Cold asphalt mixtures with high reclaimed pavement material percentages response to local traffic loading and environmental conditions

M A AL-JUMAILI and O D ISSMAEL

1Civil Engineering Department, University of Kufa, Iraq
2Highway and Transportation Department, University of Al-Mustansiriah, Iraq

Abstract. Older asphalt materials can be recycled using cold, warm, or hot output methods, and the addition of emulsion ingredients, water, and new aggregates to the old asphalt pavement can be completed either in plant or on site. Cold recycling is desirable, but there is little equipment available to processes in-place recycling of this type to enable structural and material problems to be corrected quickly without much disruption to traffic. For the purposes of assessing the performance of asphalt emulsion recycling mixtures, a cold recycling mix was designed with steps including original material selection, gradation design, adding cement as a filler material, and performance evaluation. Few investigations have been done to assess the tensile and compressive strengths, moisture sensitivity, and rutting of recycled cold mixtures with local materials containing a high percentage of reclaimed asphalt pavement (RAP) of up to 90%. There is thus a need to assess the performance of recycled cold mixtures, especially where they contain high proportions of reclaimed pavement materials that will already have been exposed to local conditions. Recycled cold mixture behaviour has been characterised by its compressive strength, indirect tensile strength, moisture sensitivity, and rut depth. Testing program results showed that cold mixtures containing high percentages of RAP at the end of the various curing periods (1, 7, 14, and 28 days) provided better resistance to permanent deformation, moisture damage, and tensile stresses than a control cold mix with no reclaimed pavement materials. This improved behaviour may be explained by the increase in recycled cold mix stiffness, which offers high RAP and cement bonding with appropriate curing times.

Key words: Cold recycling, moisture damage, RAP, compressive strength.

1. Introduction
The highways network in Iraq is moving from a construction phase to a maintenance one, which makes it essential to consider recycling as one a promising solution for rehabilitation of used asphalt concrete pavement. In the cold mix recycling of asphalt concrete pavements, no heat is needed, and thus pollution problems caused by burning bitumen are eliminated; however, cold mixes require curing time, and the produced densities are lower than in hot mixes. The output of cold reclaimed mixes utilises recycled asphalt pavement (RAP) including aggregates and is of economic interest as it reduces transportation costs, emissions, and energy losses. However, there is no generally internationally approved method for the design of cold asphalt mixtures [2]. Methods of cold mixing for surface courses appropriate for light and medium traffic normally demand a seal coat or hot asphalt concrete overlay as surface protection; however, when used in the binder or base layer, they may be appropriate for all kinds of traffic [1]. Cold mix technology based on emulsions involve pre-wetting the aggregate with water and them adding emulsion to it, with production of the mix, laying, and compaction all completed at room temperature (23 °C to 25 °C); hence, no heating of the asphalt emulsion is required and no drying or heating of the aggregate is required. Few studies have been undertaken to observe the effect of temperature on these mixtures compared with hot asphalt mixtures, although this is a very important problem in terms of road construction in Iraq [1].
current study is thus an assessment of the design of cold recycled mixes for various curing periods. Mechanical tests were done on a cold mixture sample compacted by a Marshall hammer, and these supplied good results for certain asphalt emulsion and cement amounts [2]. The phenomenon of curing appears to control the rate of strength gain in cold emulsion recycled asphalt pavement. The goal of this research was thus achieved by making an assessment of a cold-recycled mixture including a high percentage of recycled asphalt (90% by weight of total aggregate). Mix design steps chosen to select the optimum premix water amount and optimum emulsion content were proposed, and the performance of the recycled mixtures was assessed by means of an indirect tensile strength (ITS) test, rutting resistance test, and moisture susceptibility test.

2. Materials Characteristics
2.1 New Aggregate (coarse and fine aggregate)
The fresh aggregate (coarse and fine) used in this project was obtained from Al Nibaie Quarries. Aggregate is generally utilised for asphalt mixes in Baghdad, and the physical characteristics of aggregate are illustrated in Table 1. Other materials used as filler include ordinary Portland cement (OPC), which is generally inserted into the cold blends to give better connectivity and enhance the mechanical properties over time. The properties of ordinary Portland cement are thus presented in Table 2.

