Evaluation of Warm Mix Asphalt Performance Involving Synthetic Zeolite

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Abstract: Warm mix asphalt (WMA) blends at temperatures lower than those in conventional mixtures by 20-50 °C. Many additional advantages, such as a reduced susceptibility to permanent deformation, have exhibited when synthetic zeolites were used as a warm mix asphalt additive. In this research, the best gradation of aggregate was selected, and optimum asphalt content was determined for asphalt concrete layer (surface course) according to Superpave design system. All mixtures were evaluated with some tests which include Marshall characteristics, moisture damage of asphalt mixtures, Immersion–Compression, double punch shear and wheel tracking test. To compact asphalt mixtures with (100 and 150) mm in diameter, Superpave Gyratory Compactor (SGC) was used. Five different percentages (3, 4, 5, 6 and 7) of synthetic zeolite were used for preparation of warm mixes to compare with hot mixture for the effect of different percentage of synthetic zeolite on performance asphalt mixture in terms of water sensitivity. The experimental work’s results indicated that the mixture properties were affected by selected percentages of synthetic zeolite to the warm asphalt differently. The WMA mixture with 5 % of synthetic zeolite decreased the rut depths of the mixtures with increase in the punching strength of the mixtures and slight increase in the tensile strength ratio (TSR), compressive strength and index of retained strength (IRS).

Keywords:
Synthetic zeolite, tensile strength ratio (TSR), rut depth, warm mix asphalt (WMA), compressive strength and Superpave

1. Introduction
In recent years, a new technology has appeared that allows asphalt to flow to production and compaction at lower temperature than conventional hot mix asphalt (HMA), it is called warm mix asphalt (WMA). This technology can provide a better working environment, reductions in energy consumption, asphalt oxidation and carbon dioxide emission, increases the hauling distance and paving season [1]. Various researches have been focused on the effect of temperature during blending, placing and compaction processes with the development of a new paving technology known as warm mix asphalt (WMA) [2].
Moisture susceptibility is also an important performance concern for WMA like traditional HMA. It has been thought that, because the aggregate in WMA was not heated to the same temperatures as HMA, the aggregate may not be completely dried before mixing [3].

The production of WMA utilizing the synthetic zeolite additive, which is sodium aluminum silicate with crystallization mass by 21 percent of water, causes a higher workability of the mix when the temperature rises above 100°C due to the decrease in binder viscosity and creates a foaming effect [1]. The most common dosage of synthetic zeolite is 0.3 percent by weight of total mix, added to the mix at the same time as the binder or shortly before [4].

Laboratory study was conducted for the assessment of the potential of moisture damage, the dynamic modulus as well as rutting properties using two types of additives (Sasobit and Aspha-min) for WMA mixtures, then the obtained results were compared with the traditional HMA, it was found that none of these mixtures satisfied the TSR value of 80 percent (minimum requirement), the highest values of TSR and conditioned indirect tensile strength were with the Sasobit [5].

Three types of additives were utilized to produce warm mix asphalt; these additives were Advera (Synthetic zeolite), Sasobit and Evotherm. The performance was compared with the HMA with the same additives. Several laboratory tests were accomplished to assess the moisture susceptibility, dynamic modulus and potential rutting. It was established that all the mixtures had the similar values of the moisture damage and dynamic modulus as compared to HMA, all the WMA mixtures values were below 80 percent. While the better rut resistance was found in the WMA with Sasobit in comparison with the two other types of additives and HMA [6].

The warm mix asphalt mixtures perform by using two additives type, which are (Aspha-min® and Sasobit®). The WMA mixing temperatures ranged from 125-135 °C as well as the compaction temperatures ranged from 120-125 °C. They exhibited that the obtained results of WMA were lower in the indirect tensile strength, resilient modulus and fatigue resistant and higher rut depth as compared to the HMA; also they decided that the Sasobit utilized in the WMA mixtures has better performance than the Aspha-min [7].

The existing literature shows the environmental and economic reasons for utilizing the WMA technologies, as well as obvious differences in the performance of mixtures versus the moisture damage, fatigue and rutting, these differences could be referring to the implemented technology to produce WMA and the temperatures of mixing and compaction [8].

