**International Journal of Advanced Materials Research**
Vol. 5, No. 1, 2019, pp. 1-11
http://www.aiscience.org/journal/ijamr
ISSN: 2381-6805 (Print); ISSN: 2381-6813 (Online)

# Comparative Assessment of Resilient Characteristics of Warm and Hot Mix Asphalt Concrete

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## Abstract

The resilient characteristics is a measure to the flexibility of asphalt concrete. Asphalt concrete mixtures were prepared using the hot mix HMA and the warm mix WMA techniques. Specimens of 102 mm diameter and 63.5 mm height for hot mix were mixed and compacted using Marshal method at 150°C, while the two type of warm mixtures were mixed and compacted at 110°C using medium curing cutback and cationic emulsion. Specimens were subjected to repeated indirect tensile stresses ITS, and repeated double punch shear stress. Another group of specimens were subjected to moisture damage. A third group of specimens of 102 mm in diameter and 102 mm in height were tested under repeated compressive stress. Beam specimens 380 mm in length, 80 mm width and 50 mm height were prepared under static compaction to the same target density. The deformation (total, permanent and resilient) were monitored and the resilient modulus Mr under each testing technique was calculated. Higher Mr could be observed for HMA mixture under tensile and shear stresses when compared to the WMA mixtures, while the WMA shows higher Mr values than HMA under compressive and flexural stresses.

## Keywords

Warm Mix, Asphalt Concrete, Resilient, Modulus, Repeated Load, Deformation

Received: December 28, 2018 / Accepted: January 23, 2019 / Published online: March 5, 2019



## 1. Introduction

The resilient characteristics is a measure to the flexibility of asphalt concrete, when implementing new mixing and compaction techniques such as in the case of warm mix, the resilient properties of the mix should be assessed, [1]. Use of warm mix asphalt WMA is gaining popularity in the asphalt industry. Warm mix asphalt WMA technologies are capable of significantly reducing the production and placement temperatures of asphalt mixes. An attempt has been made by Panda et al [2] to prepare warm mixes by first pre-coating the aggregates with medium setting bitumen emulsion MS and then mixing the semi-coated aggregates with bitumen at a lower temperature than normally required. It has been observed that out of three mixing temperatures of (110, 120 and 130)°C tried, the mixes prepared at 120°C with bitumen-emulsion composition warm mix, offer highest Marshall stability and highest indirect tensile strength ITS, while satisfying the other Marshall parameters. The tensile strength ratio and retained stability parameters are also found to be reasonably satisfactory in such warm mixes. It was concluded by Vaitkus et al [3] that the properties of WMA mixture produced in 120°C showed best results when compared to another studied technologies. Stability, flow and values of indirect tensile strength were less scattered and were like those of control mixture produced in 150°C temperature. Laboratory tests were carried out by Jalali [4] to characterize the WMA mixtures and their counterpart reference HMA mixtures through studying and understanding the influence of reduced production temperatures on their

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mechanical performance characteristics, including volumetric properties, stiffness modulus, fatigue resistance, rutting potential and viscoelastic behavior. The results show that compaction at lower temperatures does not have a considerable effect on the performance of asphalt mixtures, unless it occurs below 100°C, in which case, despite some limited negative influences on asphalt performance, overall behavior remains in acceptable ranges. The lower the compaction temperature, the more the damage of freezing on asphalt Mixtures. The resistance of the WMA mixtures to permanent deformation, in general, is as much as or much more than the standard reference HMA. It was stated by Wu et al [5] that it is generally believed that rutting and moisture damage are the two major concerns for WMA. These two distresses are thought to be due to less ageing of the binder at the lower mixing/compaction temperatures used to produce WMA and the possibility of moisture in the water-based/containing WMA products, respectively. On the other hand, fatigue and thermal cracking are of less concern, again, due to less ageing of the binder in WMA. As for the rutting behavior, the study by Prowell et al, [6] reveals quite controversial results with most of the WMA showing an increase in rut depth. The results indicate that for WMA, the resistance against permanent deformation could become critical. As opposed to this finding, fatigue resistance of all aged WMA compared to unaged mixtures improved significantly resulting in an increase of fatigue life for the aged mixtures as expected due to increasing binder stiffness. The influence of moisture damage on the resilient properties of hot and warm mixtures asphalt concrete was investigated by Hasan et al, [7]. Based on the TSR test, it was reported that WMA mixes resulted in an increase in moisture-induced damage potential compared to HMA mixes. The fatigue behavior, indirect tensile strength ITS and resilient modulus test results for warm mix asphalt WMA as well as hot mix asphalt HMA at different ageing levels were evaluated by Sarsam, [8]. It was concluded that The ITS values increase as the ageing level of the mixture increases from unaged to long term aged. Warm mixes show higher tensile strength as opposed to control mixtures. ITS values do not have significant changes from long term aged to extra aged. The warm asphalt additives do not have a significant effect on moisture susceptibility of the mixes compared with the control mixes. A recent study by Nihad and Sarsam, [9] had concluded that HMA specimen can sustain more than 100% of load repetitions to failure higher as compared to WMA, On the other hand, the tensile strain of WMA with cutback and emulsion was (37.5 and 54)% lower than that of HMA respectively. It was reported by Sarsam and Zainalabiden [10] that the WMA has less Mr than HMA under repeated ITS. The Mr at 25 $^0$C under repeated ITS are (230 and 276) MPa for WMA-cutback asphalt and WMA-emulsified asphalt respectively. Both were lower than HMA by (39.95 and 27.94)% respectively. The Mr at 25 $^0$C under repeated compression load were (184 and 135) MPa for WMA-cutback asphalt and WMA-emulsified asphalt respectively. Both were higher than HMA by (43.75 and 5.47)%, respectively. One of the advantages of WMA is that the low viscosity of liquid asphalt will furnish the required perfect coating of aggregates and the workability for compaction, while the curing period will provide the increment in mechanical strength, and durability during traffic exposure, [11, 12]. Another investigation that was conducted by Miller and Bahia [13] indicated that the indirect tensile strength exhibits no significant difference between the WMAC mixes and the HMAC control mix. It was observed by Izadi and Mirzaiyan [14] that the critical stress intensity factor of HMA mixtures was higher than that of WMA mixtures. The ITS value for WMA mixtures was higher than HMA mixes. It was stated by Cucalon et al, [15] that the available WMA technologies can improve, deteriorate, or have a minimal effect on mixture performance. The selection of modifier type should be optimized for binder/aggregate combinations. The study by Du, [16] used dense-graded aggregate with three nominal maximum aggregate sizes of 9.5mm, 12.5mm and 19mm, it was evaluated by stability, indirect tensile strength, moisture sensitivity and permanent deformation test. The results show that the stabilities are satisfied by the specification requirements and indirect tensile strengths of tensile strength ratios are higher than the requirement of 80%. Based on two-way analysis of variance, the stability, tensile strength ratios TSR and permanent deformation values by different aggregate types have no significant effect. It was concluded that WMA with asphalt emulsion can be an alternate for pavement construction. Guidelines for the evaluation of warm-mix asphalt WMA moisture susceptibility, including a flowchart and several thresholds for laboratory tests, were developed by Yin et al, [17] based on a limited number of WMA mixtures. A laboratory experiment was completed to evaluate the effect of various moisture conditioning protocols and specimen drying methods on moisture susceptibility laboratory test parameters. The influence of mixing and compaction temperature on mix design and mechanical and workability properties of WMA mixtures have been evaluated by Kumar and Suresha [18]. Asphalt mix design properties were evaluated by the Marshall method and the Superpave method. Mechanical properties such as rutting resistance were evaluated by wheel tracking test, and the resistance to moisture-induced damage was evaluated by the Tensile Strength Ratio (TSR) approach. It was concluded that WMA mixtures prepared at lower compaction temperatures exhibited higher resistance to rut deformation because of higher Traffic Densification Index values. A comprehensive laboratory programme was conducted by Sebaaly et al, [19] to assess the impact of WMA in terms of stiffness and mixtures' resistance to moisture damage, rutting, fatigue cracking, and thermal cracking. Overall, the WMA mixtures performed comparatively like the hot mix asphalt HMA mixtures. The impact of the WMA technology was found to be aggregate dependent. A study by Kamarudin et al [20] has concluded that WMA mixture has lower rate of cooling in the field where the temperature of WMA mixture decreases slowly but still provides higher density. WMA also has higher degree of compaction which provides better workability of compaction compared to HMA mixture. Other than that, WMA mixture has lower resilient modulus than HMA mixture which could suggest that WMA mixture is more susceptible to rutting. Cracking and permanent deformation resistance were assessed by Bhargava et al, [21] in terms of tensile strength. The influence of temperature on the tensile strength and both stress and temperature levels on the permanent deformation response of aged and moisture conditioned warm mix asphalt were investigated. Results show that moisture and increase in temperature had a negative impact on the tensile strength of warm mix asphalt while aging had a positive impact. However, the variation in tensile strength of mixtures was strongly related to variation in percent air voids. Aging and interestingly moisture conditioning found to increase the resistance to permanent deformation of warm mix asphalt. It was stated by Bower et al, [22] that the effects of WMA production temperature on rutting (negatively) and thermal cracking (positively) seem to be pronounced when the WMA production temperature is less than 130°C.

