarse gradation with 10%, 20% and 30% of RAP, the VMA reduced with increasing the ratio of RAP compared to the VMA of the conventional mix. It is shown that air voids increased with increasing RAP percentage of the mixtures involved replacement of coarse gradation, because of the high aging in higher RAP quantities and the reduced bulk specific gravity. For the mixtures which involved replacing the fine aggregate, the AV reduced with increasing the ratio of RAP, since the fine aggregate has increased in RAP mixture which causes a fill in the spacing between the aggregates. The relation between VFA and AV is negative, air voids decrease as VFA increases, this can be attributed to the decrease in the air voids due to the presence of RAP containing hardened asphalt. The percentage of voids filled asphalt (VFA) of all the mixtures with different ratios RAP will meet the requirements for the specification(65-75) according to MS2, 2014 [27] of surface layer. The replacement of coarse aggregate gradation with RAP meets all volumetric properties of the mixture (AV, VMA, and VFA) for all percentages of replacement; while the replacement with fine aggregate doesn’t meet the VMA requirement especially for high percentages of replacement (40 %). This can be attributed to the high surface area of fine aggregate which may have more asphalt binder outcomes from RAP.

Table 6. Volumetric properties of the mixtures.

| %RAP | Fine gradation | Coarse gradation |
|------|----------------|------------------|
|      | AV% VMA% VFA% | AV% VMA% VFA%    |
| 0%   | (3-5) ≥14 (65-75) | (3-5) ≥14 (65-75) |
| 10%  | 4 15.1 73.5     | 4 15.1 73.5      |
| 20%  | 4.2 14.56 71.15 | 3.71 14.12 73.73 |
| 30%  | 3.88 14.27 72.81 | 4.28 14.63 70.75 |
| 40%  | 3.54 13.94 74.61 | 4.35 14.71 70.42 |

4.2. Marshall stability and flow test

Figure 3 shows the Marshall Stability value for the mixtures contained replacement the coarse aggregate with different percentages of RAP. All these mixtures meet the 8 KN minimum stability criterion and 2-4 mm Marshall Flow requirements for the surface layer according to the State Corporation for Roads and Bridges (SCRB, 2003). The results show increasing in Marshall Stability with an increase in the percentage of RAP, this is in turn helps to produce more stable blends similar to a standard mix. The Marshall stability of the mixtures improves significantly by using coarse gradation from RAP in HMA, which is mainly due to their high stiffness of recovered asphalt. RAP materials could potentially have greater resistance than virgin materials since aggregate particles in HMA are covered and protected by asphalt binder. Figure 4 illustrates the Marshall Stability value for the mixtures contained replacement the
fine aggregate with different percentages of RAP. For these mixtures, Marshall Stability values decrease with increasing percentages of RAP. This reduction in Marshall Stability may be related to the use of small sizes of RAP aggregates contributes to surface area increases, which in turn, results in a significant proportion of the aged asphalt binder in the mixtures containing a higher percentage of RAP replacing fine aggregate.

![Figure 3. Results of Marshall Stability with different percentages of RAP replacing coarse aggregate.](image)

4.3. Indirect Tensile Strength Test (ITS).

Figures 5 and 6 illustrate the results of ITS for unconditioned and conditioned samples respectively. The indirect tensile strength values increase with increasing percentages of RAP for conditioned and unconditioned specimens especially for the mixtures contained replacement for the coarse aggregate with different percentages of RAP. This is due to the fact that RAP involves hardened asphalt that gets more and more hardened and viscous with time. Therefore, mixtures of more viscous would performance better under tension, resulting in a lower decline in tensile strength when subjected to high temperature and humidity conditions [28]. For the mixtures contained replacement of fine aggregate with different percentages of RAP, the indirect tensile strength values decrease with increasing percentages of RAP for both conditions. The reason for that decreasing is that, the higher contents of RAP in the mixture means

![Figure 4. Results of Marshall Stability with different percentages of RAP replacing fine aggregate.](image)
increase small size of RAP aggregates, this will lead to reduce the stiffness of the mixtures. The results indicate that all recycled mixtures to be less susceptible to moisture damage compare to control Mix. in other word, all mixes have a good potential to resist moisture damage since the obtained TSR values are more than 80% according to (SCRB /R9, 2003) for surface layer as shown in Figures 7 and 8. The resistance moisture damage is quiet better for the mixes content replacement of coarse aggregate with RAP. This can be attributed to good aggregate interlock and better coating from binder in RAP due to the lower surface area of coarse aggregate compared with fine.

**Figure 5.** ITS results for Unconditioned and Conditioned Specimens with different percentages of RAP replacing coarse aggregate.

**Figure 6.** ITS results for Unconditioned and Conditioned Specimens with different percentages of RAP replacing fine aggregate.
5. Economic analysis.

One of the most significant factors for selecting a choice from a variety of alternatives is the economic aspect. The new strategies for reducing costs have been studied deeply by highway agencies responsible for pavement construction and maintenance [29]. Cost analysis is commonly categorized into two strategies as (1) reducing the cost of asphalt mixture, and (2) decreasing the costs associated with the material. The cost of the ingredients used in the studied mixtures is also estimated, and it is defined in Figure 9. As can be seen from this figure, by increasing the amount of RAP in mixtures, the unit price of materials would be substantially reduced. The cost of materials used in mixtures contained replacement of the coarse aggregate by 40% of RAP is reduces by about 34% compared with that produces with virgin materials. The mixtures contained replacement the fine aggregate 40% of RAP is reduced 29.3% of the materials cost compared with that produces with virgin materials. The calculations of cost of materials
based on assumption that the cost of RAP is approximately free; which means, part of the aggregate and binder used in the mixture are available as free of charge.

![Figure 9. Cost of mixtures with different percentages of RAP replacement for coarse and fine aggregate.](image)

**6. Conclusions**

The current experimental research involves the investigation of the effect of RAP particle size on volumetric and mechanical properties of HMA. According to experimental tests and results obtained the following conclusions can be drawn:

1. Using RAP material in HMA has a significant impact on the total cost of road construction and solid was management due to reducing the demand for natural resources, decreasing the quantity of used asphalt binder and solve the problem of waste disposal.
2. According to the results of the current study, the replacement of coarse aggregate with RAP gives satisfactory or good performance compared with replacement from the fine aggregate. This may be attributed to less surface area of aggregate and consequently less amount of aged asphalt, and better mechanical interlock.
3. From the Marshall test results, the replacement of fine aggregate with RAP can be adopted up to 20% of the total aggregate, while the replacement of coarse aggregate is conducted up to 40% which represents the most coarse aggregate quantity in the mix.
4. From the ITS and TSR results, the replacement of coarse aggregate and fine aggregate with RAP produce satisfactory performance, however, the replacement of coarse aggregate is relatively give better mechanical properties compared with fine aggregate.
5. The volumetric properties analysis supports the results of mechanical tests since it gives a clear idea about the mass volume relationships.

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