2. Aim of the study
In light of the above, various properties of warm asphalt mixture affect the performance of the warm mix asphalt for example the moisture susceptibility of the mixtures. Since WMA is a relatively new topic in Iraq, in order to be able to implement WMA safely, a comprehensive study of the properties and performance of the warm mixture technologies is necessary. The aim of this study is to evaluate the influence of selected Synthetic Zeolite additive on mechanical properties of warm mix asphalt.

3. Experimental Work
3.1. Materials
In the experimental work, asphalt binder of 40/50 penetration grade from Daurah refinery in Baghdad, Iraq was used, with the physical properties as shown in Table1. The aggregate used in this work was crushed quartz supplied from Al-Nibaie quarry. Also, the aggregate gradation of, as shown in Table 2, 12.5 mm was used as a nominal maximum aggregate size. Test results illustrate that the coarse and
fine aggregates met the SCRB specifications. Table 3 summarizes the results related with the SCRB specification limits.

The filler used in the experimental work is limestone dust which is supplied from lime factory in Karbala province, south west of Baghdad. Table 4 exhibits the physical as well as the chemical properties of the filler. Synthetic Zeolite used in this work as WMA additive is a hydrothermally crystallized white fine powder of sodium–aluminum–silicate crystal. “It contains 21% water by weight into the warm mix which causes the release of all the crystalline water forming a very fine water spray and a volumetric expansion of bitumen. This volume expansion will increase the workability and the compatibility of the mixture at lower temperatures” [3]. The additive percentages used in this study range from 3 - 7% by weight of the binder increasing by 1. The physical properties as well as chemical composition of the Synthetic Zeolite were prepared by the manufacturer as illustrated in Table 5.

### Table 1. The result of physical properties and standard limitation

| Test               | Test Conditions                  | ASTM Standards | Test value (measured) | Standard Limit according to SCRB/ R9, 2003 |
|--------------------|---------------------------------|----------------|-----------------------|------------------------------------------|
| Penetration        | 100 gm, 25°C, 5 sec., (0.1mm)   | ASTM D5        | 47                    | 40-50                                    |
| Ductility          | 25°C, 5cm/min                   | ASTM D113      | +120                  | +100                                     |
| Softening Point    | ASTMD36                         | 53.5           |                       |                                          |
| Specific gravity   | 25°C                            | ASTM D70       | 1.031                 |                                          |
| Flash and fire     | ASTMD92                         | Flash 291°C    | > 232 °C              |                                          |
| points             | Fire 305°C                      | Fire 305°C     |                       |                                          |
| Loss on heating    | 163 °C, 50gm, 5 hr              | ASTM D1754     | Penetration 65        | >55                                      |
|                    |                                 | Ductility 55   |                       | >25                                      |
| Rotational Viscosity| ---                             | ASTM D4402     | 0.369 @ 135°C         |                                          |
|                    |                                 |                | 0.112 @ 165°C         |                                          |

#### 3.2. Sample preparation

The production of the WMA mixtures was done by dry process; WMA additive was heated and added to the asphalt then mixed by mechanical mixer for 30 minutes at 150 °C to get required properties for mixing at compaction temperatures. The aggregate was heated and then mixed with asphalt in mixing bowl for several minutes until the surface of the aggregates was sufficiently coated by asphalt. The mixing temperatures correspond to the asphalt binder. There are no standard specifications for WMA production and compaction temperatures available in Iraq. All examined asphalt mixtures (warm and hot) were prepared in accordance to the (ASTM Designation: D 6925-03) with the standard 160 number of gyrations using superpave gyratory compactor.
Table 2. Gradation of the aggregates.

| Sieve size | Superpave Specification, 2007 | Iraqi Specification (SCRB R9, 2003) surface layer type IIIA | % Passing |
|------------|-----------------------------|-------------------------------------------------|----------|
|            | Min | Max | Min | Max |                      |        |
| 19 mm      | --  | 100 | --  | 100 |                      | 100    |
| 12.5 mm    | 90  | 100 | 90  | 100 |                      | 97     |
| 9.5 mm     | 90  | --- | 76  | 90  |                      | 86     |
| 4.75 mm    | --- | --- | 44  | 74  |                      | 60     |
| 2.36 mm    | <39.1 | >39.1 | 25 | 58 |                      | 36     |
| 1.18 mm    | 25.6 | 31.6 | --- | --- |                      | 25     |
| 0.6 mm     | 19.1 | 23.1 | --- | --- |                      | 19     |
| 0.3 mm     | <15.5 | >15.5 | 5  | 21 |                      | 14     |
| 0.15 mm    | --- | --- | --- | --- |                      | 10     |
| 0.075 mm   | 2  | 10  | 4  | 10 |                      | 6      |