The aim of this investigation is to compare the resilient characteristics (deformation and modulus) of hot and warm mix asphalt concrete under various loading conditions of (flexure, shear, compressive and tensile) stresses applied through an intensive testing program. The influence of moisture damage and testing temperature on the resilient modulus was also investigated.

# 2. Materials and Methods

## 2.1. Asphalt Cement

Asphalt cement of penetration grade 40-50 was brought from Al-Dura refinery and used for hot mix asphalt concrete specimens. Tests conducted on asphalt cement confirmed that its properties complied with the specifications of State Commission of Roads and Bridges SCRB [23]. Table 1 presents the physical properties of asphalt cement.

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

| Property as per ASTM, [24] | Result | Unit | SCRB Specification, [23] |
|---|---|---|---|
| Penetration (25°C, 100g, 5 sec) ASTM D5-97 | 43 | 1/10mm | 40-50 |
| Softening Point (Ring & Ball) ASTM D5-36 | 48 | °C | ------- |
| Ductility (25°C, 5cm/min) ASTM D113-07 | 156 | cm | >100 |
| Kinematic viscosity at 135°C ASTM D-2170 | 551 | C St. | _____ |
| Specific gravity at 25°C ASTM D-70 | 1.04 | _____ | (1.01-1.05) |
| After Thin-Film Oven ASTM D1754 | | | |
| Retained penetration of original,% D946 | 67 | % | >55% |
| Ductility at 25°C, 5cm/min. | 96 | cm | >25 |
| Loss in weight (163°C, 50g, 5h) ASTM D1754 | 0.22 | % | < 0.75 |

## 2.2. Emulsified Asphalt

Cationic Emulsified asphalt was used as binder for warm mix asphalt concrete production, it was brought from state company for mining industries. Tests conducted on Emulsified asphalt confirmed that its properties comply with the ASTM, [24]. Table 2 exhibit its properties as supplied by the producer.

## 2.3. Cutback Asphalt

Medium curing Cutback asphalt (MC-30) was used as a binder for warm mix asphalt concrete production. It was brought from Al-Dura refinery. Tests conducted on Cutback Asphalt confirmed that its properties complied with the ASTM, [24]. Table 3 shows its properties as supplied by the refinery.

**Table 2.** Physical Properties of Cationic Emulsified Asphalt.

| Test | ASTM Designation | Results | Specification Limits ASTM [24] | |
|---|---|---|---|---|
| | | | Min. | Max. |
| Particle Charge Test | ASTM D244 | Positive | Positive | — |
| Saybolt Furol viscosity at (50°C) | ASTM D245 | 250 | 50 | 450 |
| Storage Stability Test, 24 h (%) | | 0 | — | 1 |
| Coating Stability and Water Resistant | | | | |
| Coating - Dry Aggregate | | Good | Good | — |
| Coating - After Spraying | | Fair | Fair | — |
| Coating - Wet Aggregate | | Fair | Fair | — |

| Test | ASTM Designation | Results | Specification Limits ASTM [24] | |
|---|---|---|---|---|
| | | | Min. | Max. |
| Coating - After Spraying | | Fair | Fair | — |
| Sieve Test (%) | ASTM D6933 | 0 | — | 0.1 |
| Distillation | | 6 | — | 12 |
| Oil Distillate by Volume of Emulsion% | | 85 | 65 | — |
| Tests on Residue from Distillation Test | | | | |
| Penetration, 25°C, 100 g, 5 s | ASTM D5 | 135 | 100 | 250 |
| Ductility, 25°C, 5 cm/min | ASTM D113 | 185 | 40 | — |
| Solubility in Trichloroethylene | ASTM D2042 | 99 | 97.5 | — |
| Specific Gravity at 25°C | ASTM D70 | 1.02 | — | — |
| Residue by Distillation,% | ASTM D6997 | 55.3 | 57 | — |
| Residue By Evaporation | ASTM D6934 | 54.9 | 50 | 70 |
| Cement Mixing Test,% | ASTM D6935 | 0.732 | — | 2 |
| Settlement Test, 5day,% | ASTM D6930 | 0.1 | 0 | 1 |
| Day Storage Stability test, 24 h,% | ASTM D6930 | 0.04 | 0 | 1 |

