Experimental Investigation of Rutting Potential of Reclaimed Asphalt Pavement Mixtures

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Abstract: Today Due to the increasing cost of asphalt binder, environmental considerations, and an increasing number of agencies are embracing principles of sustainability in managing their activities, recycled asphalt pavement (RAP), are now being allowed to be added into hot mix asphalt (HMA). Sustainability considerations are not new, and in fact have often been considered indirectly or informally, but in recent years' significant efforts are being made to quantify sustainability effects and to incorporate them in a more systematic and organized fashion. Recognizing asphalt recycling as a key sustainable practice in the pavement industry. This paper examines the rutting and thermal cracking resistance of RAP laboratory-prepared Marshall asphalt concrete mixtures. The asphalt mixtures were produced with 0%, 5%, 10%, and 15% Reclaimed Asphalt Pavements (RAP) contents. The experimental testing program included Wheel Tracking test. The effects of different RAP contents on the rut depth of the asphalt mixtures have been mainly investigated. Moreover, the influences of testing temperatures have been observed. Test results revealed that at testing temperature of 70°C, the number of cycles to reach failure increases by 15.4%, 40%, and 53.8% for 5, 10, and 15% RAP content respectively.

Keywords: HMA, Recycled Asphalt Pavement (RAP), permanent deformation, old aggregate, old asphalt.

Introduction

“Sustainable” in the context of pavements refers to system characteristics that encompasses a pavement’s ability to (1) achieve the engineering goals for which it was constructed, (2) preserve and (ideally) restore surrounding ecosystems, (3) use financial, human, and environmental resources economically, and (4) meet basic human needs such as health, safety, equity, employment, comfort, and happiness, as in [1].

Sustainable road construction has become the interest of highway authorities in recent years. Asphalt is the sustainable material for constructing pavements. From the production of the paving material, to the placement of the pavement on the road, to rehabilitation, through recycling, asphalt pavements minimize impact on the environment. Low consumption of energy for production and construction, low emission of greenhouse gases, and conservation of natural resources help to make asphalt the environmental pavement of choice [2].

Reduce, Reuse, and Recycle: are three key words in the world of sustainability. Reduce by building to last and by not using as much material in the first place (i.e., building higher quality, longer lasting facilities reduces the need to regularly replace those facilities). Better roads and better bridges last longer reduce the need for maintenance and repair (and reduce the consumption of resources). Reuse by taking a material and returning it back to the same use (i.e., the greatest reused material in the USA is asphalt pavement. Nationwide, Reclaimed Asphalt Pavement (RAP) amounts to over 72 million tons, with another 18 million tons of asphalt pavement being recycled into other pavement materials. Recycling takes one material manufactured for a specific use and remanufactures that material for a different use (i.e., Cold-In-Place Recycling and Asphalt Shingle Recycling) [3].

A rut is a surface depression in the wheel paths. Pavement uplift may occur along the sides of the rut but in many instances, ruts are noticeable only after a rainfall when the paths are filled with water. Rutting stems from a permanent deformation in any of the pavement layers or subgrades, usually caused by consolidated or lateral movement of the materials due to traffic load [4].

Many highway agencies today use either the Hamburg wheel tracking or the asphalt pavement analyzer test to evaluate the rutting susceptibility of asphalt mixtures. In this study, the asphalt pavement analyzer test was selected for permanent deformation testing.
The results from the researches indicates that, the addition of RAP to the virgin asphalt mixtures results in stiffer mixes which indicates better rutting resistance [5].

Objectives

The main goal of the present research is to investigate the rutting characteristics for local surface HMA mixtures containing different percentages of screened RAP that meet the SCRB specification [6] and what is the suitable percentage of RAP which can be used in the mixture to get the maximum advantages throughout a designed experimental program.

Materials and Testing Methods

3.1. Materials

The Selected materials to be used in this study are locally available and currently used in road construction in Iraq.

3.1.1. Asphalt Cement

The asphalt binder used in this study with penetration grade of (40-50) was supplied from Daurah refinery plant. Which is a local asphalt binder producer. The physical properties of the asphalt binder are presented in Table 1.

