Evaluate Resistance of Warm Asphalt Mixtures to Rutting

Noor M Asmael¹, Mohammed Y. Fattah² and Abdalmhiman J. Kadhim³
¹Asst. Prof, Highway and Transportation Department, College of Engineering, Mustansiriya University, Baghdad, Iraq. Email: noor_moutaz@uomustansiriyah.edu.iq
²Professor, Civil Engineering Department, University of Technology, Baghdad, Iraq. Email: myf_1968@yahoo.com
³Graduate student, Highway and Transportation Department, College of Engineering, Mustansiriya University, Baghdad, Iraq. Email: abdulmohaimen11@gmail.com

Abstract. WMA is a new technology, which is based on reduced temperature for mixing, and compaction of asphalt mixture, like any pavement material, testing the compatibility of this technology with domestically obtainable material is essential. The objective of the current research is to assist Iraqi establishments in addressing the issues related to resistance to rutting when adopting this technology. An intensive study on the performance of WMA mixtures with local materials was carried out. Job mix formulas with 12.5 mm and 25 mm aggregate size were chosen for HMA and WMA. One WMA technology was used which is an organic additive; two additives were used Asphaltan A® and Asphaltan B®. All the mixture types are testes and compared with each other. The rutting sensitivity of the mixtures is evaluated using Wheel Track test. From the results, for surface mixtures, rut depth is directly proportional to WMA additive content. For base mixtures, more Asphaltan A® leads to more rut depth, but more Asphaltan B® leads to less rut depth. Permanent deformation results of all mixtures, WMA and HMA mixtures are within the acceptable criteria.

1. Introduction
Warm Mix Asphalt (WMA) is a new technology that has potential in reducing the energy consuming for pavement constructions, resulting in economic terms for the pavement industry during the time of escalating fuel costs. Lesser fuel gives lower harmful emissions throughout construction. Lower temperature construction could gift opportunities for extending the distance of transporting materials, furthermore as facilitate prolonging the construction period in the colder weather of the year [1].

Initial reports of WMA were presented in 1999-2001 in Europe, and the first field trials were conducted in 2004 in USA [2]. Although the use of WMA technologies is very appealing in terms of its contributions to green construction, the probability of performance under long-term traffic loading is questionable. There is a pressing demand to evaluate mixtures using widespread WMA technologies due to the many benefits it presented. As with any construction material, testing the compatibility of this technology with locally available material is essential. Rutting represents one of the major distresses occurred in pavement in Iraq due to high in-service temperature. To help Iraqi institutions address the various concerns associated with the use of WMA in the pavement construction, the resistance of WMA mixtures to rutting were investigated.

Similar or better performance of WMA than that of HMA should be ensured to avoid future problems during pavement life. It is vital to deal with the major problems of WMA mixtures before to decide to adopt and application this technology in the field. Organic additive technology was studied in this research. The production of WMA with different dosages of organic additives was produced to know if it has an equal performance to HMA mixture or not. This goal is adapted to achieve the
principle of Sustainability. The results of such study will provide a performance data required to design asphalt concrete pavements’ utilization of WMA and help Iraqi engineers to use these technologies with additional confidence.

2. Background
Due to the widespread green technology, in order to save the current resources, and to reduce the environmental effects produced from asphalt industry, WMA technology presented and adopted in many countries. This technology reduces the mixing and compaction temperature in the production of asphalt mixture. The performance of the new technology must be examined and compared to the traditional mixture. The suitability of warm mixture is a concern in hot regions. Literature state that warm mixtures exhibits less rutting resistance due to less aging during construction. Rashwan [3] investigated warm mixtures with three technologies (Advera, Evotherm J1, and Sasobit), and state that lower rutting resistance of WMA when compared to HMA. Bower, N. et al.[4] Investigate various WMA technologies and state that the rutting is the only adverse effect on the performance. Jun Zhang [5] evaluates the feasibility use of WMA technology in produce Nebraska pavements. Zeolite, Sasobit, and evotherm were selected to produce these warm mixtures, according to the results, warm mixtures produced better results in rutting resistance, and Sasobit represent the best in decrease rutting. Thomas Bennert [6] states that warm and traditional mixture behaves the same in rutting resistance. Thomas Martin Clements [7] state that WMA does not perform well as the performance of HMA in rutting test, which performed at 64 C. Jie JI et al. [8] said that the four constituent of binder altered when the warm additives introduced into the binder, so the asphaltene increased, and the colloid decreased which will enhance the rutting resistance. Rani, Shivani [9] tested different warm mixtures with the addition of Polyphosphoric Acid using a Hamburg Wheel Tracking (HWT) device; the test results show lower rutting potential values. S. N. Naqibah et al. [10] evaluate different mixtures with two types of warm additives (Evotherm (ET) and Evoflex (EF)), the results appeared that the addition of 0.4 % ET and 0.3 % EF would reduce the rutting. KL Roja et al. [11] tested two types of warm mixtures, one with chemical additives and the other with wax additives. The results revealed that warm mixtures with wax additives have better resistance to rutting than warm mixtures with chemical additives at temperature between 40-50 C. YirenSun [12] investigated the performance of asphalt binder modified by RAP and two warm additives (wax and chemical additives). The results approved that both RAP and warm additives were enhancing the rutting resistance. Mahdi Rezapour [13] evaluated warm mix asphalt overlay with Evotherm 3G in Valley City project. This overlay was aged for three years, the city experiences a drop in temperature to -34 C, the samples were tested by Asphalt Pavement Analyzer, and the results indicate that aged samples are more rutting than unaged samples.

