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# Assessment of Warm Mix Asphalt Concrete Green Pavement

**Saad Issa Sarsam*, Zainalabiden Nihad**

Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq

## Abstract

One of the finest choices of green and sustainable paving materials in asphalt concrete paving operation is the Warm mix asphalt concrete. The lower temperatures implemented in the mixing, handling, and compaction of the mix gets in saving energy, cutting emissions and significant cuts in construction costs. The concept of the WMA is to produce mixture which have the same durability, performance and strength as that of traditional hot mix asphalt concrete HMA. As the result of decline in the temperature of WMA, it exhibits less aging of asphalt mixture. It is known that, asphalt oxidation lead to stiffen of the binder and may cause various pavement distresses. In this work, the temperature susceptibility of two types of warm mix have been compared with those of HMA. Cylindrical specimen of 63.5 mm in height and 101.6 mm in diameter have been prepared using medium curing cutback and cationic emulsion in case of warm mix and asphalt cement in case of hot mix. Specimens were tested for indirect tensile strength ITS at 5 and 20 °C. It was concluded that WMA are less susceptible to temperature than HMA. The temperature susceptibility at optimum asphalt content are (24, 17 and 19) kPa/°C for the HMA, WMA-emulsified asphalt and WMA-cutback asphalt respectively. WMA exhibit higher ITS at 25°C than HMA by 30.59% and 23.9% when using cutback asphalt and emulsified asphalt with WMA respectively, on the other hand, WMA exhibit higher ITS at 5°C than HMA by 11.77% and 4.14% when using cutback asphalt and emulsified asphalt with WMA respectively.

## Keywords

Warm Mix, Hot Mix, Temperature Susceptibility, Indirect Tensile Strength, Asphalt Concrete, Green Pavement

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## 1. Introduction

Increased environmental awareness regarding emissions of volatiles when producing and placing of HMA have led to the development of the WMA. One of the important advantages of using WMA is that it can decrease the mixing and compaction temperatures of bitumen mixtures. The low production and paving temperatures of WMA meaningfully decrease the emissions and fumes, [1]. Lower fumes and emissions are useful to the workers exposed to the fumes produced by the HMA paving operation. WMA mixtures consist of aggregates of various sizes, mineral filler, and liquid asphalt, were produced at 110°C, and compacted at 100°C in the laboratory study by Sarsam, [2]. Classifying of the WMA is according to the technology that is utilized to manufacture the mixture, into three main groups, (organic, chemical, and foaming) additives, [3]. Figure 1 as presented by López et al [4] exhibit the asphalt mixture classification according to the manufacturing temperature. Potential paving benefits of implementing WMA comprise lower production temperatures, decrease fuel consumption, protraction of the paving season in cold weathers, longer haul distances, longer storage times and improves compaction. On the environmental side, reduced production temperatures and decreased fuel consumption causes a lower emission at the plant and paving location, which is required for sustainable and green pavement, [5]. It was stated by Raghavendra et al, [6] that the low viscosity of liquid asphalt

* Corresponding author
E-mail address: saadisasarsam@coeng.uobaghdad.edu.iq (S. I. Sarsam)

will furnish the required perfect coating of aggregates and the workability for compaction, whereas the curing period will provide the increase in mechanical strength, and durability during traffic exposure. WMA's disadvantages addressed by [7-9] are principally related to the potential of decrease material durability, and potential for rutting and moisture susceptibility cases. The lower mixing and compaction temperatures of the WMA by 20-40°C as compared with HMA can donate of inadequate drying of the aggregate, thus increase the potential for the moisture damage in the pavement, [10]. The significant decreases in Marshall Stability could be detected for WMA as compared to that of HMA regardless of asphalt content., this was attributed to the fact that hot aggregates absorb high percentages of liquid asphalt through the mixing process, then the excess volatiles evaporate, leaving more voids when compared to low liquid asphalt content, the excess voids will be more susceptible to the reduction in the strength property, [11]. The aging behavior and performance of several WMA-cutback asphalt roadways causes decrease in the rut depth with ageing as reported by Raab et al, [12]. Mixture design framework of WMA was developed by Goh, [13] through assessing its mechanical characteristics, it was stated that the HMA exhibit higher tensile strength than that of the WMA. Temperature susceptibility of bitumen was characterized by the extent to which its consistency changes in temperature. It may be measured by comparing consistency measurements such as penetration or viscosity at two or more temperatures or by determining the penetration-softening point relationship, [14].

