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# The Effect of Using Sustainable Materials on the Performance-Related Properties of Asphalt Concrete Mixture

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**Abstract**

Sustainability is very important in this world at this time. One of the best materials used for sustainability in asphalt concrete pavements is the warm mix asphalt (WMA) as well as the reclaimed asphalt pavement (RAP). WMA technology has the ability to reduce production temperature to reduce the fuel usage and emissions. RAP is the old concrete asphalt mixture that is out of service and using it again leads to preservation of the virgin material. This search studied the viability of using WMA with different percentages of RAP (10%, 30%, and 50%) and compared them with control hot mix asphalt (HMA) and WMA. The Marshall properties, Tensile strength ratio (TSR), rut depth and fatigue life were determined in this work. The results showed that the tensile strength ratio (TSR) for HMA was better than that for WMA by 6%, rut depth for HMA was (4.37 mm) lower than that for WMA was (6.5mm), better fatigue life was obtained for WMA was (700 cycle) as compared to HMA was (500 cycle). In case of WMA with RAP (WMA-RAP), when the percentage of RAP increased with WMA, the moisture damage resistance improved by 2.5%, 13.3% and 15.4% for G1, G3 and G5 respectively, also the rutting resistance improved by 34.6%, 48% and 62.3% for G1, G3 and G5 respectively, but deteriorated of fatigue life by 45.8%, 74% and 88.5% for G1, G3 and G5 respectively.

*Keywords:* WMA; RAP; Marshal's Properties; TSR, Wheel Truck; Rutting Resistance; Flexural Beam Fatigue Testing; Fatigue Resistance.

## 1. Introduction

The Warm Mix Asphalt (WMA) is a novel method to save energy and environment-friendly protection by lowering the mixing and compaction temperatures, with relatively lesser consumption of energy and emission of exhaust when compared with the conventional hot mix asphalt (HMA). The WMA technologies have the ability to decrease production temperature (15°C to 40°C)[1]. As shown in Figure 1, in recent years, environmental protection is becoming an important factor in transport engineering, especially asphalt production. Even with the HMA used significantly in all the countries, some current researches recommend using different technologies that decrease the production temperature of asphalt mixtures. This technology is called the WMA, and it is generally used in the United States [2]. RAP is a method of reuse of materials from the existing asphaltic roads that has no ability to serve the future traffic. RAP can be used a sustainable technology, because it reduces emissions and reduces economic cost. When pavement mixtures deteriorate, they can be removed or recycled. The utilization of RAP can be considered environmentally friendly, because this technology reduces the use of natural resources and may perform better than the virgin asphalt mixtures [3].

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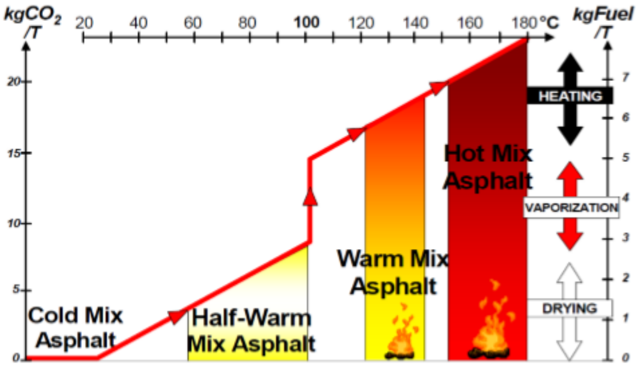



**Figure 1. Types of asphalt mixtures by temperature [4]**

## 2. Background

The manufacture of HMA pavements has devolved from mixing by hand to good automatic equipment, which tracks and maintains the quality of materials. Throughout this period, the belief has been that pavement performance depends on temperature control. Temperature is important for a good coating of aggregate, compaction, and stability. To improve that, increase in production temperature is the most common method. Despite its benefits, increased production temperature increases emissions and energy costs [5]. Techniques developed to save energy, reduce temperature of production, and reduce emissions, have previously been used in asphalt manufacturing. The way to determine appropriate Compaction temperature includes a comparison of the volumetric Density or air void content in compacted WMA samples and control HMA [6].

In the United States, in 1956, in the University of Iowa Ladies Csanyi, foamed asphalt was used as a soil binder. In 1968, cold water was added instead of steam by Mobil Oil Australia. This process made the foaming processes better economically [7]. Jenkins et al. (1999) discovered a new method that included half-warm foamed asphalt treatment. Jenkins investigated the concept and benefit of preheating the aggregate to a temperature above ambient level and below 100 °C, before adding foamed asphalt. The results exhibited a good coating of particles, cohesion of the mix, tensile strength, and compaction [8]. López et al. (2017) studied the mixing and compaction process of WMA, manufactured with super-stabilized, emulsified and assessed their characteristics in relation to the HMA [9]. Raab et al. (2017) stated the aging behavior and performance of several WMA-cutback asphalt roadways causes a decrease in the rut depth with ageing [10]. Albayati (2018) used zeolite to manufacture WMA in plant and evaluation this process [11]. Sarsam (2018) studied the behavior of WMA mixture under moisture damage [12]. Mahdi et al. (2019) studied Moisture Damage of Warm Mix Asphalt Concrete [13].

## 3. Research Methodology

The program of this work can be seen in by a flow chart as shown in Figure 2.