<table>
<thead>
<tr>
<th>Test</th>
<th>Unit</th>
<th>ASTMD 7</th>
<th>SCRB Specifications</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration (25˚C, 100g, 5sec)</td>
<td>1/10 mm</td>
<td>D 5</td>
<td>40-50</td>
<td>47</td>
</tr>
<tr>
<td>Softening point</td>
<td>°C</td>
<td>D 36</td>
<td>50-60</td>
<td>51</td>
</tr>
<tr>
<td>Ductility (25˚C, 5cm/min)</td>
<td>Cm</td>
<td>D 113</td>
<td>≥100</td>
<td>164</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>D 92</td>
<td>≥232</td>
<td>259</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>……</td>
<td>D 70</td>
<td>……</td>
<td>1.041</td>
</tr>
<tr>
<td>Absolute Viscosity at 60°C (*)</td>
<td>Poise</td>
<td>D 2171</td>
<td>2065</td>
<td>……</td>
</tr>
<tr>
<td>Kinematics' Viscosity at 135˚C (*)</td>
<td>C St.</td>
<td>D 2170</td>
<td>370</td>
<td>……</td>
</tr>
</tbody>
</table>

(*) The test was conducted in Dourah refinery
a: State Commission of Roads and Bridges

3.1.2. Aggregate

Natural fine and crushed coarse aggregates are used in this research. The source of aggregate is from Al-Nibaay quarry in Taji, north of Baghdad. To produce identical controlled gradation, aggregates were sieved and recombined in laboratory to meet the wearing course gradation as required by SCRB specification. The gradation, physical and chemical properties for the aggregate is shown in Table 2, Table 3, Table 4 and Figure 1.

Table 2. Combined Gradation of Aggregate and Mineral Filler for Wearing Course.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Sieve Opening, mm</th>
<th>Percentage passing by Weight of total Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4&quot;</td>
<td>19</td>
<td>100 (SCRB)</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>12.5</td>
<td>90-100 (95)</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>9.5</td>
<td>76-90 (83)</td>
</tr>
<tr>
<td>No.4</td>
<td>4.75</td>
<td>44-74 (59)</td>
</tr>
<tr>
<td>No.8</td>
<td>2.36</td>
<td>28-58 (43)</td>
</tr>
<tr>
<td>No.50</td>
<td>0.3</td>
<td>5-21 (13)</td>
</tr>
<tr>
<td>No.200</td>
<td>0.075</td>
<td>4-10 (7)</td>
</tr>
</tbody>
</table>

Figure 1. Specification Limits and Mid-Point Gradation of SCRB [6] for Wearing Course Layer.

Table 3. Physical Properties of Al-Nibaee Aggregates.

<table>
<thead>
<tr>
<th>Property</th>
<th>Coarse Aggregate</th>
<th>Fine Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Result</td>
<td>ASTM Designation</td>
<td>Result</td>
</tr>
<tr>
<td>Bulk Specific Gravity</td>
<td>2.632</td>
<td>C 127</td>
</tr>
<tr>
<td>Apparent Specific Gravity</td>
<td>2.670</td>
<td>C 127</td>
</tr>
<tr>
<td>Percent Water Absorption</td>
<td>0.433</td>
<td>C 127</td>
</tr>
<tr>
<td>Percent Wear (Los-Angeles Abrasion)</td>
<td>20.2</td>
<td>C 131</td>
</tr>
</tbody>
</table>

Table 4. Chemical Composition of Al-Nibaee Coarse Aggregates

<table>
<thead>
<tr>
<th>Chemical Compound</th>
<th>Content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica, SiO2</td>
<td>82.52</td>
</tr>
<tr>
<td>Lime, CaO</td>
<td>5.37</td>
</tr>
</tbody>
</table>
Magnesia, MgO
Sulfuric Anhydride, SO3
Alumina, Al2O3
Ferric Oxide, Fe2O3
Loss on Ignition
Total

Mineral Composition
Quartz
Calcite

*The tests were done in cooperation with National center for construction laboratories and researches (Baghdad).

3.1.3. Mineral Filler

One type of mineral filler is used: ordinary Portland cement was brought from local market. It is thoroughly dry and free from lumps or aggregations of fine particles.