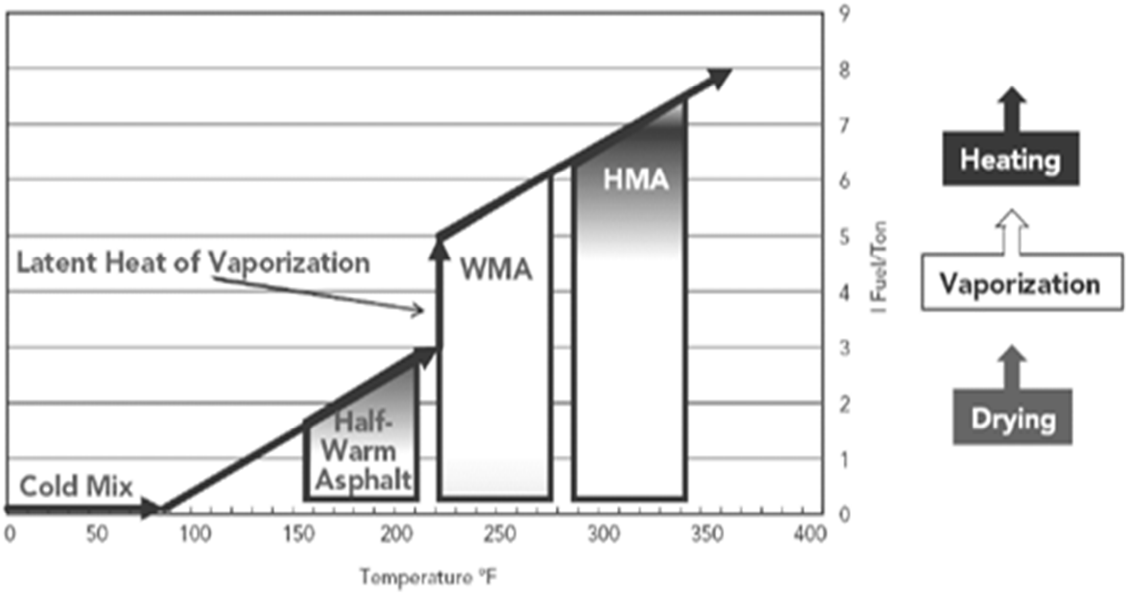


**Figure 1.** Asphalt mix classification by manufacturing temperature [4].

Three asphalt properties are considered so important regarding to the performance of the roadway in service. These are, aging, viscoelasticity and temperature susceptibility, [15]. The property of being temperature susceptible should necessarily be present in a binder which means it should easily flow at high temperatures to smooth coat the aggregate at the time of mixing, therefore during compaction, these aggregates can ease move against each other. At low temperatures or at room temperature the binder should be capable to become viscous again, therefore in the pavement it can hold the aggregate together. The base binder should retain this property when using WMA, [16]. The motive of the WMA is to improve the workability of the bituminous mix; thus, it becomes necessary to know how another type of asphalt will affect in the temperature susceptibility of the mixture [17]. In a study of WMA, emulsified asphalt properties were compared with HMA and find that the temperature susceptibility for WMA-emulsified asphalt is less than HMA [18]. The WMA- emulsified asphalt has improved properties of asphalt mixture over HMA, including decrease in the temperature susceptibility and rate of the aging, [19].