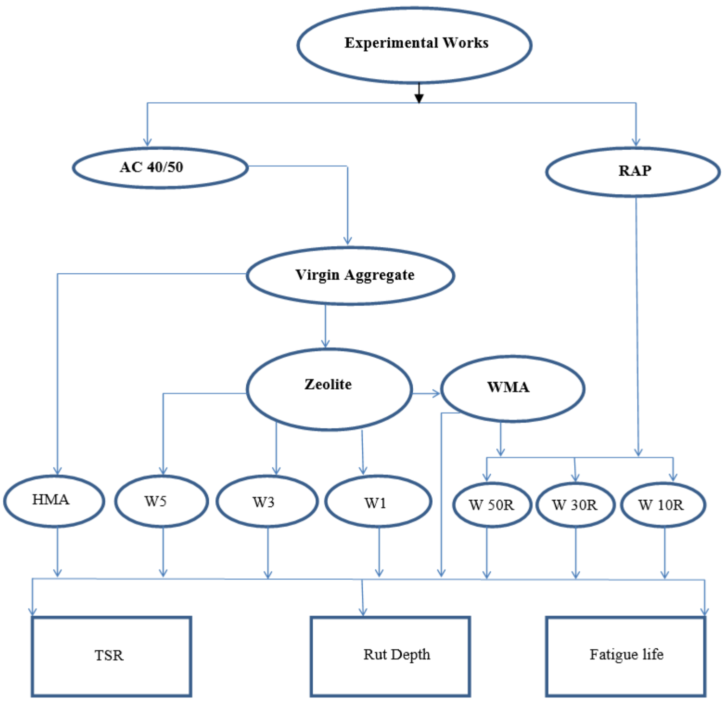



**Figure 2. Flow Chart for Research Methodology**

# 4. Materials

The materials utilized in this article consist of asphalt cement as well as aggregate, mineral filler to produce HMA, for the production of WMA zeolite additives were used besides the materials mentioned above, and a reclaimed asphalt mixture were used for the production of both types of asphalt concrete mixture as a partial replacement for virgin materials.

## 4.1. Asphalt cement

In this study, the asphalt cement (40–50) was used. It was brought from the Doura refinery. All test results met the Iraqi specification [14]. Physical properties of this type are shown in Table 1.

**Table 1. Physical Properties of Asphalt Cement**

| Property | ASTM Designation No. | Value | SCRB Specification |
|---|---|---|---|
| Penetration, 1/10 mm, 25˚c, 100 g, 5 sec | D5 | 44 | 40–50 |
| Softening Point, (c ring & ball) | D36 | 48 | - |
| Ductility, cm (25˚C, 5 cm/min) | D113 | 125 | > 100 |
| Specific Gravity, 25˚C | D70 | 1.04 | - |
| Flash Point, C, Cleaveland open cup | D92 | 269 | > 232 |
| **After thin film oven test proprieties D1754** | | | |
| Retained Penetration of Residue,% (25˚C, 100 g, 5 sec) | D5 | 60 | > 55 |
| Ductility of Residue, cm (25˚C, 5 cm/min) | D113 | 83 | > 25 |
| Loss on Weight% (163ºC, 50 g, 5 h) | | 0.3 | _ |

## 4.2. Mineral Filler

A filler is a material that passes through sieve No. 200. The source of this material is the lime plant in the city of Karbala. The physical properties of the lime stone filler are shown in Table 2.

**Table 2. Physical Properties of the Mineral Filler**

| Property | Test Result | SCRB Specification |
|---|---|---|
| Specific gravity | 2.73 | - |
| Passing Sieve No. 200 (0.075 mm),% | 94 | 70–100 |

## 4.3. Aggregates

The aggregate used in this study was derived from the Al-Neibaie quarry, north of Baghdad. This type is generally utilized in Iraq for asphalt pavements. In this study the coarse aggregate is isolated from the fine aggregate followed by recombining it to the best possible extent with a filler to satisfy the Iraqi standard specification [14]. For the wearing layer. Routine tests were completed on the coarse, fine, and filler to assess their physical properties. Physical properties of the aggregate shown in Table 3 and the aggregate gradation and specification limits shown in Figure 3.

**Table 3. Physical Properties of the Aggregate**

| Property | ASTM Designation No. | Coarse Aggregate | Fine Aggregate | SCRB R/9 2003 |
|---|---|---|---|---|
| Bulk Specific gravity | ASTMC127 and C128 | 2.647 | 2.635 | ----- |
| Apparent Specific gravity | ASTM C127 and C128 | 2.666 | 2.655 | ----- |
| Percent water absorption | ASTM C127 and C128 | 0.13 | 0.524 | ----- |
| Percent wear (Los-Angeles Abrasion) | ASTM C131 | 19.7 | ----- | 30 Max |
| Fractured pieces,% | ----- | 97 | ----- | 90 Min |
| Sand Equivalent | ASTM D 2419 | ----- | 56 | 45 Min. Super pave (SP-2) |
| Soundness loss by sodium sulfate solution,% ( C-88) | ----- | 3.6 | ----- | 12 Max |