3.1.4. RAP Material

The RAP material was collected from Al-Adel neighborhood in the west of Baghdad city, the capital of the Republic of Iraq and its asphalt content was found to be 4.6 % with penetration grade of (40-50). The top 50 mm of the asphalt layer was removed and collected from the damaged surface of pavement layer. The collected RAP was milled, sieved and recombined in predetermined percent with new aggregate and new asphalt grade (40-50). Two types of RAP were used in terms of fraction: coarse RAP and fine RAP. Figure 2 represents the gradation of recycled asphalt pavement used in this study. Plate 1 shows samples of Recycled Asphalt pavement.

3.2. Mix Design

The Marshall Mix design method was employed to determine the optimum asphalt content (O.A.C) for the mix with zero RAP percent. The optimum asphalt content for HMA mixture with 0% RAP was found to be 4.8%.

3.3. Methodology of Adding RAP

Virgin HMA mixtures were mixed with three different percentages of RAP (5, 10, and 15) % (by weight of total mix).

First the fractionated RAP obtained from Al-Adel neighborhood is dried to make it workable and to mix it with the virgin materials. The RAP is heated to a temperature of 110°C (230°F) for a time of no more than 2 h. In this study the RAP was fractionated into coarse RAP (+4.75 mm) and fine RAP (−4.75 mm). Half of the weight of RAP selected to be added to the virgin HMA was coarse RAP and the other half was fine RAP. When batching out the RAP aggregates, it is important to remember that part of the weight of the RAP is binder. It is necessary to increase the weight of RAP and decrease the amount of new binder added to take the presence of this RAP binder into account.

3.4. Asphalt Concrete Slab Specimens Preparation

In order to evaluate the RAP mixtures against permanent deformation characteristics, compacted asphaltic slab samples are prepared. The dimensions of compacted slabs used in this study are (400 mm) (15.7 inch) in length, (300 mm) (11.8 inch) in width, and (50 mm) (1.9 inch) in height.

The asphaltic slabs are pressed using standard iron section with dimensions ((400 mm) (15.7 inch) in length, (300 mm) (11.8 inch) in width, and (120 mm)
(4.7 inch) in height), as shown in Plate 2.

Plate 2. Molds for Pressing Asphalt Slabs.

An asphalt beam which weighs (14100 gm.) of asphalt mixture with different RAP content is prepared to represent surface wearing layer. The aggregate is combined in a mixing bowl and heated in the oven to the mixing temperatures prior to mixing it with heated asphalt and heated RAP. The hot asphalt and the hot aggregate and RAP are mixed together in the mixing bowl by hand on hot plate until asphalt had sufficiently coated the aggregates or until a homogeneous mixture is achieved. The bowl with its content is transferred to oven and stored for 2 hours at 135˚C to allow the aggregate pores to absorb the asphalt binder. The mix is stirred every 30 minutes to ensure uniform aging throughout the mix.

Then, the mix is compacted in the heated mold at the specified compaction temperature using the Roller Compactor in accordance with EN 12697-33, as shown in Plate 3. The mold was left for 24 hours and then the specimen are extracted from their mold. The prepared specimens are shown in Plate 4.

Plate 4. Slab Specimens Prepared for this Study.

3.5. Test Methods

The flow chart shown in Figure 3 is clearly describes the experimental tests design.

![Flow Chart of Experimental Work](image)

**Figure 3. Flow Chart of Experimental Work**

3.5.1. Wheel Tracking Test

The Pavement Wheel Tracker is a device commonly used to assess the rutting potential of the control mix and the mixtures with various RAP contents by simulating the actual rutting development in the pavement. The test device is shown in Plate 5 and is specified by AASHTO Designation [8]. The test provides information about the rate of permanent deformation from a moving, concentrated load. External Linear Value Displacement Transducers (LVDT’s) are used to determine the maximum rut depths at regular pass intervals. The load applied by the wheel is approximately 700 N (158lbs) with a total distance of travel of (230±10) mm and a constant loading frequency of (26.5±1.0) load cycles per 60 seconds at...
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contact points and passes repetitively over the sample for up to 10,000 cycles. If the maximum allowed deformation is reached before 10,000 cycles, the wheel will lift off the failed sample.