The aim of this investigation is to evaluate the influence of implementing medium cutback asphalt and cationic emulsion as a binder on the temperature susceptibility of WMA through an intensive testing program and present the WMA as a possible green pavement alternative. This research methodology was divided into four stages, the first stage covers obtaining the properties of raw materials includes aggregate and liquid asphalt (cationic emulsions and medium curing cutback asphalt). The second stage includes the design of the warm mix using the available materials and obtaining the design asphalt content of each case. The third stage includes the measurement of indirect tensile strength test of the mixtures, while the fourth stage was be concerned with the temperature susceptibility of the mixture. Test results will be compared with HMA properties.

## 2. Materials and Methods

Materials implemented in this research were assured to be locally available, and economically valuable. They could be categorized into three groups, aged materials, asphalt cement, and recycling agents.

### 2.1. Asphalt Cement

Asphalt cement of penetration grade 40-50 was obtained from Al-Dura refinery and implemented for hot mix asphalt concrete specimens. Table 1 presents the physical properties of asphalt cement.

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

| Test | Result | Unit | Specification ASTM, [20] |
|---|---|---|---|
| Penetration (25°C, 100 gm, 5 sec) | 43 | 1/10, (mm) | ASTM D-5 |
| Ductility (25°C and 5cm/minute) | 156 | cm | ASTM D-113 |
| Softening point (ring & ball) | 49 | °C | ASTM D-36 |
| Absolute Viscosity @ 60°C | 2150 | Poise | ASTM D-2171 |
| Specific gravity (25°C) | 1.041 | — | ASTM D-70 |
| After thin film oven test | | | |
| Retained penetration of original,% | 67.4 | 0.1 mm | ASTM D-5 |
| Loss in weight (163°C, 50gm, 5h)% | 0.220 | % | ASTM D-1754 |
| Ductility (25°C and 5 cm/ minute) | 96 | cm | ASTM D-113 |

### 2.2. Cutback Asphalt

Medium curing cutback asphalt (MC-30) was implemented as a binder for warm mix asphalt production. The cutback asphalt was obtained from Al-Dura refinery. The tests implemented on the cutback asphalt complies with ASTM, [20]. Table 2 shows its properties as supplied by the refinery.

**Table 2.** Physical characteristics of cutback asphalt.

| Test | Results | Limits of Specification | ASTM, [20] Designation |
|---|---|---|---|
| Viscosity @ 60°C, Cst. | 40 | 30-60 | ASTM D2170 |
| Water% V (max) | 0.2 | 0-0.2 | ASTM D95 |
| Density, kg/m$^3$ | 0.91 | 0.91-0.93 | — |
| Test on the Residue from Distillation | | | |
| Penetration@25°C, 100 g, 0.1mm, 5sec | 150 | 120-250 | ASTM D2027 |
| Ductility @ 25 °C | 100 | 100+ | ASTM D2027 |
| Solubility in Trichloro Ethylene% wt. | 99 | 99 Min. | ASTM D2027 |

### 2.3. Emulsified Asphalt

Cationic Emulsified asphalt was used as a binder for warm mix asphalt production, it was brought from the state company for the mining industries. Test implemented on the emulsified asphalt meet with the ASTM, [20]. Table 3 exhibit its properties as supplied by the producer.

**Table 3.** Physical characteristics of emulsified asphalt.

| Test | ASTM, [20] Designation | Results | Specification Limits ASTM, [20] | |
|---|---|---|---|---|
| | | | Min | Max. |
| Particle Charge Test | ASTM D-244 | Positive | — | — |
| Say bolt Furol viscosity (50 °C) | ASTM D-245 | 250 | 50 | 450 |
| Oil Distillate by Volume of Emulsion (%) | — | 85 | 65 | — |
| Penetration, (25°C, 100 g and 5sec) | ASTM D-5 | 135 | 100 | 250 |
| Ductility, (25°C and 5 cm/min) | ASTM D-113 | 187 | 40 | — |
| Solubility in the Trichloroethylene | ASTM D-2042 | 101 | 97.5 | — |
| Specific Gravity (25°C) | ASTM D-70 | 1.02 | — | — |
| Residue by Distillation,% | ASTM D-6997 | 60 | 57 | — |

### 2.4. Coarse and Fine Aggregates

The crushed coarse aggregates which retained on the sieve No. 4 were brought from AL-Nibaee quarry. Such aggregates are widely utilized in Baghdad city for asphalt concrete mixture. Natural and crushed sand were utilized as fine aggregates (passing sieve No. 4 and retained on sieve No. 200). It consists of tough grains, hard, free from loam and deleterious materials. The aggregates were tested for physical properties and Table 4 exhibits the test results.