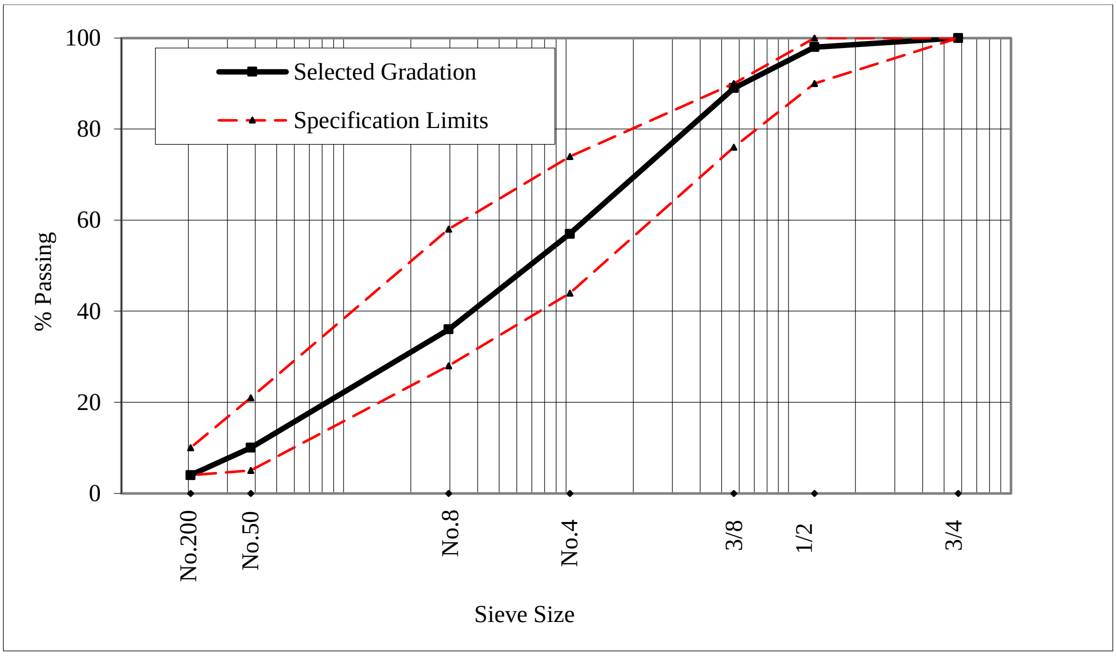



**Figure 3. Aggregate Gradation and Specification Limits**

## 4.4. Zeolite

Zeolites are crystalline hydrated aluminium silicates. The material of zeolites is shown in Figure 4. Artificial Zeolite has been used in this study. This material has been tested, and an X-ray Fluorescence (XRF) device has been used to find its chemical composition, Figure 5 shows the (XRF) device that used to find the chemical composition of zeolite. The chemical composition of zeolite is given in Table 4.

**Figure 4. The material of zeolite**

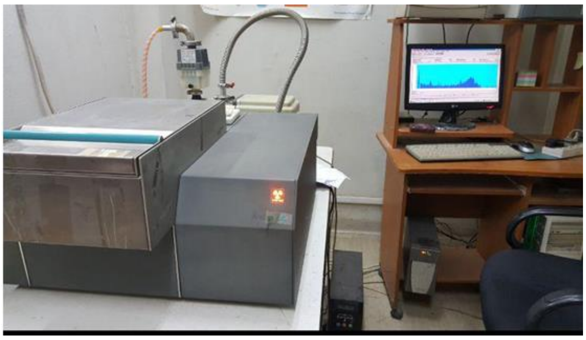


**Figure 5. (XRF) device**

**Table 4. The Chemical Composition of Zeolite**

| Chemical composition | Result |
|---|---|
| SiO2 | 32.2% |
| Al2O3 | 28.5% |
| Na2O | 15.3% |
| L.O.I | 24.0% |

## 4.5. Reclaimed Asphalt Mixture

Reclaimed Asphalt Mixture was obtained from the road (Baghdad – Anbar) near the city of Fallujah, west of Baghdad. According to the directorate of roads and bridges of Anbar, this road was established in 1994 by a local company. The RAP was subjected to an extraction test to obtain the asphalt content and aggregate gradation. The result of the asphalt content and the physical properties of the aggregate are presented in Table 5. Also the aggregate gradation is shown in Figure 6.

**Table 5. Properties of Aged Materials after Extraction Test**

| Material | Property | Value |
|---|---|---|
| Asphalt binder | Asphalt content | 4.2% |
| Coarse aggregate | Bulk specific gravity | 2.552 |
| | Apparent specific gravity | 2.590 |
| Fine aggregate | Bulk specific gravity | 2.585 |
| | Apparent specific gravity | 2.819 |
| Mineral filler | Percent passing sieve No. 200 | 99% |
| | Specific gravity | 2.81 |