3. Materials
The local materials prepared to production the warm mixtures, these materials are locally available and used in the construction of many roads in Iraq. Details of the materials used in the research study, the aggregates, virgin binder, and additives, along with their properties are provided. The selected materials are very widely used in asphalt pavements in Iraq. The requirements satisfied with the SCRB/R9 specification (2003) [14], were considered to be followed. The materials used were being presented as follows.
3.1 Asphalt Cement

One type of asphalt cement was used to prepare warm mixtures; its properties were shown in Table 1. Asphalt cement with (40-50) penetration was produced by Al-Durah refinery.

Table 1. Bitumen physical properties.

| Test                              | Standard                  | Result | Unit   |
|----------------------------------|---------------------------|--------|--------|
| Penetration (25°C)               | ASTM D5/D5M − 13         | 41     | dmm    |
| Ductility (25°C)                 | ASTM D113 − 07           | >100   | cm     |
| Specific gravity (15.6°C)        | ASTM D70 − 09            | 1.04   |        |
| Flash Point                      | ASTM D22 - 72            | 326    | °C     |
| Softening Point                  | ASTM D36/D36M − 14       | 51.5   | °C     |
| percent of weight soluble in C2HCL3 | ASTM D2042 − 15        | 0.999  | (%)    |

3.2 Aggregates

Coarse and fine aggregates were obtained from Al-Nibaae quarry located in the north of Baghdad. The two selected gradation of aggregate is according to Iraqi Standard Specifications for Roads and Bridges [14] and was in the light of the gradation recommendation of Superpave for the base and surface layer as shown in Table 3 and Figure 1. The physical properties of aggregates used in this study were listed in Table 2.

Table 2. Aggregate physical properties.

| Test                              | Aggregate Type |
|----------------------------------|----------------|
|                                  | Coarse         |
| Specific Gravity                 | 2.62           |
| Water Absorption                 | 0.56%          |
| Los Angeles Abrasion Test        | 16.7%          |
| Clay Content NMAS 25 mm          | 0.01%          |
| Clay Content NMAS 19 mm          | 0.19%          |
|                                  | Fine           |
|                                   | 2.618          |
|                                   | 0.64%          |

Table 3. Aggregate gradation.

| Sieve opening mm | Specifications | Base Layer | Surface Layer |
|------------------|---------------|------------|---------------|
|                  | Lower | Upper | Restricted zone | Lower | Upper | Selected zone |
| 37.5             | 90    | 100   | 83             | 72    | 100   | 95           |
| 25               | 76    | 90    | 33             | 24    | 58    | 58           |
| 19               | 56    | 80    | 44             | 33    | 44    | 33           |
| 12.5             | 48    | 74    | 24             | 24    | 28    | 24           |
| 9.5              | 29    | 59    | 39.5           | 33    | 44    | 33           |
| 4.75             | 19    | 45    | 26.8           | 24    | 28    | 24           |
| 2.36             | 18.1  | 24.1  | 25.6           | 25.6  | 31.6  | 31.6         |
| 1.18             | 13.6  | 17.6  | 19.1           | 19.1  | 23.1  | 23.1         |
| 0.6              | 5     | 17    | 11.4           | 8     | 5     | 21           |
| 0.3              | 2     | 8     | 5              | 5     | 4     | 10           |
| 0.075            | 2     | 8     | 5              | 5     | 4     | 10           |
3.3 Mineral filler

Dust of crushed stones of coarse aggregates is used as mineral filler. Mineral filler is dried in overall and clean from deleterious materials or aggregations of particles. Table 4 lists more physical information about mineral filler.

| Table 4. Physical properties of mineral filler. |
|-----------------------------------------------|
| Test                | Specific Gravity | Sand Equivalent | Plasticity Index |
| Result             | 2.72             | 76%              | 2.9%              |