**Table 4.** Physical characteristics of fine and coarse aggregate.

| Laboratory Test | ASTM, [20] Designation | Coarse Aggregate | Fine Aggregate |
|---|---|---|---|
| Bulk Specific Gravity | ASTM C127 | 2.610 | 2.631 |

| Laboratory Test | ASTM, [20] Designation | Coarse Aggregate | Fine Aggregate |
|---|---|---|---|
| Water Absorption,% | ASTM C127 | 1.4 | 1.7 |
| Emulsion Absorption,% | ASTM D4469 | 1 | 1.4 |
| Cutback Absorption,% | ASTM D4470 | 0.6 | 0.9 |
| AC (40-50) Absorption,% | ASTM D4471 | 0.4 | 0.6 |
| % Wear (Los Angeles Abrasion) | ASTM C131 | 19.5 | -- |

## 2.5. Mineral Filler

Mineral filler implemented in this study is Portland cement, it was produced by Al-Mas Company. The physical characteristics of the Portland cement are presented in the Table 5.

**Table 5.** Physical characteristics of the Portland cement.

| Property | Test result | Requirements of SCRB, [21] |
|---|---|---|
| % Passing Sieve No. 200 (0.075mm) | 98 | 95 |
| Bulk Specific Gravity | 3.1 | — |
| Fineness by Blaine ($m^2$/kg) | 312 | ≥230 |

## 2.6. Selection of Aggregates Gradation

The selected gradation of the aggregates in this work followed SCRB, [21], with nominal maximum size 19 (mm). Figure 2 presents gradation of the aggregates for binder course.