**Table 3.** Physical Properties of Cutback Asphalt.

| Test | Result | limits of Specification | | ASTM [24] Designation |
|---|---|---|---|---|
| Grade | MC-30 | Min. | Max. | |
| Flash Point (C.O.C)°C (min) | 38 | 38 | — | ASTM D3143 |
| Kinematic Viscosity @ 60°C, Cst, | 40 | 30 | 60 | ASTM D2170 |
| Dynamic Viscosity @ 60°C, Pa. s | | 30 | 120 | ASTM D4402 |
| Water% V (max) | 0.2 | — | 0.2 | ASTM D95 |
| Density, kg/m$^3$ | 0.91 | 0.91 | 0.93 | |
| Distillation Test to 360°C, Distillate% V of Total Distilled | | | | |
| To 225°C (max) | 25 | — | 35 | ASTM D402 |
| To 260°C (max) | | 30 | 75 | ASTM D402 |
| To 316°C (max) | | 75 | 95 | ASTM D402 |
| Residue from Distillation to 360°C% V (min) | | 50 | — | ASTM D402 |
| Tests on Residue from Distillation | | | | |
| Penetration @ 25°C (100 g, 5 sec., 0.1 mm) | 150 | 120 | 250 | ASTM D2027 |
| Ductility @ 25°C (cm) (min) | 100 | 100 | — | ASTM D2027 |
| Solubility in Trichloro Ethylene% wt. (min) | 99 | 99 | — | ASTM D2027 |

## 2.4. Mineral Filler

Mineral filler used in this study is Portland cement, it was produced by Al-Mas Company and obtained from the local market, the physical properties of the filler are listed in Table 4.

**Table 4.** Physical Properties of Portland cement.

| Property | Test result | SCRB Requirements [23] |
|---|---|---|
| % Passing Sieve No. 200 (0.075mm) | 98 | 95 |
| Bulk Specific Gravity | 3.1 | — |
| Fineness by Blaine (m$^2$/kg) | 312.5 | ≥ 230 |

## 2.5. Coarse and Fine Aggregate

Crushed coarse aggregate (retained on sieve No. 4) was obtained from AL-Nibaee quarry. Such aggregates are widely used in Baghdad city for asphalt concrete mixes. Crushed sand and natural sand were used as Fine aggregate (particle size distribution between sieve No. 4 and sieve No. 200). It consists of hard, tough grains, free from loam and other deleterious substances. Coarse and fine aggregate were tested for physical properties and Table 5 exhibit the test results.

**Table 5.** Physical Properties of Coarse and Fine Aggregate.

| Laboratory Test | ASTM [17] Designation | Test Results | SCRB [23] Specification |
|---|---|---|---|
| Coarse Aggregate | | | |
| Apparent Specific Gravity | ASTM C127 | 2.642 | — |
| Bulk Specific Gravity | ASTM C127 | 2.61 | — |
| Water Absorption,% | ASTM C127 | 1.471 | — |
| Emulsion Absorption,% | ASTM D4469 | 1 | — |
| Cutback Absorption,% | ASTM D4470 | 0.6 | — |
| AC grade (40-50) Absorption,% | ASTM D4471 | 0.4 | — |
| Percent Wear (Los Angeles Abrasion),% | ASTM C131 | 19.5 | 30 Max |
| Fine Aggregate | | | |

| Laboratory Test<br>Coarse Aggregate | ASTM [17] Designation | Test Results | SCRB [23] Specification |
|---|---|---|---|
| Apparent Specific Gravity | ASTM C128 | 2.683 | — |
| Bulk Specific Gravity | ASTM C128 | 2.631 | — |
| Water Absorption,% | ASTM C128 | 3.734 | — |
| Emulsion Absorption,% | ASTM D4469 | 1.4 | — |
| Cutback Absorption,% | ASTM D4470 | 0.9 | — |
| Asphalt Cement Absorption,% | ASTM D4471 | 0.6 | — |

## 2.6. Selection of Aggregate Gradation and Preparation of Hot Mix Asphalt Concrete (HMA)

The selected gradation in this study followed the SCRB, [23] specification, with 19 (mm) nominal maximum size. Table 6. Shows the selected gradation for binder course. The aggregates were sieved and separated to different sizes, then combined to meet the specified gradation for binder course layer, SCRB, [23]. The combined aggregate was heated to temperature of 160°C, while the asphalt cement was heated to a temperature of 150°C to produce a kinematic viscosity of (170 ± 20) centistokes. The hot asphalt cement was added to the heated aggregate to achieve the required amount of asphalt content. The aggregate and the asphalt were mixed in mixing bowl by hand on hot plate for three minutes until asphalt had sufficiently coated the surface of the aggregates, while the mixing temperature was maintained to 145°C.