Results of the wheel tracker tests are plotted on a graph displaying rut depth (typically in millimeters) versus the number of passes for each test at three testing temperatures 40˚C, 55 ºC, and 70 ºC, as shown in Figures 4, 45 and 6. It can be seen that, permanent displacement (RD) influenced when temperature changes from 40 to 70 ºC.

4. Results and Discussion

Permanent Deformation Test Results

The Permanent deformation, or rutting, has been and continues to be a problem in the performance of hot mix asphalt (HMA) pavements. Rutting is defined as the accumulation of small amounts of unrecoverable strain resulting from applied loads to the pavement. This deformation is caused by the consolidation, a lateral movement of the HMA under traffic, or both. Shear failure (lateral movement) of the HMA courses generally occurs in the top 100 mm of the pavement surface [9].

In recent years, the potential for rutting on the highways in Iraq has increased due to higher traffic volumes (equivalent single axle loads [ESALs]) and the increased use of radial tires, which typically exhibits higher inflation pressures.

The rut depth development monitored with an automatic displacement measuring device by setting the machine motion and taking readings of the vertical displacement initially, r˳, and then after every (25±1) load cycles with the center of the test specimen within 10 mm of the center point of the loaded area at the mid-point of transverse. The failure criteria for all testing samples is continuing for 10000 load cycles or until a rut depth of 25 mm is reached, whichever is the shorter.

From the above Figures, an improvement in rutting resistance was observed as RAP content increased from 0% to 15%. Because of that, the addition of RAP increasing the stiffness of mixture.

Plate 5. Slab Specimen Testing Using Wheel Tracking Device

Figure 4. Influence of RAP Content on Rutting Depth at Testing Temperature 40 ºC.

Figure 5. Influence of RAP Content on Rutting Depth at Testing Temperature 55 ºC.

Figure 6. Influence of RAP Content on Rutting Depth at Testing Temperature 70 ºC.
Fig. 7, 8, and 9 show the relation between the number of cycles to failure and the RAP content at the selected testing temperature.

![Figure 7](image)

**Figure 7. Influence of RAP Content on the Number of Cycles to Failure at Testing Temperature 40 °C.**

![Figure 8](image)

**Figure 8. Influence of RAP Content on the Number of Cycles to Failure at Testing Temperature 55 °C.**

![Figure 9](image)

**Figure 9. Influence of RAP Content on the Number of Cycles to Failure at Testing Temperature 70 °C.**

In order to evaluate the results of the mixtures with RAP, the Traffic Benefit Ratio (TBR) term can be used. TBR can be defined as; the number of cycles for RAP sample to the number of cycles for control sample. Figures 10, 11, and 12 show the Traffic Benefit Ratio (TBR) for RAP mixtures at selected testing temperatures.

![Figure 10](image)

**Figure 10. Effect of RAP Content on Traffic Benefit Ratio at Testing Temperature 40 °C.**

![Figure 11](image)

**Figure 11. Effect of RAP Content on Traffic Benefit Ratio at Testing Temperature 55 °C.**

![Figure 12](image)

**Figure 12. Effect of RAP Content on Traffic Benefit Ratio at Testing Temperature 70 °C.**
From Figure 13, it can be noticed that the increase in testing temperature decreases the number of cycles to reach 25 mm rut depth.

5. Conclusions

Based on the findings of this comparative study for various percentages of RAP materials included in Marshall Mixtures, the following conclusions can be put forward:

1. In general, it is concluded that, the inclusion of RAP material in specified percentage in this study improves the performance characteristics of flexible pavement (permanent deformation resistance and thermal cracking resistance).

2. Inclusion of RAP in HMA mixtures appear to be an effective means in restricting the development of permanent deformation in wearing course mixes caused by heavy loads and high temperatures. The results of rut depth using wheel tracking test show that, at testing temperature of 70°C, the number of cycles to reach failure increases by 15.4%, 40%, and 53.8% for 5, 10, and 15 % RAP content respectively.

3. Results of experimental work indicate that the amount of new binder in the RAP mixture can be reduced without any effect on the quality of the produced mixes.

6. References