Table 1. Physical characteristic of new aggregates

| Property                                      | ASTM Designation | Test results | SCRB specifications |
|-----------------------------------------------|------------------|--------------|---------------------|
| **Coarse aggregate**                         |                  |              |                     |
| • Bulk specific gravity                      | C 127            | 2.616        | ....                |
| • Apparent specific gravity                  | C 127            | 2.675        | ....                |
| • Percent wear by Los Angeles abrasion, %    | C131             | 21.28        | 30 Max.            |
| • Soundness loss by sodium sulfate solution,%| C88              | 3.41         | 12 Max.            |
| • Degree of crushing, %                      |                  | 98           | 90 Min.            |
| **Fine aggregate**                           |                  |              |                     |
| • Bulk specific gravity                      | C127             | 2.660        | ....                |
| • Apparent specific gravity                  | C127             | 2.695        | ....                |
| • Sand equivalent, %                         | D2419            | 56           | 45 Min.            |
The tests for these properties were undertaken in the National Centre for Construction laboratories in Baghdad.

2.2 *Recycled asphalt pavement (RAP)*

The materials under investigation were cold-milled ancient road pavement (also known as recycled asphalt pavement or RAP) from asphalt runway pavement at Al-Najaf airport, as illustrated in figure 1. The asphalt amount in the RAP was 3.97% based on centrifuge extractor tests per ASTM D 2172[6]. The full results for extracted asphalt cement are shown in table 3. The specific surface area of RAP is much smaller than that of aggregate, which affects the bonding between RAP and the new binder. With sufficient crushing of RAP, the addition of new aggregates, and fine gradation design can increase the tensile strength of cold recycled asphalt mixtures by reducing the agglomeration of RAP and improving the bonding between RAP and the binder [8].

**Table 2. Ordinary Portland cement (OPC) properties**

| Physical Properties      |       |
|--------------------------|-------|
| Specific surface area [m²/kg] | 419   |
| Density [g/cm³]          | 3.13  |
| Passing sieve No. 200    | 95%   |

| Chemical testing (XRF)     |       |
|---------------------------|-------|
| SiO₂                      | 21.51 |
| Al₂O₃                     | 5.62  |
| Fe₂O₃                     | 3.30  |
| CaO                       | 62.51 |
| MgO                       | 3.75  |
| SO₃                       | 1.61  |
| Loss of Ignition          | 1.31  |
| **Total**                 | 99.61 |

The tests for these properties were undertaken in the National Centre for Construction laboratories in Baghdad.

**Figure 1. Recycle asphalt pavement (RAP)**
2.3 Asphalt Emulsion

The emulsified asphalt is classified as cationic slow setting of low viscosity (CSS-1), making it very suitable for aggregate graduation according to Iraqi specifications [1]. The emulsion grade as a whole is thus cationic slow setting [3], which is more general than other types [10]. The test results illustrate that the emulsified asphalt including asphalt residue is rated at about 61%, and this value is within the range adopted by the manufacturing company Richmond in EAU. The physical properties of the emulsion are illustrated in table 4.

### Table 3. Extracted asphalt cement results

| Property                                   | ASTM Designation | Test Results |
|--------------------------------------------|------------------|--------------|
| Penetration at 25 °C, (0.10mm)             | D5               | 28           |
| Ductility at 25 °C, (cm)                   | D113             | 53           |
| Specific gravity at 25 °C                  | D70              | 1.03         |
| Softening point -ring and ball, [9]        | D136             | 64.7         |

These tests were carried out at the National Centre for Construction laboratories in Baghdad.
3. Recycled cold mixtures
Until recently, cold blend has been considered to be a worse option than other mixtures such as hot asphalt mix due to certain weaknesses: (a) the air-void content of the compacted blend can be high; (b) it can demonstrate weak early life strength due to trapped water; and (c) the curing period is long due to the need for evaporation of water/volatile content and setting of the emulsion to obtain the desired maximum performance [11]. In this research, the recycled cold mix has been designed to meet the grading of SCRB specifications for surface courses [1]. The RAP material and fresh aggregate gradation are illustrated in table 5 and figure 2.