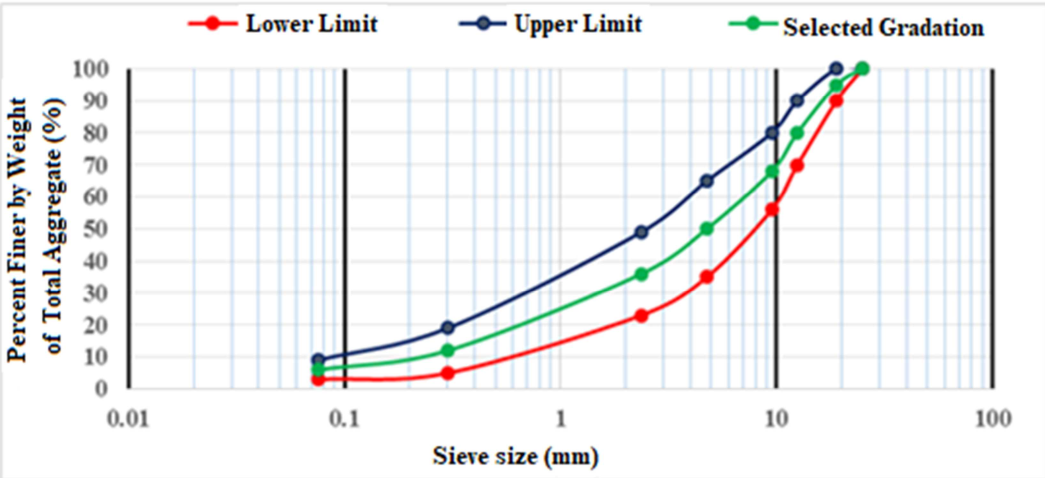


**Figure 2.** The implemented aggregate gradation of binder course layer according to SCRB, [21].

## 2.7. Preparation of HMA

The virgin aggregates and filler were sieved and combined in order to meet a specified gradation of the binder course layer as per SCRB, [21]. The combined aggregates were heated to a temperature 160 °C, while the asphalt was heated to temperature 150°C to produce a kinematic viscosity of (170 ± 20) centistokes, then the asphalt was added to the preheated aggregate to the required volume of asphalt. The asphalt and the aggregate were mixed by hand in the mixing bowl on the hot plate for 3 minutes until the asphalt had adequately coated the surface of the aggregate, while the mixing temperature was maintained at 145 °C, specimens were compacted with Marshall Hammer using 75 blows on each side, according to ASTM, [20]. Mixtures with 0.5% of asphalt cement above and below the optimum have also been prepared to verify the impact of asphalt content on the temperature susceptibility.

## 2.8. Preparation of WMA

The virgin aggregates and filler were sieved and combined in order to meet a specified gradation of the binder course layer according to SCRB, [21]. The combined aggregate was heated to a temperature of (110°C) before mixing with (emulsion or cutback asphalt), then the optimum requirement of liquid asphalt (6.8 and 5.8)% for the WMA-emulsified asphalt and WMA-cutback asphalt respectively at 20°C was added to the preheated aggregate to reach the desired amount of asphalt content, and mixed thoroughly by hand by the spatula for 3 minutes until all aggregates were coated with thin layer of asphalt. Mixtures with 0.5% of liquid asphalt above and below the optimum have also been prepared to verify the impact of asphalt content on the temperature susceptibility. The procedure of obtaining the optimum asphalt content and the volumetric properties was published elsewhere, [11]. The cylinder specimens (63.5 mm) in height and (101.6 mm) in diameter were compacted with Marshall Hammer using 75 blows on each side, ASTM, [20]. Specimens were removed from the mold after 24 hours. In case of cutback asphalt mixtures, specimens were collapsed after removal from the mold because there was not enough time for evaporation of the volatile's materials contained in the asphalt components. Therefore, after several attempts using different curing periods and based on the literature, [15] and [17], it was decided to implement Short-Term Aging (STA) technique as prescribed by AASHTO, [22]. Figure 3 shows group of the prepared cylindrical samples.

**Figure 3.** Part of the prepared cylindrical specimen for temperature susceptibility.

### 2.9. Short Term Aging (STA)

The loose mixture of cutback-aggregate was placed in the pan and spread to a thickness of 30 mm, then stored in a conditioning oven for 4 hours ± 5 min. at 135 ± 3°C. The mixture was stirred every 1 hours throughout the (STA) process in order to obtain a homogeneous aging process. At the end of the aging period, the mixture was cooled to the compaction temperature of 100°C and poured into the mold and subjected to 75 blows on the top of the sample and 75 blows on the bottom of the sample with Marshal compaction hammer. This procedure was implemented in accordance AASHTO, [22]. This aging signifies to the aging which occurs in the field among mixing and placement which allows for absorption of the asphalt into the pores of aggregate and evaporation of the volatiles of a binder.

## 3. Results and Discussion

### 3.1. Effect of Testing Temperature on ITS

As demonstrated in Figure 4, the ITS values at OAC and 25°C increased by (30.59 and 23.9)% when cutback asphalt and emulsion were implemented respectively as compared to asphalt cement. On the other hand, The ITS values at OAC and 5°C increased by (11.77 and 4.14)% when cutback asphalt and emulsion were implemented respectively instead of asphalt cement. Such behavior of materials complies with the findings by [23].