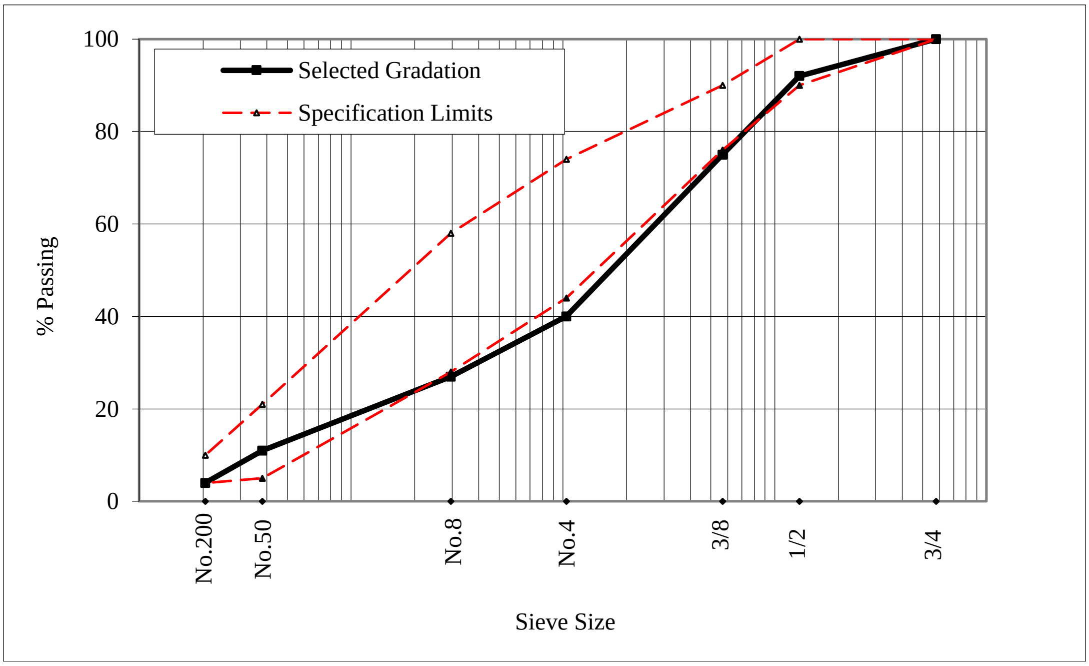



**Figure 6. Aggregate Gradation and Specification Limits for RAP mixture**

## 5. Mix Design

To find the optimum asphalt content according to the Marshall method, five Marshall specimens were prepared with different asphalt contents (3.5%, 4%, 4.5%, 5%, and 5.5%, with an aggregate of the surface layer, and a Marshall test was used for this purpose. The average of the following values was taken to adopt the optimum asphalt content for wearing courses;

- Maximum bulk density ⟶ asphalt content
- Maximum stability ⟶ asphalt content
- Air voids at 4% ⟶ asphalt content

Hence, the optimum asphalt cement content was 4.6%.

## 6. Preparation of HMA and WMA

The fine and coarse aggregates were washed and dried to a constant weight at 110 °C and then cooled and separated according to the desired gradation. A mineral filler, material that passes through sieve No. 200 was used. To prepare the HMA, coarse and fine aggregate with the filler was recombined to meet the required gradation, according to the Iraqi Standard Specification [14]. Next, the total mixture of aggregate was heated to 160 °C before mixing it with asphalt cement. Asphalt cement was heated to a temperature that produced a viscosity of 170 ± 20 centistokes, after which the asphalt was added to the heated aggregate and mixed well until all the aggregate particles were coated with the asphalt cement. Preparation of WMA was different from HMA by compaction temperature, which was 115 °C. Also, in the case of the preparation of WMA (the zeolite was added to the heated aggregate) the mixture was mixed well for half a minute and then the asphalt was poured and the zeolite of 0.3% was added manually (by weight of the total mix) to the mixer. The aspha-min as well as the addition process is shown in Figure 7.

**Figure 7. Zeolite Addition to Aggregate Blend**

## 7. WMA-RAP Aggregate Gradation

Different percentages of RAP were mixed with WMA. These percentages were 10% of RAP with 90% of WMA, 30% of RAP with 70% of WMA, and 50% of RAP with 50% of WMA; the gradations of mixtures after mixing are shown in Figures 8 to 10. WMA were also prepared with the same gradations shown in Figures 8 to 10, where gradations, as shown in Figures 8 to 10, were equal to G1, G3, and G5, respectively. The performance of these mixtures was evaluated in terms of Marshall properties of moisture resistance, rutting resistance, and fatigue resistance.