Table 3. The aggregates physical properties

| Property                                      | ASTM Designation | Test results | SCRB specifications |
|-----------------------------------------------|-----------------|--------------|---------------------|
| Bulk specific gravity (Coarse agg.)           | C-127           | 2.580        | ....                |
| Apparent specific gravity                    |                 | 2.591        | ....                |
| Bulk specific gravity (Fine agg.)             | C-128           | 2.616        | ....                |
| Apparent specific gravity                    |                 | 2.642        | ....                |
| Percent wear by Los Angeles abrasion, %       | C-131           | 21.3         | 30 Maximum         |
| Soundness loss by sodium sulfate solution,%   | C-88            | 3.2%         | 12 Maximum         |
| Flat and elongated particles ,%               | C-4791          | 2.5%         | 10 Maximum         |
| Degree of crushing, %                         | D-5821          | 97%          | 90 Minimum         |
| Sand equivalent, %                           | D-2419          | 89.6         | 45 Minimum         |

Table 4. Physical and chemical properties of Filler.

| Property    | Test Result |
|-------------|-------------|
| Cao         | 29          |
| Sio2        | 10          |
| Al2O3       | 6           |
| Mgo         | 16          |
| Fe2O3       | 1           |
| So3         | 0.12        |
| L.O.I       | 37          |
| Specific gravity | 2.92   |
| Passing percent Sieve No.200 (0.075 mm) | 94 |
Table 5. Chemical composition and physical properties of Synthetic zeolite.

| Property                  | Test Results |
|---------------------------|--------------|
| Colour                    | White        |
| Shape                     | Powder       |
| Diameter of Particles     | 325 Mesh     |
| SiO₂ %                    | 41.07 %      |
| Al₂O₃ %                   | 28.25 %      |
| CaO %                     | 0.03 %       |
| MgO %                     | 0.81 %       |
| K₂O %                     | 0.21 %       |
| Na₂O %                    | 0.05 %       |
| Ti₂O %                    | 12.99 %      |
| Bulk Density              | 0.5 gm/cm³   |
| PH                        | 9.3          |
| Water Content             | 21 %         |
| H₂O Static Adsorption     | 25.9 %       |

4. Testing program

Many mixtures were prepared with limestone dust filler for control mix and warm mixture with different percentages of Synthetic Zeolite. All mixtures were evaluated with some tests:

4.1. Marshall and Volumetric Properties

The Marshall test was performed during the mix design according to the ASTM Designation: D 6927-15. The Marshall test was performed at the temperature of 60 °C and with a deformation rate equal to 51 mm/min (2 inch/min). The properties acquired from this test are the Marshall Flow and Marshall stability. The Marshall stability is defined as the ultimate resistance load taken during a constant rate of deformation loading sequence. The Marshall flow is the complete sample deformation. Marshall Stability is reported in (kN) as well as Marshall Flow was reported in (mm) of deformation. Three specimens were tested and an average was reported and used in the analysis. Table 6 shows the results of volumetric properties and the specification limits set by the SCRB/R9.

4.2 Indirect Tensile Strength Test

ASTM D 4123 was adopted to perform this test. The experimental procedure is based on compression loading diametrically to the specimen to create a tension region along the loaded diameter of the specimen; it is used to define the splitting or tensile strength of a specimen. The maximum indirect tensile strength can be stated as following:

\[
\sigma_t = \frac{2P_{\text{max}}}{\pi HD}
\]  

(1)

Where:

\(\sigma_t\) = the indirect tensile strength (kPa),

\(P_{\text{max}}\) = the maximum load applied (kN),

\(H\) and \(D\) = Specimen’s height and diameter (m), respectively.
Table 6. Marshall and volumetric properties of different asphalt mixture types

| Type of filler | Dosage of Zeolite (%) | Marshall Stability (kN) | Marshall Flow (mm) | Voids in total mix (%) | Voids in mineral aggregate (%) | Voids fill with binder (%) | Bulk density (gm/cm³) |
|---------------|-----------------------|-------------------------|--------------------|------------------------|-------------------------------|----------------------------|---------------------|
| Limestone Dust 0 | 12.00 | 3.4 | 4.0 | 15.75 | 74.60 | 2.329 |
| 1 | 11.10 | 4.0 | 4.2 | 15.38 | 73.99 | 2.325 |
| 4 | 12.20 | 3.9 | 3.8 | 15.26 | 73.79 | 2.330 |
| 5 | 13.40 | 3.2 | 3.3 | 15.20 | 73.68 | 2.333 |
| 6 | 11.90 | 3.6 | 2.8 | 15.18 | 73.65 | 2.335 |
| 7 | 10.60 | 3.8 | 2.5 | 15.17 | 73.63 | 2.336 |