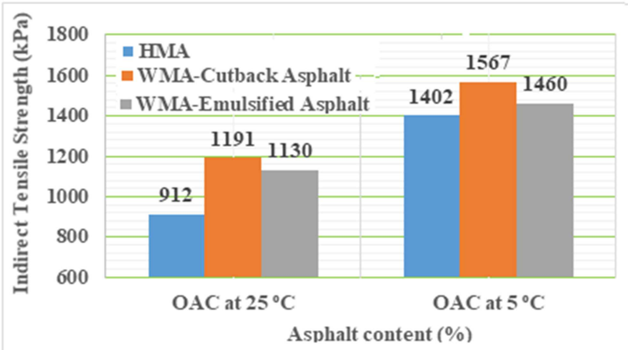


**Figure 4.** Effect of Testing Temperature on ITS according to the Asphalt binder Type.

The reduction of ITS is significant when increasing the testing temperature since the increase of temperature causes reduction in the cohesion of aggregate particles of asphalt mixture due to the reduction in viscosity of asphalt. On the other hand, the reduction in adhesion between asphalt and aggregate leads to lower the tensile strength. Different percentages of asphalt content have been tried, namely OAC ± 0.5% in order to study the impact of the variation in asphalt content on the ITS value tested at 25°C for different mixtures as shown in Figure 5. The results of HMA show that the ITS decreased by (25.10 and 23.14)% when the asphalt content increased or decreased by 0.5% from OAC respectively, this gives an indication that at the OAC, the asphalt mixture has good resistance to ITS, such behavior of materials comply with the findings by [24]. The results of WMA-cutback asphalt show that the ITS at OAC equal to 1191 kPa and when the asphalt content increased or decreased by 0.5% from OAC, specimen was fractured. The results of WMA-emulsified asphalt show that the ITS was decreased by (28.58 and 4.51)% when the asphalt content increased or decreased by 0.5% from OAC respectively.

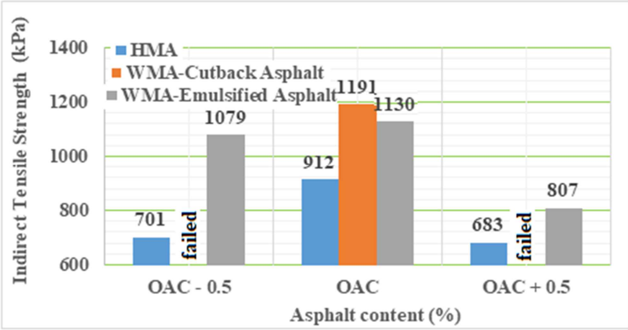


**Figure 5.** Effect of Asphalt Content on the ITS at 25°C.

Figure 6 demonstrates the ITS test results at 5°C. It can be observed that for HMA, the ITS was decreased by (6 and 13.62)% when the asphalt content increased or decreased by 0.5% from OAC respectively. on the other hand, the results of WMA-cutback asphalt at 5°C show that the ITS was decreased by 5.68% when the asphalt content decreased by 0.5 from OAC and when the asphalt content increased by 0.5% from OAC, specimen was fractured.

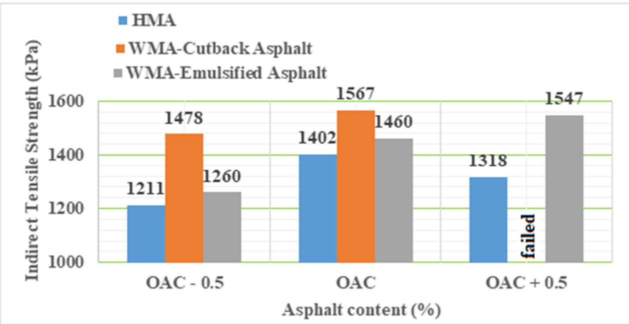


**Figure 6.** Effect of Asphalt Content on The Indirect Tensile Strength at 5°C.

The results of WMA-emulsified asphalt at 5°C show that the ITS was increased by 5.96% and decreased by 13.7% when the asphalt content increased or decreased by 0.5% from OAC respectively. The increase and decrease in the asphalt content by 0.5% from OAC cause reduction in ITS due to the increment in the asphalt content which produces thicker films around the individual aggregate particles, therefore tend to thrust the aggregate further separately subsequently. The reduction in the asphalt content increases the stiffness of the mixture, that causes reduction in the required cohesion between asphalt and aggregate which leads to weaken the tensile strength.