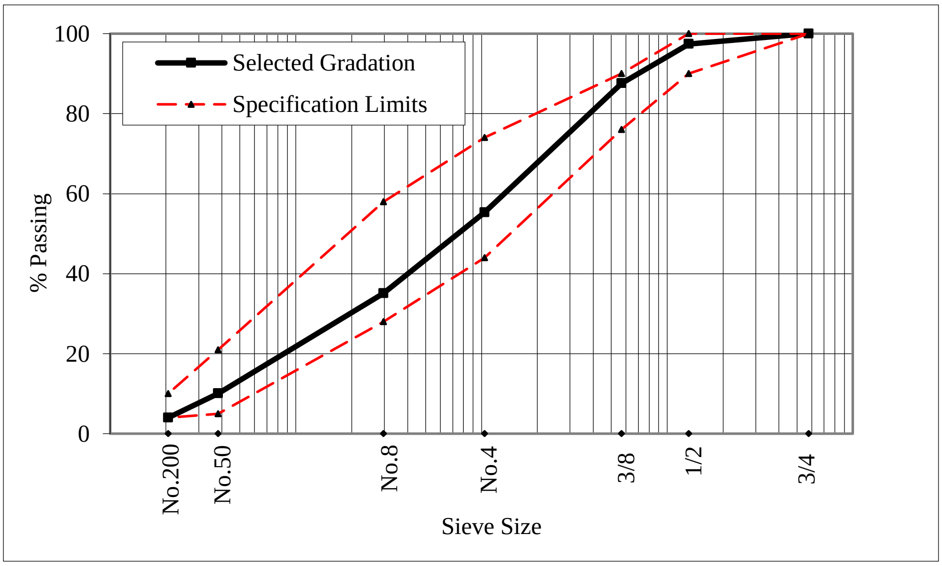



**Figure 8. Aggregate Gradation and Specification Limits for (W + 10R) = G1**

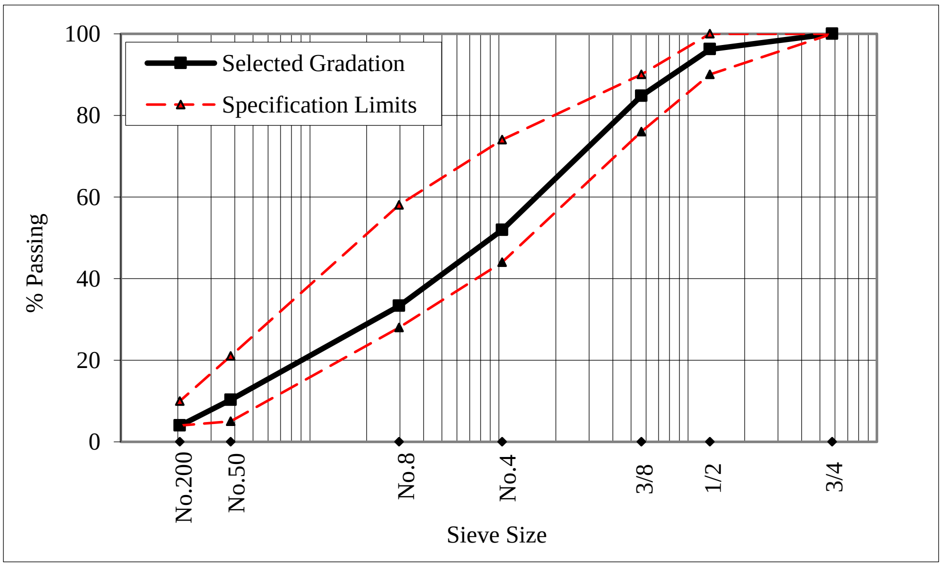



**Figure 9. Aggregate Gradation and Specification Limits for (W + 30R) = G3**

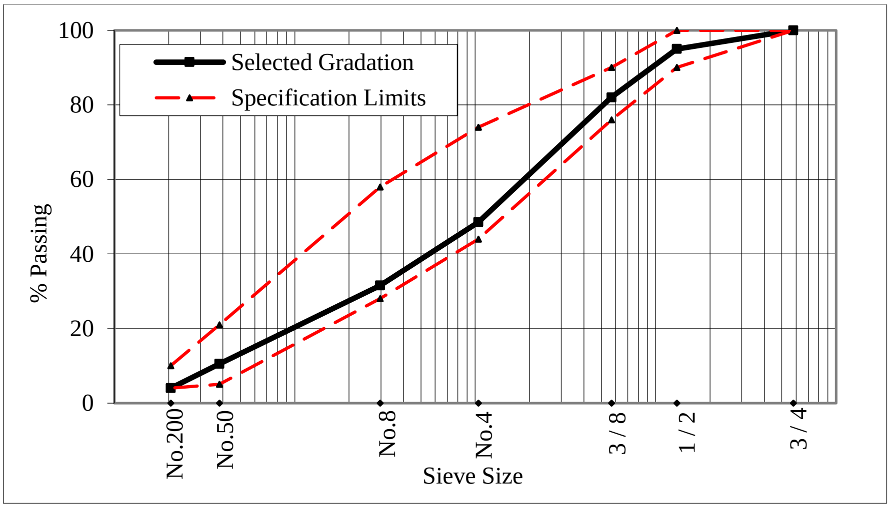



**Figure 10. Aggregate Gradation and Specification Limits for (W + 50R) = G5**

# 8. Performance Testing and Results

## 8.1. Marshall Properties

The Marshall specimens were prepared, with 100 mm (4-in diameter) and 63 mm (2.5-in height) specimens, three replicates for each type of mixture. These were compacted at a temperature of 135°C in case of HMA and 115°C in case of WMA and WMA-RAP. The compaction was achieved by 75 blows per each face. Next, the compacted specimens were immersed in water as shown in Figure 11 at 60°C, for 45 minutes, and then the stability and flow were tested.