SCRB specifications Min. 8 kN (2 – 4) mm (3 – 5) % Min. 14 (65-85) % ---

4.3. Moisture Damage of Asphalt Mixtures

AASHTO T283 was adopted to assess the moisture sensitivity of WMA and HMA mixtures. Six specimens were prepared for each percent of WMA mixture and the traditional HMA mixture. The specimens of dry condition were placed at 25 °C for 2 hours in the water bath while the specimens of wet condition, were placed in sealed pack at -18 °C for 16 hours in a freezer when the degree of saturation was (55 - 80) % after that, placed at 60 °C for 24 hours followed by conditioning at 25 °C for 2 hours in water bath. Moisture damage in asphalt mixtures is defined as the loss of strength due to the presence of moisture in terms of the tensile strength ratio (TSR) that is simplified as a ratio of the wet specimen's indirect tensile strength to that of a dry specimen.

4.4. Immersion–Compression Test:

This test was conducted according to ASTM D1075. Six specimens were prepared for both (hot and warm) asphalt mixtures using the (SGC), to achieve 6 percent of air voids content. The reason for using this method of compaction is to simulate the field compaction. The compressive strength of three specimens were tested at 25.0± 1°C, which is called unconditioned set, as well as, the other three specimens were immersed in water bath at 60.0 ± 1°C for 24 hours, which is known as conditioned set. After conditioning, these specimens were transferred to water bath at 25 °C for 2 hours. In order to determine the compressive strength of specimen, ASTM D1074 was adopted. The index of retained strength was defined as the resistance of bituminous mixtures to the impact of water damage, which is the main strength that was retained after the immersion period, as a percentage, the minimum percentage of index of retained strength for surface course was adopted by (SCRB/R9, 2003) should not be less than 0.7 (or 70%), as shown below:

\[ \text{Index of Retained strength} = \left( \frac{S2}{S1} \right) \times 100 \]  

Where:

S1 = dry specimen’s compressive strength, kPa
S2 = Immersed specimen’s compressive strength, kPa.

4.5. Double Punch Shear Test:

This test was utilized for determining the stripping of the asphalt from the aggregates and developed at the University of Arizona by Jimenez in 1974. In this test, Marshall Specimen was utilized for all asphalt mixtures (warm and hot) and in the same manner used for mixing and compaction of Marshall test specimens. The total number of prepared specimens is 36, 30 specimens for WMA and six for HMA mixtures. The test specimens were placed at 60 °C for 30 minutes before testing in the water bath. Two cylindrical steel punches (25.4 mm in diameter) was placed on the top and bottom surface
of the test specimen and then centrally loaded until failure at a rate of 25.4 mm/minute, in order to record the maximum load resistance.

Farouki, O.T. and Rolt, J., 1985 presented the following equation to determine the punching shear strength:

$$\sigma_t = \frac{P}{\pi(1.2bh - a^2)}$$  \hspace{1cm} (3)

Where:
- $\sigma_t$ = Punching shear stress, Pa.
- $P$ = Maximum applied load, N.
- $a$ = Radius of punch, mm.
- $b$ = Specimen’s radius, mm.
- $h$ = Specimen’s height, mm.

4.6. Wheel-Tracking Test
Wheel-Tracking test was done according to the EN 12697-22:2005. The Pavement Wheel Tracking is a device for testing the wearability of asphalt mixtures by simulating conditions of the pavement. The wheel was loaded with about 700 N (158 pounds) of load at contact points and repetitively passed over the sample for up to 10,000 cycles. To prepare the asphaltsic slabs, asphalt mixtures were compacted at four percent of air voids, the Roller Compactor Device was utilized according to the (EN12697-Part 33:2005) as well as Superpave system (AASHTO Designation: T 312). As proposed by (EN 12697-Part 22:2003), the compacted specimen’s dimensions were 400 mm x 300 mm x 50±6 mm. The testing temperature was 60 °C. The rut depth induced on the material with respect to the number of wheel passes was raised. The WMA rut depth was slightly lower than the HMA rut depth; however, both were less than the commonly used criterion of 20mm at 20,000 passes.