Table 5. RAP and new aggregate gradation with SCRB specification

| Sieve [12] | Specification for surfacing course | Selected gradation | RAP gradation | 90% RAP Aggregate | 10% new aggregate and filler |
|------------|-----------------------------------|--------------------|---------------|-------------------|-----------------------------|
| 19         | 100.0                             | 100.0              | 100.0         | 90.0              | 10.0                        |
| 12.5       | 90.0                              | 95.0               | 95.2          | 85.7              | 9.3                         |
| 9.5        | 76.0                              | 82.0               | 81.2          | 73.1              | 8.9                         |
| 4.75       | 44.0                              | 50.0               | 45.6          | 41.0              | 9.0                         |
| 2.36       | 28.0                              | 32.0               | 25.7          | 23.1              | 8.9                         |
| 0.3        | 5.0                               | 12.0               | 3.9           | 3.5               | 8.5                         |
| 0.075      | 4.0                               | 7.0                | 1.3           | 1.2               | 5.8                         |

Figure 2. Percentages of RAP and new aggregate to meet SCRB specifications.
The initial residual asphalt amount (P) was estimated using the following equation [13]:

\[ P = (0.05 \ A + 0.1 \ B + 0.5 \ C) \times 0.70 \] \hfill (1)

Where:
- \( P \) = Percent (%) by weight of initial residual asphalt content by mass of total mixture;
- \( A \) = percent (%) of mineral aggregate retained on sieve 2.36 mm;
- \( B \) = percent (%) of mineral aggregate passing sieve 2.36 and retained on sieve 0.075 mm;
- \( C \) = percent (%) of mineral aggregate passing sieve 0.075 mm.

After this, equation (2) was applied to take into consideration the percentage of asphalt in the RAP [5]:

\[ P_{nb} = P_b \times \frac{(100 - r)P_{sb}}{100} \] \hfill (2)

where
- \( r \) is the percentage of new aggregate to be added to the recycled cold mix, and
- \( P_{sb} \) is the amount of asphalt in the RAP.

The content of initial emulsion (IEC) was defined as below:

\[ IEC = \left( \frac{P_{nb}}{X} \right) \times 100\% \] \hfill (3)

where
- \( X \) is the percentage of asphalt in the emulsion (0.61% in the emulsion used in the research).

To determine the optimum pre-wetting water quantity required for a good coating (OPWwc), information was sought from the Asphalt Institute [5]. The quality of coating of emulsion on the aggregate depends on percent of fine materials in the blend. MS-14 was used to estimate various percentages of pre-mix water and estimated emulsion quantities to determine the lowest pre-mix water amount that would ensure the best coating percentage, beginning with 1.5, 2, 2.5, and 3 wt.% of aggregate. Thanaya [14] illustrated that inadequate pre-wetting water content result in billing of the binder with the finest portion of the aggregate. When optimising the residual bitumen amount, many tests were conducted on various residual bitumen percentages using the OPWwc constant. The compacted samples were subjected to the curing system, before tests such as volumetric properties and Marshall Stability were conducted, and the ORBC refined accordingly.
The final blends were created by proportioning the RAP and fresh aggregates to obtain the chosen aggregate grading specification; the aggregates were then dry blended and pre-wetted with water before being evenly mixed. Subsequently, the preferred asphalt emulsion was added and mixed further for up to five minutes, until the emulsion equally coated the aggregates at room temperature. The loose blend was then checked: if the blend was too wet, air drying was indicated until the mixture was sufficiently loose, neither too dry nor too wet; each mix was then compacted in a Marshall mould. Subsequently, the samples were compacted with 75 blows on each face. After this compaction step, the specimen remained in the mould for one day at ambient temperature, and was then taken out [15] to cure at 40 °C. As this work depended on maximum density, maximum stability was tested at 25 °C according to ASTM specifications. In this research, the IEC as calculated from equation (1) was adopted as 5.0% approximately, with step variations of 1% or 0.5% including 7.5, 7, 6.5, 6 wt.% of aggregate, used to determine the optimum residual bitumen content based on volumetric properties and Marshal tests. The optimum pre-wetting water in this research was thus found to be 3.0 % by weight of aggregate and the optimum residual bitumen content was 6.0% by weight of aggregate, with 90% RAP as shown in figure1.