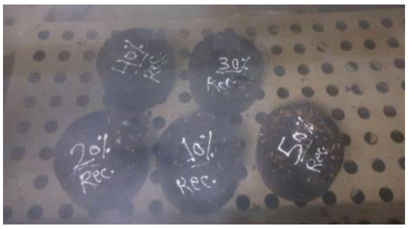
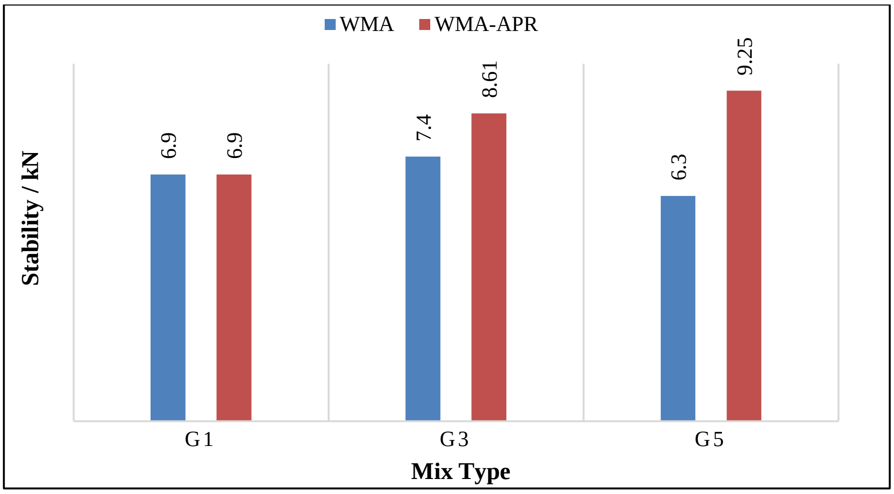
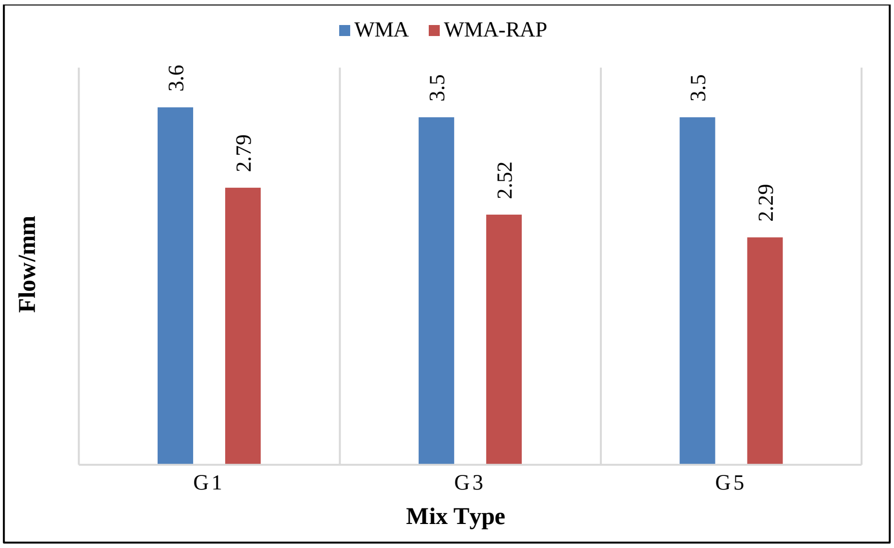


**Figure 11. Specimens in the Water Bath**

The Marshall stability in HMA was (8.5 KN) better than the Marshall stability in WMA was (6.7 KN) by 27% at the same gradation and same optimum asphalt content. As shown in Figure 12 the stability was increased by 16% in case of WMA after addition of 30% of RAP and by 17% after addition of 50% of RAP. Based on the Marshall flow values, the Marshall flow (standard (2 mm – 4 mm)) in HMA was (2.77 mm) less than in WMA was (2.85 mm) at the same gradation. Also as shown in Figure 12, When the RAP was added to WMA, a decrease in the value of the Marshall flow was observed. The mixture (W 50R) showed the lowest flow value when compared to other mixtures and when compared to WMA at the same gradation. This was on account of the mix becoming more stiff and brittle when the percentage of RAP was increased in it and also because the percentage of asphalt decreased after adding RAP. The results showed that the bulk density in HMA was (2.327 gr/cm$^3$) slightly better than that in WMA was (2.299 gr/cm$^3$). Also as shown in Figure 12, the bulk density increased in the WMA by 8%, at the same gradation, after addition of 10% of RAP, by 39% after addition of 30% of RAP, and by 53% after addition of 50% of RAP.





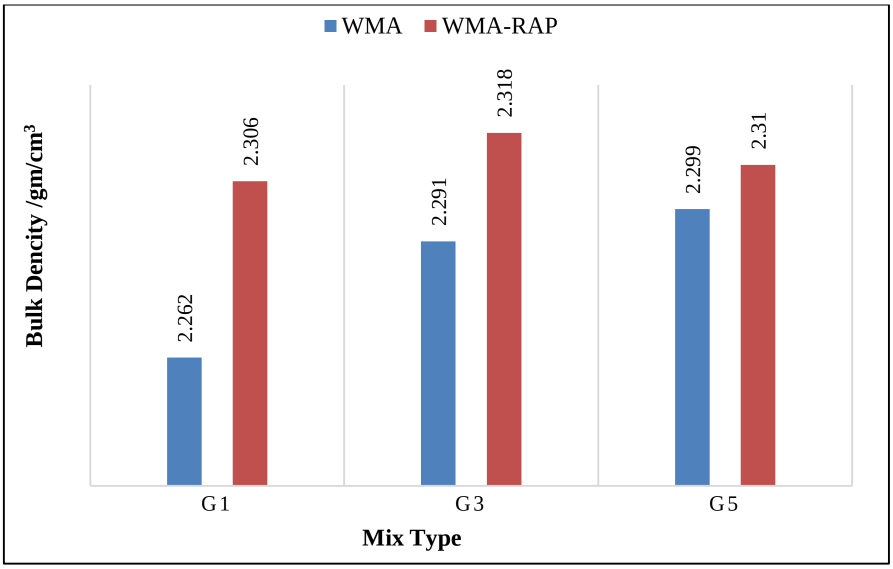




**Figure 12. Effect of WMA-RAP and WMA on the Marshall properties**

## 8.2. Moisture Susceptibility

The adopted procedure to evaluate the moisture susceptibility of WMA, WMA-RAP, and HMA specimens is AASHTO T 283-07. There were six specimens used for this test (three for the un-conditioned and three for the conditioned). They were prepared for all variables to an air void level ranging from 6% to 8%. The unconditional specimen was put in a water bath at 25°C, for 120 ± 10 minutes, to test it directly for indirect tensile strength (ITS). Conditional specimens were placed in frozen temperatures, at -18 ± 2°C, for 16 hours, and then in 60 ± 1°C for 24 hours. Three conditioned and three unconditioned specimens were tested using the Versa Tester Machine. The average value was computed as SII "ITS for moisture-conditioned specimens", and as SI "ITS for unconditioned specimens". The tensile strength ratio could be calculated from the Equation 1:

$$TSR = (SII\ /\ SI) \times 100 \tag{1}$$

Based on the results the WMA had a lower tensile strength ratio (TSR) was 77% than HMA was 82%. From results presented in Figure 13, it can be seen that After the addition of a percentage of RAP to WMA, the TSR of the WMA-RAP mixture considerably increased, becoming higher than the TSR of WMA, at the same gradation; by 3% after adding 10% of RAP, by 13% after adding 30% of RAP, and by 15% after adding 50% of RAP. This indicated that the material in the RAP was stiff and had higher strength. These results showed that RAP might increase the moisture resistance. This could be explained scientifically by the fact that the bond between the binder, which is a mix of virgin binder and aged binder, and the recycled aggregate was stronger than the bond between the virgin asphalt and virgin aggregate.

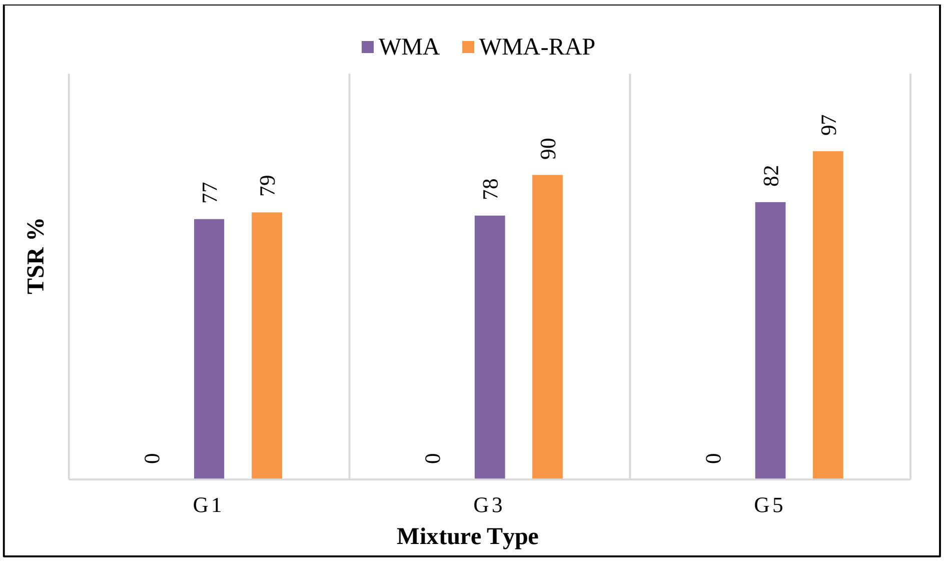



**Figure 13. Tensile strength Ratio for WMA and WMA-RAP at Same Gradation**

## 8.3. Rutting Resistance

The wheel-tracking machine was used to evaluate the rut depth according to EN 12697-22:2003 for WMA, WMA-RAP, and HMA. Two slabs were tested for each variable; the dimensions of the slab were (400×300×50) mm. The slabs were compacted by using Dyna-Comp Pneumatic Roller Compactor according to European Standard (EN 12697 – 33).Test temperature was 40°C for all type of mixes.

From the results, the rut depth at 10,000 cycles for HMA was (4.37 mm) lower than that of WMA was (6.5mm) by 33%. From the results in Figure14 ,after the addition of a percentage of RAP to WMA, the rut depth of the WMA-RAP mixtures decreased in comparison to WMA at the same gradation; by 35% after adding 10% of RAP, by 48% after adding 30% of RAP, and by 62% after adding 50% of RAP. This indicated the binder in RAP was more stiff and brittle because of aging. This was the reason for improvement in rutting resistance for WMA after addition RAP.