**Table 6.** Grain size distributions of the design mix.

| Sieve size (mm) | 25.4 | 19.2 | 12.5 | 9.5 | 4.75 | 2 | 1 | 0.6 | 0.25 | 0.125 | 0.075 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % finer by weight | 100 | 93 | 76 | 66 | 63 | 35 | 26 | 20 | 14 | 10 | 7 |

## 2.7. Preparation of Warm Mix Asphalt Concrete (WMA) with Emulsion and Cutback Asphalt

The aggregates were sieved and separated to different sizes, then combined to meet the specified gradation for binder course layer, SCRB, [23]. The combined aggregate mixture was heated to temperature of 110 $^0$C before mixing with liquid asphalt (emulsion or cutback), then the optimum requirement of liquid asphalt at 20°C was added to the heated aggregate to achieve the desired amount and mixed thoroughly by hand using a spatula for two minutes until all aggregate particles were coated with asphalt. The procedure of obtaining the optimum asphalt content and the volumetric properties were published elsewhere, [9, 10]. The mixture of liquid asphalt and aggregate was then transferred to the cylinder 102 mm diameter and 63.5 mm height or to the cylinder of 102 mm diameter and 102 mm height, or to beam mold of 380 mm in length, 80 mm in width and 50 mm in height. Cylinder and Beam mold and spatula, were heated in the oven to a temperature of 110 $^0$C, A piece of non-absorbent paper, was placed in the bottom of the mold before the mixture was poured into the mold, then the asphalt mixture was placed in the preheated mold, and spaded vigorously with a heated spatula 15 times around the perimeter and 10 times around the interior and carefully finished to have uniform surface elevation. Another piece of non-absorbent paper was placed on the top of the mixture. The beam mold was inserted into the compression device and subjected to static compaction to the target density. Specimens were withdrawn from the mold after 24 hours. For cylinder mold, the mixture was poured into the mold and spaded vigorously with a heated spatula 15 times around the perimeter and 10 times around the interior and carefully finished to have uniform surface elevation. The mixtures practice the 75 blows of Marshall hammer on both sides. In case of cutback asphalt mixtures, specimens were collapsed after withdrawal from the mold, then it was decided to use the short-term aging technique as prescribed by AASHTO, [25].

## 2.8. Short Term Aging (STA)

The loose mixture of cutback-aggregate was placed in a pan and spread to an even thickness ranging between 35 mm, the mixture in the pan was placed in the conditioning oven for 4 h ± 5 min. at 135 ± 3°C and the mix was stirred every 60 minutes during the short-term aging process to obtain a homogeneous aging process. At the end of the aging period, the mixture was cooled to the compaction temperature of 110°C and poured into the mold and practices the 75 blows of Marshall hammer on both sides. This procedure was carried out in accordance with AASHTO, [25]. Figure 1 shows the pneumatic repeated load system PRLS and part of the prepared beam and cylinder specimens.

## 2.9. Repeated Flexural Bending Test

The beam specimens were subjected to repeated flexural bending in the Laboratory using pneumatic repeated Load system apparatus (PRLS) shown in Figure 1. Four-point loading test with free rotation beam holding fixture at all loading and reaction point was used to estimate deformation and micro cracking potential in the flexural beam fatigue test.

The numbers of loading cycles that initiates micro crack failure of the beam is commonly considered as indicator of fatigue cracking potential. The specimen was left in conditioned chamber for one hour at testing temperature 25°C to allow uniform distribution of temperature within the specimen and the position of applied loading was marked on the specimens.

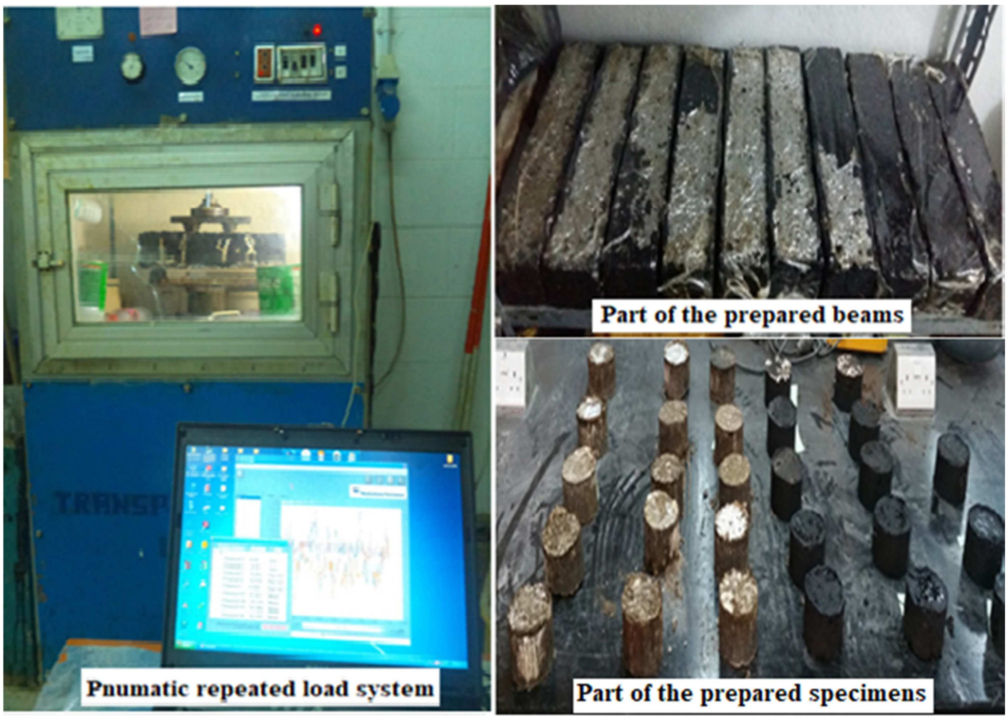


**Figure 1.** PRLS and the prepared specimens.

Dial gages and a video capture have been used to monitor the deformation (total, permanent, and resilient) of the beam under each load cycle and Positioned onto the specimen and set to zero. The repetitive flexural stress was through a heavier sine pulse of (0.1 sec. load duration and 0.9sec. rest period) applied to the specimen and the flexural deformation at the central third of the specimen is measured under each load repetitions as recommended by Nihad and Sarsam, [9] and Sarsam and Zainalabiden, [10]. Before the test, Specimens were stored in the chamber of the testing machine at room temperature 25±1°C, dial gage of the deformation reading was set to zero before test start and the pressure actuator was adjusted to the specific stress level equal to 69 kPa. A digital video camera was fixed on the top surface of the (PRLS) to capture dial gage reading. The test start to allow for the initiation of micro cracks and stopped after 1200 load repetitions or when the specimen fail. Data have been analyzed, and the plot of strain-load repetitions was conducted.