5. Results and Discussion
After completing the experimental works above, six results have been found from these experimental works. Firstly, Figure 1 indicates the results of the indirect tensile strength (ITS) for traditional hot asphalt concrete and the warm asphalt mixtures with different percentages of synthetic zeolite. In general, the WMA with 5% of synthetic zeolite demonstrates higher values of ITS than other mixtures. WMA with 3% of synthetic zeolite mixtures have lower strength than the other mixtures. However, this figure shows that some of WMA mixtures have lower tensile strength which demonstrates low resistance under tension stresses.

Figure 2 illustrates the tensile strength ratio (TSR) values in HMA and WMA, TSR gives an idea of moisture sensitivity of various mixtures. Control HMA and warm asphalt mixes got TSR higher than the acceptable value of 80%. The WMA with 5% of zeolite mixture showed higher TSR than other warm asphalt mixtures. Accordingly, Warm mix asphalt mixtures have a similar behavior that occurs with the conventional hot asphalt pavement for indirect tensile strength, it was found to be increased with decreasing air void content. Lower temperatures utilized for preparing WMA can result in a partially drying of the aggregates. Moisture damage may be caused by the resulting trapped water in the coated aggregates. This could be attributed to the fact that the WMA mixes gives lower TSR values than for the HMA. Care must be taken to monitor this.
Figure 3 shows the result of Punching Shear for both mixes, it is observed that the value of punching shear of warm mixture is higher than control mix and it increases with an increase in Zeolite percent up to 5%.

It could be noticed from Figure 4 that the highest compressive strength is at 5% Synthetic Zeolite with (4150.8 kPa) and the lowest value at 7% Synthetic Zeolite with (3221.3 kPa) for dry condition. While in wet condition the highest value (3506.8 kPa) for 5% Synthetic Zeolite and the lowest value (2415.5 kPa) for 7% Synthetic Zeolite.

Another reference of water damage in various asphalt mixtures is Index of Retained Strength (I.R.S). Figure 5 shows that all WMA mixtures were more susceptible to water damage as compared to HMA mixtures except for WMA with 5% of zeolite there is a slight improvement. (I.R.S.) values for (hot and warm) mixtures exceeded the minimum of (SCRB/R9) specifications for surface course, which is 70%. Figure 6 clarifies the rut depth values of WMA and HMA. As shown in Figure 6, the average rut depth of the WMA with 5 percentage of zeolite was less than that of the HMA by about 47.9. The addition of Synthetic Zeolite to asphalt mixtures enhanced the resistance of wheel-tracking, despite decreasing the compaction temperature by 30 °C. A better pavement structure can be achieved by using WMA in the construction than HMA.

![Figure 1. Indirect tensile strength for different asphalt mixtures.](image1)

![Figure 2. Tensile strength ratio for different asphalt mixtures.](image2)
Figure 3. Punching shear for different asphalt mixtures.

Figure 4. Compressive strength for asphalt mixtures.

Figure 5. Index of Retained Strength Results for different asphalt mixtures
6. Conclusions

Based on laboratory tests for hot and warm mixtures the following conclusions can be drawn:

1. All the tested mixtures (warm and hot) satisfy the requirement of Iraqi specification SCRB/R9 for Marshall properties. Maximum Marshall Stability obtained is 13.4 kN for warm mix asphalt mixtures with 5% of Synthetic Zeolite.

2. Compressive strength for conditioned and unconditioned samples increases with increase in Synthetic Zeolite percentages up to 5%.

3. Tensile Strength Ratio (TSR) for warm mix asphalt mixtures with 5% of Synthetic Zeolite is similar to control mix.

4. The average of punching shear for WMA with 5% of Synthetic Zeolite is higher than that of traditional HMA by 25.2 %, the average of index of retained strength and rut depth for WMA with 5% of Synthetic Zeolite is lower than that of hot mix asphalt by 4.1 and 47.9 percent, respectively.

5. For all of the mixtures (hot and warm) with different percentages of Synthetic Zeolite, the mixture with 5% Synthetic Zeolite is better.

6. The warm asphalt mixtures are suitable to Iraqi environmental conditions because of the reduction in mixing and compaction temperatures.

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