3.4 Warm Mix Additives

One technology of the WMA technologies were studied in this research. The organic additives: Asphaltan A® and Asphaltan B®, manufactured by Romanta Company are used. The two additives were incorporated at three dosages: 1, 2 and 3% by weight of binder. Plate 1 shows the two-additives. The physical properties of the additives were presented in Table 5. The point at which the melting happens is 80 °C to 95 °C [15].

| Table 5. Warm Additive physical properties |
|-------------------------------------------|
| Organic additive | Ignition temperature, °C | Flashpoint, °C | Solidification point, °C | Viscosity mPa.s |
|------------------|--------------------------|----------------|--------------------------|----------------|
| Asphaltan A      | > 300                    | > 200          | 133 - 143                | 5-15 at 150 °C |
| Asphaltan B      | > 300                    | > 250          | 95 - 105                 | 20-200 at 120 °C |
4. Preparation of Warm Mix Asphalt Mixtures

As per SCR&B specifications[14], both HMA and WMA were designed as Asphalt Concrete Surface Course type IIIA and Base Course. For mixing Asphaltan A® and Asphaltan B® with binder, Romonta Company suppliers reported temperatures for plant mixing should be as low as 120 °C. Based on the available literature, WMA mixing and compacting temperatures of 120 °C and 110 °C were selected in this study. Marshall method for mix design is performed, by Iraqi standards, to determine the optimum content of asphalt binder. The Marshall method performs many processes to find the plastic flow resistance of cylindrical specimens of asphalt mixtures loaded on the horizontal surface with the help of Marshall apparatus by AASHTO Designation R 48-15[16]. The Marshall method comprises the process of preparation of cylindrical bituminous specimens that are 10.16 cm in diameter and 6.35 cm in height with different contents of asphalt binder (4, 4.5, 5, 5.5 and 6%) for surface layer and (3.5, 4, 4.5, 5 and 5.5 %) for the base layer. Three prepared specimens for each content are produced, and the average results are recorded. Stability and flow tests are conducted for all the prepared specimens. All the cylindrical shaped specimens are placed in bath water preheated at 60 °C for half-hour, then applied to constant loads on the lateral surface at a rate of 50.8 mm/min until the failure point. Loads and deformations are recorded to determine the values of stability and flow. The optimum binder content for all mixtures is shown in Table 6, Addahhan et al. 2019[17].

| Mixture ID | Mix Description | O.B.C |
|------------|----------------|-------|
| BC         | Control mix 1   | 4.65  |
| BA1        | Mix 1 with 1% of Asphaltan A | 4.70 |
| BA2        | Mix 1 with 2% of Asphaltan A | 4.80 |
| BA3        | Mix 1 with 3% of Asphaltan A | 4.93 |
| BB1        | Mix 1 with 1% of Asphaltan B | 4.98 |
| BB2        | Mix 1 with 2% of Asphaltan B | 5.10 |
| BB3        | Mix 1 with 3% of Asphaltan B | 4.93 |
| SC         | Control mix 2   | 5.15  |
| SA1        | Mix 2 with 1% of Asphaltan A | 5.35 |
| SA2        | Mix 2 with 2% of Asphaltan A | 5.45 |
| SA3        | Mix 2 with 3% of Asphaltan A | 5.60 |
| SB1        | Mix 2 with 1% of Asphaltan B | 5.70 |
| SB2        | Mix 2 with 2% of Asphaltan B | 5.43 |
| SB3        | Mix 2 with 3% of Asphaltan B | 5.28 |
5. Preparation Slab Specimens for Rutting Test

Materials to be used for permanent deformation tests are prepared and compacted in slab-shaped specimens by standard EN 12697-33. Rectangular mold is used to produce slab specimens with the required dimensions; laboratory process is conducted to compact the bituminous mixture utilizing controlled-load application with the sliding plate method until a specified volume and therefore void content is obtained. The dimensions of the slab specimen after compaction process are the length, \( l = 400 \text{ mm} \), width, \( w = 300 \text{ mm} \) thickness, \( t = 80 \text{ mm} \) for base layer, and \( 50 \text{ mm} \) for surface layer. The following equation below is used to find the required mass of bituminous mixture to produce the shaped slab specimens:

\[
M = 10^{-6} \times l \times w \times t \times \rho_m \times \left( \frac{100 - v}{100} \right)
\]

Where:

- \( M \) represents slab weight, kg;
- \( l \) represents slab length, mm;
- \( w \) represents slab width, mm;
- \( t \) represents slab thickness, mm;
- \( \rho_m \) represents G\text{mm} of bituminous mixture, kg/m\(^3\);
- \( v \) required VTM in slab, %.