## 2.10. Repeated Indirect Tensile Stress, Double Punch Shear and Compressive Stress Test

The test was conducted according to ASTM, [24]. The Pneumatic repeated load system (PRLS) shown in Figure 1 was implemented. The first set of asphalt concrete specimens was subjected to repeated indirect tensile stress for 1200 load repetitions at 25°C to allow the initiation of micro cracks. Such timing and test conditions were suggested by Nihad and Sarsam, [10]. Compressive repeated loading was applied on the specimen which was centered on the vertical diametrical plane through two parallel loading strips 12.7 mm wide. Such load assembly applies indirect tensile stress on the specimen in the form of rectangular wave with constant loading frequency of (60) cycles per minutes. A heavier sine pulse of (0.1) sec load duration and (0.9) sec rest period was applied over the test duration. Before the test, Specimens were stored in the chamber of the testing machine at room temperature 25±1°C, dial gage of the deformation reading was set to zero before test start and the pressure actuator was adjusted to the specific stress level equal to 69 kPa. A digital video camera was fixed on the top surface of the (PRLS) to capture dial gage reading. The test was continued for 1200 load repetitions, upon completion of test, the recording was terminated. The average of two specimens was calculated and considered for analysis as recommended by Sarsam and Husain [26]. Figure 2 demonstrates the repeated (ITS) test assembly. The second set of asphalt concrete specimens was subjected to repeated double punch shear stresses for 1200 load repetitions at 25°C to allow the initiation of micro cracks. Compressive repeated loading was applied on the specimen which was centered between the two plungers of

25.4mm diameter as per the procedure described by Sarsam and Husain [26]. Such load assembly applies compressive load which was resisted by the specimen through shear force between the plunger and the surface of the specimen. The stress on the specimen is in the form of rectangular wave with constant loading frequency of (60) cycles per minutes. A heavier sine pulse of (0.1) sec load duration and (0.9) sec rest period was applied over the test duration. Before the test, Specimens were stored in the chamber of the testing machine at room temperature 25±1°C, dial gage of the deformation reading was set to zero before test start and the pressure actuator was adjusted to the specific stress level equal to 69 kPa. A digital video camera was fixed on the top surface of the (PRLS) to capture dial gage reading. The test was continued for 20 minutes, upon completion of test, the recording was terminated. The average of two specimens was calculated and considered for analysis. Figure 2 demonstrates the repeated (PSS) test assembly. The specimens were subjected to axial repeated compressive loading using the pneumatic repeated load system PRLS shown in Figure 1. The test was performed on cylindrical specimens, 102 mm in diameter and 102 mm in height. In this tests, repetitive compressive loading was applied to the specimen and the axial deformation was measured under the successive loading repetitions. Compressive loading was applied in the form of rectangular wave with a constant loading frequency of 60 cycles per minute and includes 0.1 second load duration and 0.9 second rest period. The stress level of 69kP and temperatures 25°C were used in the tests. The specimen was left in the conditioned chamber for one hour at testing temperature (25°C) to allow for uniform distribution of temperature within the specimen. Dial gages and video capture have been used to monitor the deformation of the specimen under each load cycle and Positioned onto the specimen and set to zero. Then, the recorded data was analyzed for finding strain at any number of load cycles desired for every test. The test start to allow for the initiation of micro cracks and was stopped after 1200 repetitions or when failure occurs, then specimens were withdrawn from the testing chamber. Figure 2 demonstrates the test techniques implemented.

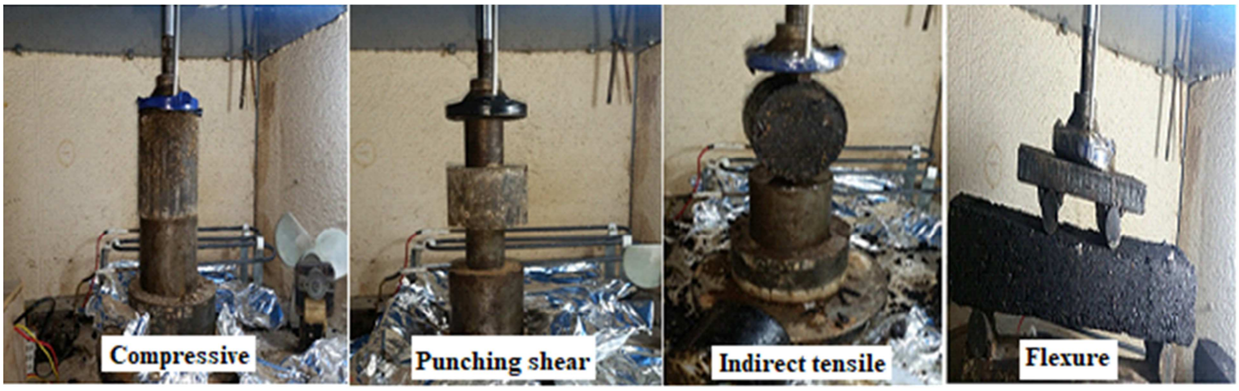


**Figure 2.** Testing technique of the prepared specimens.

## 3. Results and Discussions

### 3.1. Assessment of Resilient Modulus Mr of Asphalt Concrete

The resilient modulus Mr was assessed using four testing techniques by implication of (tensile, shear, compressive, and flexure) stresses application at 25°C using the pneumatic repeated load system PRLS. Variation of Mr could be observed among different testing techniques for various asphalt concrete mixtures. The variation of Mr under testing techniques may be attributed to the size of the specimen (cylinder or beam) and the loading sequence (diametral, facial or four-point bending scheme). Figure 3 exhibit the variation in resilient modulus among testing technique and mixture type.