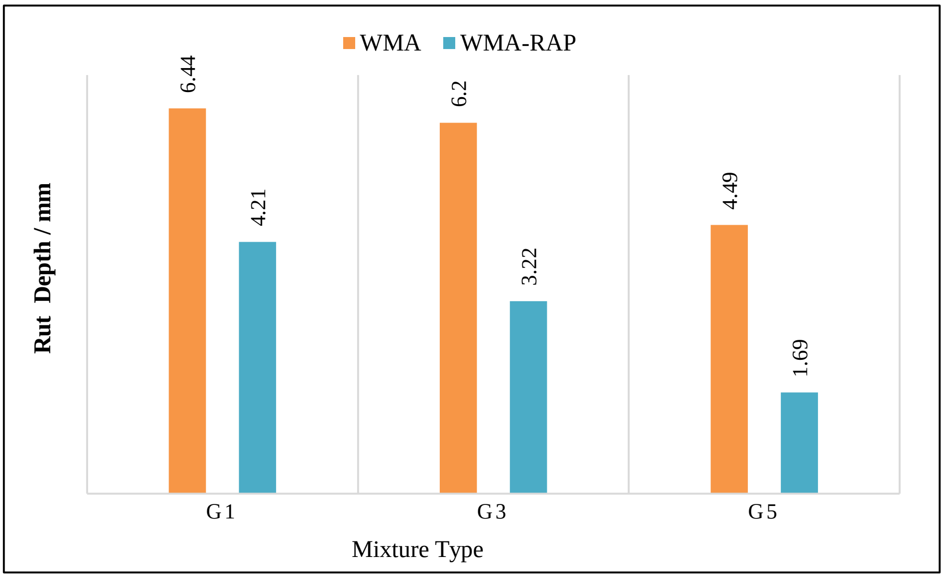



**Figure 14. Max. Rut depth at 10,000 cycles for WMA and WMA-RAP at Same Gradation**

## 8.4. Flexural Beam Fatigue Testing

The Flexural Beam Fatigue Test estimates the cracking potential of the asphalt pavement due to repeated heavy traffic loading. The pneumatic repeated load system is used in this work for conducting the fatigue life test. This test includes one stress level of 20 psi, one temperature 20 ± 1°C, and Test Frequency, the time of loading (0.1 sec), and a rest time of 0.9 second, asphalt type. Slab specimens for flexural fatigue testing were compacted by using a roller compactor device and then the slab was cut to obtain beam specimens. The total number of beam specimens obtained from the sawed Water-Cutter Roller compacted slabs were used for the Flexural Fatigue test. The dimensions of the beams were a length of 38 cm, width of 5 cm, and a height of 6 cm. They were used in the constant stress level test. Figure 15 shows the Water-Cutter machine and Figure 16 shows the Fatigue Beam Specimens.

**Figure 16. Sawing the Slab Using the Water-Cutter machine**

**Figure 16. Fatigue Beam Specimens**

From results, it can be seen that the WMA mixture had better performance of fatigue resistance than the HMA by 29%, where the fatigue life was 500cycle for HMA, and 700 cycle for WMA. As shown in Figure 17 ,after the addition of percentage of RAP to WMA, the fatigue life of the WMA-RAP mixtures decreased in comparison to the WMA, at the same gradation; by 44% after adding 10% of RAP, by 74% after adding 30% of RAP, and by 89% after adding 50% of RAP. This indicated the zeolite made WMA softer and the RAP made mixture made it more stiff and brittle, this was explained by [15].Also because the percentage of asphalt in WMA-RAP mixtures, however the percentage of asphalt decrease in case of WMA-RAP because the percentage of asphalt in recycled material lowest from virgin material. It can be seen that fatigue life decreased as asphalt content decreased, because the decreasing thickness of the asphalt film led to an increase in tensile strain at the bottom of the layer, accordingly the fatigue life increased. This agreed with the findings of [16].

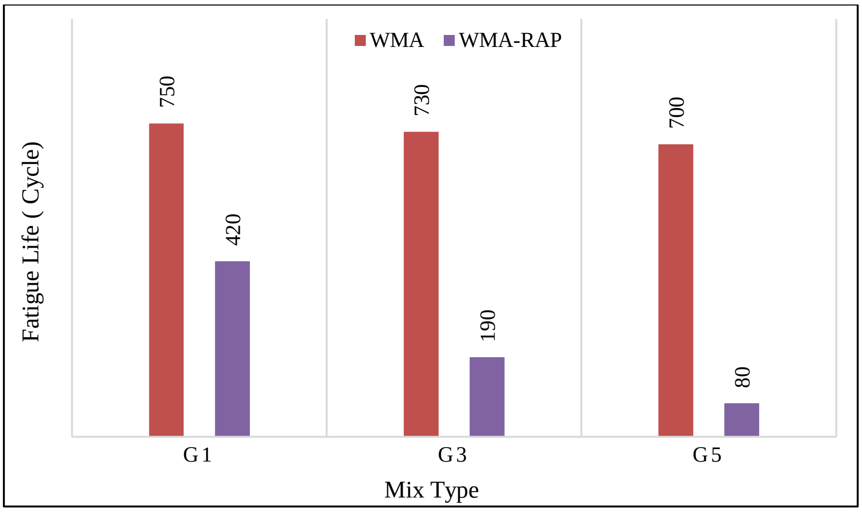



**Figure 17. The Number of Cycles to Reach Fatigue Failure for WMA and WMA-RAP at Same Gradation**

## 9. Conclusions

Based on limitation and the testing results, the following points could be concluded:

- HMA showed better moisture resistance than WMA by 6%, WMA-RAP mixtures showed improved moisture resistance, better than WMA, the addition of RAP to WMA showed much better moisture resistance than WMA. With zero percentage of RAP, the result showed TSR values for WMA with 10% RAP was (79%) higher than WMA was (77%), at the same gradation by 2.5%, for WMA with 30% RAP was (90%) higher than WMA was

(78%), at same gradation by 13.3%, and for WMA with 50% RAP was (97%) higher than WMA was (82%), at same gradation, by 15.4%.

- Rut depth for WMA was 6.5 mm, for HMA was 4.37 mm at 10,000 cycles, and the rut depth of WMA was higher than HMA by 33%. After adding RAP, WMA improved the rutting resistance. The rut depth for G1 was 6.44 mm for WMA and 4.21 mm for WMA-RAP, which meant, the rut depth was reduced by 35% after 10% RAP was added. Rut depth for G3 was 6.2 mm for WMA and 3.22 mm for WMA-RAP, which meant, the rut depth was reduced by 48% when 30% of RAP was added. Rut depth for G5 was 4.49 mm for WMA and 1.69 mm for WMA-RAP, which meant, the rut depth was reduced by 62% when 50% RAP was added.
- The number of cycles to reach fatigue failure in WMA was higher than HMA by 29%. WMA-RAP had a lower number of cycles to reach fatigue failure than WMA; by 44% when 10% RAP was added, by 73% when 30% RAP was added, and by 88% when 50% RAP was added, and due to the mixture which contained the RAP became more brittle.

## 10. Conflicts of Interest

The authors declare no conflict of interest.

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