### 3.2. Effect of Asphalt Type and Content on Temperature Susceptibility

The Temperature Susceptibility (TS) results exhibited in Table 6 showed that the HMA was more influenced by temperature than WMA. The results show that the TS of HMA is higher than that of WMA-cutback asphalt by 26.3% while it is higher than WMA-emulsified asphalt by 41.1% respectively at optimum asphalt content, such behavior of materials comply with the findings of [14, 17]. The results show that the TS for WMA-cutback asphalt was lower than HMA due to the less binder content in this mixture, nature of aged materials and the hardening of the asphalt which lead to mixture of less susceptibility to temperature variation. Table 6 show that the TS for WMA-emulsified asphalt is lower than HMA due to the lesser binder content of this mixture than HMA since emulsified asphalt contain some of water and emulsifying agent. It can also be observed that WMA-Emulsified asphalt exhibits the lowest temperature susceptibility among other tested mixtures at various asphalt percentages. The cutback treated mixture was sensitive to the change in asphalt content, specimens with ± 0.5 asphalt rather than OAC collapsed during the test. Similar findings have been reported by [25, 26].

**Table 6.** Effect of Asphalt Type and Content on the Temperature Susceptibility.

| HMA | | WMA-Cutback Asphalt | WMA-Emulsified Asphalt |
|---|---|---|---|
| **Asphalt content%** | **Temperature Susceptibility (kPa/°C)** | **Temperature Susceptibility (kPa/°C)** | **Temperature Susceptibility (kPa/°C)** |
| OAC-0.5 | 26 | Failed | 9 |
| OAC | 24 | 19 | 17 |
| OAC+0.5 | 32 | Failed | 24 |

Table 7 summarizes the ITS test results at OAC and two testing temperature which furnishes the data for TS calculation.

**Table 7.** Effect of Temperature on the Indirect Tensile Strength at OAC.

| HMA | | WMA-Cutback Asphalt | WMA-Emulsified Asphalt |
|---|---|---|---|
| **Asphalt%** | **ITS kPa** | **ITS kPa** | **ITS kPa** |
| OAC at 25°C | 912 | 1191 | 1130 |
| OAC at 5°C | 1402 | 1567 | 1460 |

## 4. Conclusions

Based on the limitations of the testing program, the following conclusions may be drawn.

1. WMA have higher ITS at 25°C than HMA by 30.59% and 23.9% when using cutback asphalt and emulsified asphalt with WMA respectively, on the other hand, WMA have higher ITS at 5°C than HMA by 11.77% and 4.14% when using cutback asphalt and emulsified asphalt with WMA

respectively.

2. The ITS at 25°C was decreased by (25.10 and 28.58)% and by (23.14 and 4.51)% when the asphalt content increased or decreased by 0.5% from OAC for HMA and WMA- emulsion asphalt respectively. For WMA-cutback asphalt, the ITS value at OAC equal to 1191 kPa and it exhibit sensitive behavior to the variation in asphalt content.
3. WMA are less susceptible to temperature variation than HMA, the temperature susceptibility values were (17 and 19) kPa/°C for the WMA-emulsified asphalt and WMA-cutback asphalt respectively, which are lower than that of HMA by 29.17% and 20.83% respectively.
4. The ITS values of WMA at OAC and 5°C increased by (11.77 and 4.14)% when cutback asphalt and emulsion were implemented respectively as compared to HMA.
5. The ITS values of HMA decreased by (6 and 13.62)% when the asphalt content increased or decreased by 0.5% from OAC respectively, while for WMA-cutback asphalt at 5°C, the ITS decreased by 5.68% when the asphalt content decreased by 0.5 from OAC.
6. Temperature susceptibility of HMA is higher than that of WMA-cutback asphalt and WMA-emulsified asphalt by 26.3% and 41.1% respectively at optimum asphalt content.
7. Warm mix asphalt concrete can be considered as a green and sustainable pavement due to its lower susceptibility to temperature variation as well as lower mixing, handling and compaction temperature.

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