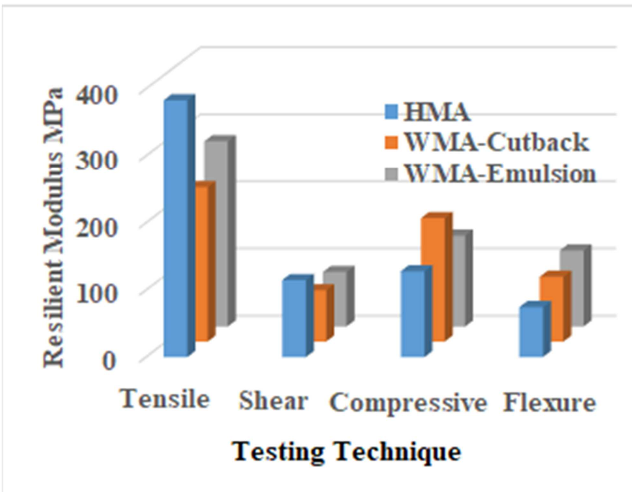


**Figure 3.** Influence of testing technique on Mr.

For HMA mixture, the values of Mr decreased by (70, 66.5, and 80)% for testing technique under (shear, compressive, and flexure) stresses as compared to that under tensile stress. Similar trend of reduction in Mr among various testing techniques could be noticed for WMA with cutback and emulsion. For WMA-Cutback mixture, the values of Mr decreased by (66.5, 20, and 58)% for testing technique under (shear, compressive, and flexure) stresses as compared to that under tensile stress. For WMA-Emulsion mixture, the values of Mr decreased by (70.5, 51, and 59)% for testing technique under (shear, compressive, and flexure) stresses as compared to that under tensile stress. On the other hand, higher Mr could be observed for HMA mixture under tensile and shear stresses when compared to the WMA mixtures, while the WMA exhibits higher Mr values than HMA under compressive and flexural stresses. Such findings agree well with the work reported by Sarsam and Zainalabiden, [10], and López, 11].

### 3.2. Influence of Moisture Damage on Mr

The influence of moisture damage on Mr under indirect tensile stress is demonstrated in Figure 4, it can be observed that the moisture damage has negative impact on Mr for various asphalt concrete mixtures. The Mr decreases after moisture damage by (42, 25, and 58)% for HMA, WMA-Cutback, and WMA-Emulsion respectively when compared to the case before moisture damage. Such behavior could be attributed to the possible initiation of micro cracks and the stripping of asphalt binder after practicing the moisture damage. Similar findings were reported by Wu et al, [5], Hasan et al, [7], Du, [16], Kumar and Suresha, [18].

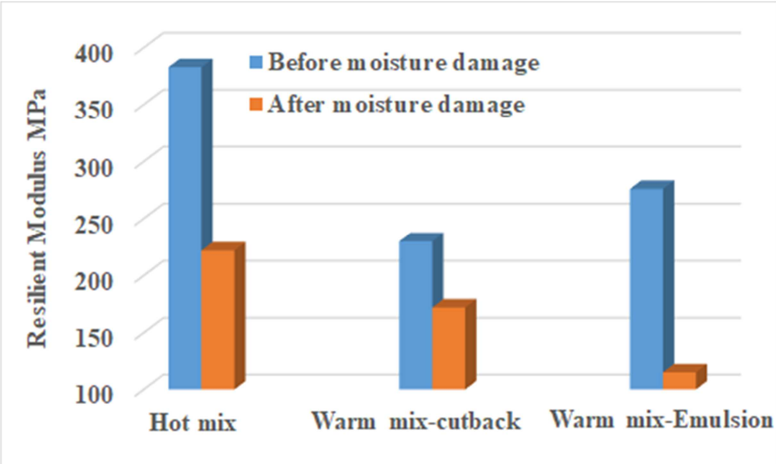


**Figure 4.** Influence of moisture damage on Mr.

### 3.3. Influence of Testing Temperature on Mr

The influence of testing temperature on Mr under indirect tensile stress is demonstrated in Figure 5, it can be noticed that lower testing temperature of 5°C exhibit higher Mr by (12.5, 25, and 25)% than that at 25°C for HMA, WMA-Cutback, and WMA-Emulsion respectively. Such behavior could be attributed to the fact that the liquid asphalt in WMA (cutback and emulsion) exhibit increment of viscosity by two folds at low temperature of 5°C as compared to the asphalt binder in HMA. Such finding agrees well with Bhargava et al, [21] work.

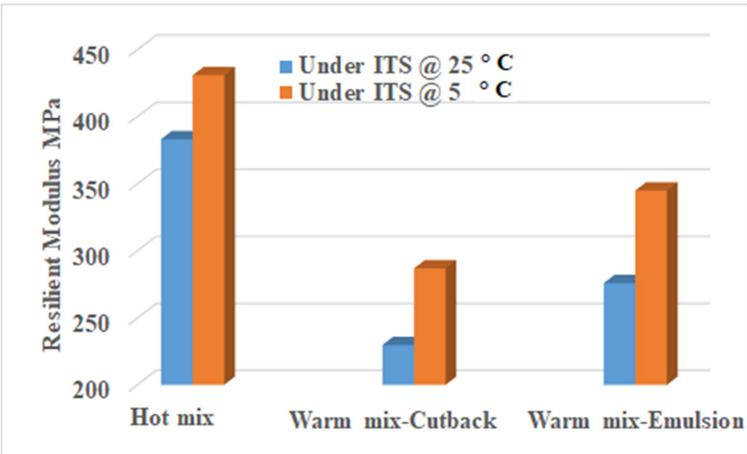


**Figure 5.** Influence of testing temperature on Mr.

### 3.4. Assessment of Deformation of Asphalt Concrete

As demonstrated in Figure 6, HMA is highly susceptible to the increment of stress level, the stress levels implemented are (0.069, 0.138, and 0.207) MPa representing low, medium and high traffic loading. The resilient microstrain increases by (46 and 550)% after the application of moderate and high stress level respectively. The permanent microstrain increases by (140 and 630) while the total microstrain increases by (105 and 600)% after the application of moderate and high stress level respectively. It can be observed that the resilient deformation represents (37, 27, and 35)% of the total deformation under low, medium and high traffic loading respectively.