![Figure 3. Optimised residual bitumen content](image)

4. Indirect Tensile Strength Test

An indirect tensile strength (ITS) test was applied to find the tensile characteristics of the asphalt concrete, which further depend on the cracking characteristics of the pavement [16]. The Indirect Tensile Strength (ITS) test can also help identify the strength property of the CAEMs, according to ASTM D 6931[7]. The test involved adding compressive loads to the Marshall sample in the middle of two loading strips, which created tensile stresses along the vertical diametric plane, causing splitting failure. A major development during the curing step is the evaporation of water from the CAEMs, and thus water loss in the CAEMs was monitored by means of successive weight measurements at 1, 7, 14, and 28 days. These results are illustrated in figure 4; they show that advancement in the mechanical and performance characteristics of the CAEMs is achieved only after significant evaporation/loss of moisture from the mixture. The results also illustrate the role of cement and its usefulness in positively developing the mechanical and performance properties of CAEMs, especially in the early stages.
5. Moisture Damage Tests

The moisture damage test estimates the influence of saturation and running moisture on compacted CAEMs specimens by using freeze-thaw cycles as per AASHTO T283. The tensile strength ratio (TSR) was determined as the ratio of the indirect tensile strength of conditioned group to the unconditioned group. The indirect tensile strength was calculated as

\[
\text{ITS} = \left( \frac{2000 \ast (\pi \ast t \ast D)}{P} \right) \quad \text{.................................(4)}
\]

Where:

- \(\text{ITS} = \) indirect tensile strength in (kPa),
- \(P = \) maximum load in (N),
- \(t = \) specimen thickness (mm),
- \(D = \) specimen diameter (mm).

Such that:

\[
\text{TSR} = \frac{\text{ITS of conditioned Subset}}{\text{ITS of Unconditioned Subset}} \quad \text{.................................(5)}
\]

The study thus investigated the influence of water saturation and accelerated water conditioning on the CAEMs, as shown in figure 5.
The results show that an increase in the percent of RAP increased TSR. This could be a reason for the function of water in the hydration of Portland cement. Hydration is a continuous operation, and when cured with soaked case, Portland cement has access to all water required for complete hydration, thus acquiring more strength.

6. Wheel Track Tests
A wheel track (WT) test was performed using a wheel-tracking device for the assessment of pavement performance at high temperatures. Samples were blended with the selected asphalt amounts, and the rolling machine was applied. Permanent deformation was calculated by means of rut depth using the wheel tracking device using BS EN 12697-22: 2003 as a guide. Loading and environmental conditions were similar to those found in the field. The sample was a slab with dimensions 400 x 300 mm, with thickness of 50 mm containing the optimum binder amount, and the load was subjected to a steel wheel with frequent movement along the length of the sample. A total load of 700 N was applied at a rate of 26 passes per minute; the total rut depth was registered at the end of the test. Three specimens were tested for all RAP mixtures [17]. The Wheel Track Apparatus (WTA) is illustrated in Figure 4, and the WT test was performed at 40 °C and 60 °C to assess the rutting performance of samples depending on AASHTO Standard T-324 (AASHTO, 2011). Figures 7 and 8 show the effects of curing time on rut depth; an increase in curing time decreases rut depth in mm.
Figure 6. Results of wheel track test after curing to 14 days

Figure 7. Results of wheel track test after curing to 28 days

7. Conclusion
Examining the results and analysis, it can be concluded that
1. Reclaiming cold asphalt mixes with a high percentage (90%) of RAP offers a good match with SCRIB specifications.
2. The strength of the mixture increases with increased curing time and the percentage of RAP required depend on evaporating the water from the mixture, using a percentage of asphalt in the RAP, and using cement as a filler to decrease moisture damage.

3. The results of indirect tensile strength tests illustrate that the addition of Portland cement to a cold asphalt mixture with increased RAP percentage improves the tensile strength and reduces the void content of such recycled mixtures.

4. The wheel track test showed an improvement in permanent deformation in surface course mixes even under heavy loads and high temperatures due to the mixture's increased stiffness thanks to the addition of RAP.

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