The bituminous mixture is prepared according to ASTM D6926-16\[18\] with specified mixing temperature (120 °C for WMA mixtures and 163 °C for HMA mixtures) and the optimum content of asphalt. The mold is preheated together with the sliding plates to the specified compaction temperature (110 °C for WMA mixtures and 153 °C for HMA mixtures) for more two hours and, then, lightly sprayed with base plate with a non-adhesive product with bituminous binder and filled with the required mass which is spread by a spatula with avoidance any degradation. Before applying the loads for compaction, the specimen surface is adjusted properly. The sliding plate is placed on top of specimen surface in a way to touch the top surface of the mixture. The moving table into motion, the roller pushes down onto the steel plates, and the constant load is applied and kept ± 20 % during the compaction process until the required volume is achieved. The slab is left to be cooled to reach the room temperature before extracting the mold when compaction is completed.
6. Wheel Tracking Test

This test is performed to describe the rutting sensitivity of bituminous mixture samples in the wheel-tracking apparatus by measuring the rate of permanent deformation from moving loads according to BS EN 12697-22. The Wheel-track setup consists of a loaded wheel that sets on a specimen securely-held on a specified table. Either the table is moving below the loaded wheel, or the wheel is moving above the table, and a provided device record rutting develops at the surface of the test specimen in millimeters at each cycle. The apparatus includes a treadless tire of between 20 and 20.5 cm outside diameter was fitted to a wheel and has a rectangular cross profile to a depth of 5 ± 0.5 cm employing load applied to the tire. The load is equal to 700 ± 10 N under standard test condition, and LVDT monitors the vertical position of the loaded wheel to ± 0.2 mm with a range of more or equal than 2 cm. There is a table that constructed to help to hold a rectangular laboratory-prepared test specimen securely in place with its horizontal surface and in the tracking plane that required and with centering the position to ensure symmetrical tracking movement. The wheel-track apparatus is designed in a way to help the loaded wheel to be moved smoothly back and forth on the settled specimen. Tire-track centerline was less than 0.5 cm from the theoretic center of the settled specimen. The moving tire travels with a total distance of 23 cm and a frequent movement of 26.5 load cycles per minute for the test device. The nominal thickness of the specimens is chosen to be 5 cm for surface layer and 8 cm for the base layer, the thickness that mostly being laid in Iraqi roads. Surface layer specimens are conditioned at 50 ± 1 °C for a period before testing of 4 hours, and that of base layer for 6 hours.

7. Results and Discussion

Permanent deformation is significant distress occurred in the pavement at high temperature. WMA and HMA mixes are tested with the wheel track device to make a comparison between the control and warm mixes. The test was conducted at 50 °C temperature according to BS EN 13108-20-2016. The wheel travels a total distance of (230 ± 10) mm and a frequency of (26.5 ± 1) load cycles per 60 sec. Rut depth measurements are recorded during the test and are shown in figures: 2 to 7. From the results of surface layer, it appears that all warm mixtures have permanent deformation higher than HMA, except the mixture with 1% Asphaltan A® which reduces the rut depth by 4% than HMA, mixture with 1% Asphaltan B® which reduces the rut depth by 3.8% than HMA, and mixture with 2% Asphaltan B® which has an approximately equal rut depth to the control mix.

From the results of the base course, it appears that all warm mixtures have lower values of the rut depth in comparison to HMA except mixture with 3% Asphaltan A®. It can be shown that the warm mixture with 3% Asphaltan B® has a higher reduction percentage in rut depth equal to 12.5%, while other mixtures reduce the percent of the rut depth as follows (A1=9.3%, A2 =1.9%, B1=3.4%, B2=4.6%).

![Figure 2. Rut depth versus load cycle for the surface layer](image-url)
Figure 3. Rut depth versus load cycle base layer

Figure 4. Permanent strain versus load cycle for the surface layer

Figure 5. Permanent strain versus load cycle for the base layer
8. Conclusions

The rutting sensitivity of the warm mixtures is evaluated using Wheel Track test. Permanent deformation results of all mixtures, WMA, and HMA mixtures are within the acceptable criteria. Rut depth values for Wheel Track test have a good indication of performance for WMA mixtures compared with HMA. For surface mixtures, rut depth is directly proportional to WMA additive content. For base mixtures, more Asphaltan A® leads to more rut depth, but more Asphaltan B® leads to less rut depth. Asphaltan B® expressed better permanent deformation resistance than Asphaltan A® for all mixtures. 3% of Asphaltan B® results less rutting resistance in comparing with HMA for the base layer. 1% of Asphaltan A® or Asphaltan B® will be enough to improve rutting resistance for
surface mixtures. 1% of Asphaltan A® or 3% of Asphaltan B® will be enough to improve rutting resistance for base mixtures.

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