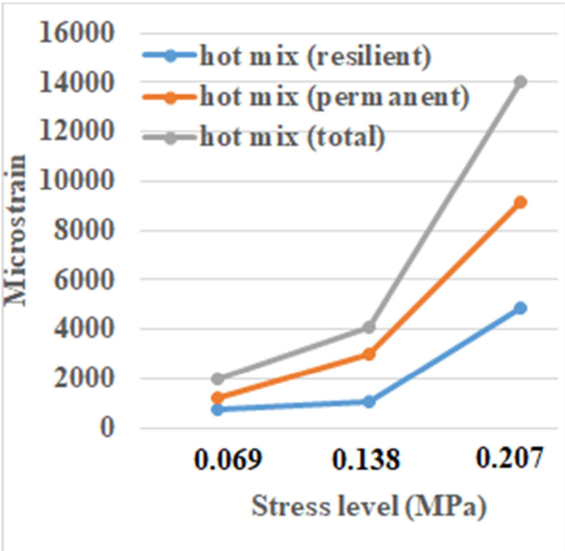


**Figure 6.** Impact of compressive stress level on deformation for HMA.

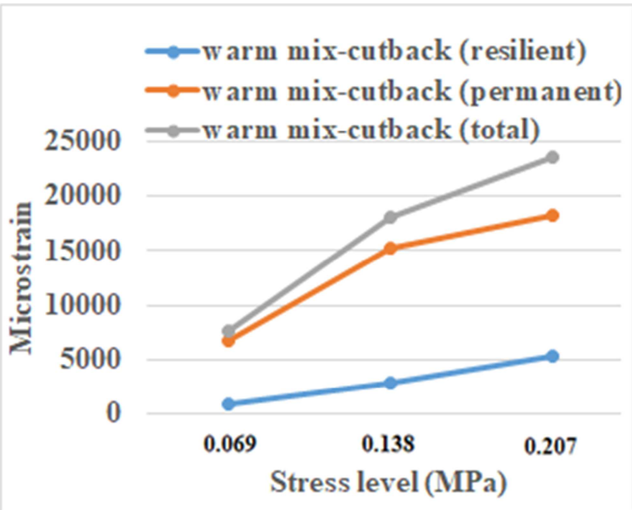


**Figure 7.** Impact of compressive stress level on deformation for WMA-Cutback.

Figure 7 exhibit the behavior of WMA-Cutback under the increment of stress level. The resilient microstrain increases by (214 and 500)% after the application of moderate and high stress level respectively. The permanent microstrain increases by (126 and 170) while the total microstrain increases by (136 and 208)% after the application of moderate and high stress level respectively. It can be noticed that the resilient deformation represents (11.5, 15, and 22)% of the total deformation under low, medium and high traffic loading respectively.

As presented in Figure 8, for WMA-Emulsion, the resilient microstrain increases by (60 and 1417)% after the application of moderate and high stress level respectively. The permanent microstrain increases by (25.5 and 229) while the total microstrain increases by (28.5 and 335)% after the application of moderate and high stress level respectively. It can be observed that the resilient deformation represents (9, 11, and 31)% of the total deformation under low, medium and high traffic loading respectively. Similar findings have been reported by Du, [16].

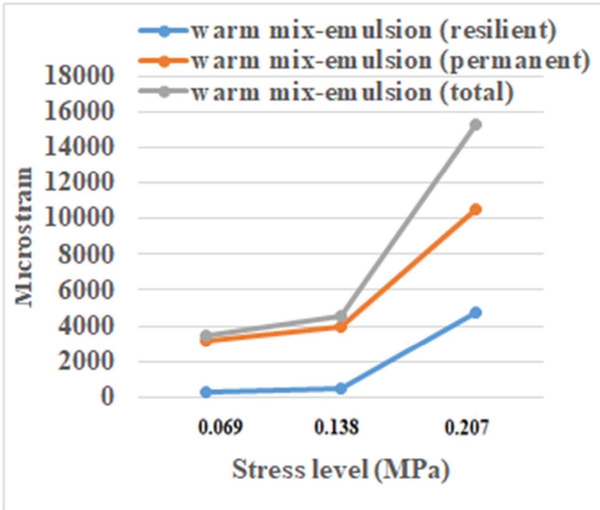


**Figure 8.** Impact of compressive stress level on deformation for WMA-Emulsion.

It can be indicated that the HMA mixture exhibit more flexibility under various traffic loading modes than that of WMA.

## 4. Conclusions

Based on the testing program, it can be concluded that for HMA mixture, the values of Mr decreased by (70, 66.5, and 80)% for testing technique under (shear, compressive, and flexure) stresses as compared to that under tensile stress. On the other hand, the values of Mr decreased by (66.5, 20, and 58)% for testing technique under (shear, compressive, and flexure) stresses as compared to that under tensile stress for WMA-Cutback mixture, while the values of Mr decreased by

(70.5, 51, and 59)% for testing technique under (shear, compressive, and flexure) stresses as compared to that under tensile stress for WMA-Emulsion mixture. It can be noted that higher Mr could be observed for HMA mixture under tensile and shear stresses when compared to the WMA mixtures, while the WMA shows higher Mr values than HMA under compressive and flexural stresses. The Mr decreases after moisture damage by (42, 25, and 58)% for HMA, WMA-Cutback, and WMA-Emulsion respectively when compared to the case before moisture damage. Lower testing temperature of 5°C exhibit higher Mr by (12.5, 25, and 25)% than that at 25°C for HMA, WMA-Cutback, and WMA-Emulsion respectively. For HMA, the resilient deformation represents (37, 27, and 35)% of the total deformation under low, medium and high traffic loading respectively. On the other hand, the resilient deformation represents (11.5, 15, and 22)% of the total deformation under low, medium and high traffic loading respectively for WMA-Cutback, while the resilient deformation represents (9, 11, and 31)% of the total deformation under low, medium and high traffic loading respectively for WMA-Emulsion. It can be indicated that the HMA mixture exhibit more flexibility under various traffic loading modes than that of WMA.

# References

[1] Sarsam S. I. (2016) "Comparative Assessment of Tensile and Shear Behavior of Warm and Hot Mix Asphalt Concrete", Scientific Research Gate, International Journal of Engineering papers; 1 (2): pp 1–8.

[2] Panda M., Padhi M, Giri J. (2017) "Use of emulsion for warm mix asphalt", International Journal of Transportation Science and Technology 6 pp 78–85. www.elsevier.com/locate/ijtst. (accessed 01. 08. 2018.).

[3] Vaitkus A., Cgas D., Laurinavicius A., Vorobjovas V., Perveneckas Z. (2016) "Influence of warm mix asphalt technology on asphalt physical and mechanical properties", Construction and Building Materials 112, pp 800–806. www.elsevier.com/locate/conbuildmat. (accessed 2. 12. 2018.).

[4] Jalali V., (2016) "Performance of warm mix asphalt compacted at reduced temperature", PhD thesis, University of Nottingham. England, http://eprints.nottingham.ac.uk/33488/1/Venon%20JALALI-4176639-PhD%20Thesis-Corrections-24.05.16-Final.pdf. (accessed 3.12. 2018.).

[5] Wu S., Wen H., Zhang W., Shen S., Mohammad L., Faheem A. & Muhunthan B., (2016) "Field performance of top down fatigue cracking for warm mix asphalt pavements", International Journal of Pavement Engineering, DOI: 10.1080/10298436.2016.1248204. http://dx.doi.org/10.1080/10298436.2016.1248204. (accessed 8. 11. 2018.).

[6] Prowell B., Hurley G., Crews E., (2013) "Field Performance of Warm Mix Asphalt at the NCAT Test Track". Available at: http://www.pavetrack.com/documents/Pdf/E9-E10-2005.pdf (accessed 01.08.16.).

[7] Hasan Z., Hamid B., Amir I., Danial N., (2013) "Long term performance of warm mix asphalt versus hot mix asphalt", J. Cent. South Univ. 20: 256−266. DOI: 10.1007/s11771-013-1483-1.

[8] Sarsam S. I., (2018) "Behavior of Warm Mix Asphalt Concrete under Moisture Damage", International Journal of Engineering Papers, vol. 3 (1), 3 February, pp. 21–28.

[9] Nihad Z., Sarsam S., (2018) "Deformation and Resilient Behavior of Hot and Warm Mix Asphalt Concrete", Civil Engineering Journal, Vol. 4, No. 10, October. pp 2398-2410. DOI: 10.28991/cej-03091168.

[10] Sarsam S. I., Zainalabiden N. (2018) "Flexural Behavior of Warm Mix Asphalt Concrete", Trends in Transport Engineering and Applications, Vol. 5, Issue 2, pp 10-20.

[11] López C. (2017) "Study of warm mix asphalt with super stabilized emulsion", Revista Ingeniería de Construcción. *RIC*.; 32 (1): pp 57–64. DOI: 10.4067/s0718-50732017000100006.

[12] Raghavendra A., Medeiros M., Hassan M., Mohammad L. and King W., (2016) "Laboratory and Construction Evaluation of Warm-Mix Asphalt." Journal of Materials in Civil Engineering, American Society of Civil Engineers, vol. 28 (7), July, pp 0899-1561, DOI: 10.1061/(ASCE) MT. 1943-5533.0001506.

[13] Miller I., and Bahia H, (2009) "Sustainable asphalt pavements: technology, knowledge gaps, and opportunities" Modified Asphalt Research Centre, University of Wisconsin, Madison.

[14] Izadi A., and Mirzaiyan D. (2016) "SCB Samples Fracture Resistance Evaluation of Hot Mix Asphalt vs Warm Mix Asphalt by ITS, Fatigue tests", Proceedings, 9th International Conference on Latest Trends in Engineering and Technology (ICLTET'2016) Oct. 13-14, Abu Dhabi (UAE). DOI: 10.15242/iie. e1016. https://doi.org/10.15242/IIE.E1016009. (accessed 2. 11. 2018.).

[15] Cucalon L., Kassem E., Little D. & Masad E. (2016) "Fundamental evaluation of moisture damage in warm-mix asphalts", Road Materials and Pavement Design, DOI: 10.1080/14680629.2016.1266765. https://doi.org/10.1080/14680629.2016.1266765. (accessed 1. 10. 2018.).

[16] Du J. (2017) "Laboratory Evaluation of Warm Asphalt Emulsion Mixture", 5th International Conference on Innovation in Environment, Civil, Materials and Architecture Engineering (IECMAE-17) Aug. 8-9, Singapore. DOI: 10.17758/eirai. f0817301. https://doi.org/10.17758/EIRAI.F0817301. (accessed 2. 12. 2018.).

[17] Yin F., Martin A., Arámbula-Mercado E. (2016) "Warm-Mix Asphalt Moisture Susceptibility Evaluation for Mix Design and Quality Assurance", Transportation Research Record: Journal of the Transportation Research Board. No. 2575, Transportation Research Board, Washington, pp 39–47. DOI: 10.3141/2575-05.

[18] Kumar S., and Suresha S. (2018) "Evaluation of Workability and Mechanical Properties of Non-foaming Warm Mix Asphalt Mixtures", Advances in Civil Engineering Materials, 7 (1), pp 132-157, DOI: 10.1520/acem20170060. https://doi.org/10.1520/ACEM20170060. (accessed 2. 8. 2018.).

[19] Sebaaly P., Hajj E. and Piratheepan M. (2015) “Evaluation of Selected Warm Mix Asphalt Technologies”, Road Materials and Pavement Design, April vol. 16, pp. 475-486, DOI: 10.1080/14680629.2015.1030825.

[20] Kamarudin S., Hainin M., Satar M. and Warid M. (2018) “Comparison of Performance between Hot and Warm Mix Asphalt as Related to Compaction Design”, Journal of Physics: Conference Series, (July 2018), DOI: 10.1088/1742-6596/1049/1/012036.

[21] Bhargava N., Das B. and Siddagangaiah A., (2018) “Synergistic Influence of Aging and Moisture on Performance of Warm Mix.", International Journal of Pavement Research and Technology, June DOI: 10.1016/j.ijprt.2018.06.002.

[22] Bower N., Wen H., Wu S., Willoughby K., Weston J. and DeVol J., (2015) “Evaluation of The Performance of Warm Mix Asphalt in Washington State”, International Journal of Pavement Engineering, January, 17 (5), pp. 423-434. DOI: 10.1080/10298436.2014.993199. http://www.tandfonline.com/loi/gpav20. (accessed 2. 10. 2018.).

[23] SCRB. (2003) “General Specification for Roads and Bridges.” Section R/9, Hot-Mix Asphalt Concrete Pavement, Revised Edition. State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq.

[24] ASTM. (2015) “Road and Paving Materials Vehicle Pavement Systems.” Annual Book of ASTM Standards, Vol. 04.03, American Society for Testing and Materials.

[25] AASHTO. (2013) “Standard Specification for Transportation Materials and Methods of Sampling and Testing”, American Association of State Highway and Transportation Officials, 14th Edition, Part II, Washington, D. C.

[26] Sarsam S. I. and Husain H. K, (2017) “Monitoring the Deformation of Asphalt Concrete under Repeated Tensile and Shear Stresses through Micro Cracks Healing Cycles” Proceedings, International Conference on Highway Pavements and Airfield Technology, American Society of Civil Engineers, Philadelphia, August, USA. DOI: 10.1061/9780784480939.004.