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Moisture Damage of Warm Mix Asphalt Concrete

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ABSTRACT

Implementation of Warm Mix Asphalt concrete (WMA) is getting global acceptance due to the restrictions for protecting the environment and the requirements to reduce fuel consumption. In this investigation, two WMA mixtures have been prepared in the laboratory using medium curing cutback (MC-30) and Cationic emulsion asphalt. Hot Mix Asphalt (HMA) was also prepared for comparison. The cylinder specimens (63.5mm) in height and (101.6mm) in diameter were constructed from the mixtures and subjected to indirect tensile strength test to determine the Tensile Strength Ratio (TSR). The cylinder specimens of (101.6mm) in height and (101.6mm) in diameter were also constructed from those mixtures and subjected to static compressive strength test to determine the Index of Retained Strength (IRS). It was concluded that the WMA are more prone to moisture damage than HMA, the TSR are (92 and 86) % for (emulsion and cutback) WMA respectively, both are lower than of HMA by (2.13 and 8.51) % respectively. As the asphalt content increases, the TSR also increases and reached to peak value of Optimum Asphalt Content (OAC) then decreases. The WMA has less IRS than HMA, the IRS are 70% and 78% for the WMA-emulsified asphalt and HMA respectively.

Key words: Warm Mix, Emulsion, Cutback, Tensile Strength Ratio, Index of Retained Strength.

ضرر الرطوبة في الخلطة الاسفلتية الدافئة

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الخلاصة

تنفيذ الخلطة الاسفلتية الدافئة حصل على قبول عالمي بسبب القيود المفروضة على حماية البيئة ومتطلبات تقليل استهلاك الوقود. في هذا البحث تم تحضير خلطتين من الخلطات الاسفلتية الدافئة في المختبر باستخدام الاسفلت السائل والأسفلت المستحلب الكاتيوني كما تم تحضير الخلطة الاسفلتية الساخنة لغرض المقارنة. تم اخذ عينات من هذه الخلطات والتي تتضمن عينات مارشال ذات قطر (101.6 ملم) وارتفاع (63.5 ملم) لغرض فحص قوة الشد غير المباشر لتحديد نسبة قوة الشد غير المباشر وعينات أسطوانية بقطر (101.6 مم) وارتفاع (101.6 ملم) لغرض فحص قوة الانضغاط بالاحمال الساكنة لتحديد مؤشر القوة المتبقية. تم استنتاج أن الخلطة الاسفلتية الدافئة أكثر عرضة لضرر الرطوبة، حيث كانت نسبة قوة الشد غير المباشر 92٪ و86٪ عند استخدام الأسفلت المستحلب والاسفلت السائل مع الخلطة الدافئة على التوالي، كلاهما أقل من الخلطة الاسفلتية الساخنة بنسبة 2.13٪ و8.51٪ على التوالي. عند زيادة محتوى الأسفلت، تزداد نسبة قوة الشد غير المباشرأيضًا وتصل إلى قيمة الذروة عند المحتوى الأسفلتي الأمثل ثم تنخفض. الخلطة الاسفلتية الدافئة تمتلك مؤشر للقوة المتبقية اقل من

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الخلطة الاسفلتية الساخنة، حيث مؤشر القوة المتبقية هو 70 ٪ و78 ٪ للخلطة الاسفلتية الدافئة مع الاسفلت المستحلب والخلطة الاسفلتية الساخنة على التوالي.

الكلمات الرئيسية: الخلطة الدافئة، الاسفلت المستحلب، الاسفلت السائل، نسبة قوة الشد غير المباشر، مؤشر القوة المتبقية.

1. INTRODUCTION

The primary purpose of the bitumen binder in mixes is to provide sufficient workability, coating and binding of aggregates for a strong structure. The performance of mixture relies upon internal and external conditions, the external circumstances are traffic loading and environmental (effect of aging and moisture). The internal circumstances are characteristics of the materials, procedure of construction, structure and design of the bitumen mixtures layers, **Chowdhury, et al., 2001**.

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, 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, **D'Angelo, et al., 2008**, thus, lower fumes and emissions are useful to the workers exposed to the fumes produced by the HMA paving operation. The 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, 2018.**

Classifying of the WMA is according to the technology that is utilized to manufacture the mixture, into three main groups **Hansen** and **Copeland, 2012** :

1- Organic or wax additives .
2- Chemical additives.
3- Foaming techniques.

The (TSR) test was used to evaluate resistance of the mixture to moisture susceptibility, according to procedure of ASTM D4867 **ASTM, 2015** and the (IRS) test is implement to quantify the loss of cohesion which causing by the action of water on compacted asphalt mixture, the test procedure followed the ASTM D1075 **ASTM, 2015**.

Moisture damage is one of the complex distresses, but common form of the distresses in the pavement. In general, moisture is considered a serious enemy to the long life performance of all roadways. Moisture damage is defined as the loss of stability and strength which produced by the active existence of the moisture. The propagation of moisture damage frequently happens by two main mechanisms, first, the loss of cohesion and second, the loss of adhesion. The loss of adhesion occurs among the aggregate and surrounding bitumen film, whereas the loss of cohesion happens within the bitumen itself. Moisture damage causes and accelerates some roadway distresses such as shoving, bleeding, and raveling, **Qasim, 2014**. Moisture damage is greater concern for WMA because of the use of lower production temperature, which may not be higher enough to completely dry the aggregates. The low viscosity of liquid bitumen 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, **López, et al., 2017** and **Raghavendra, 2016**.

WMA's disadvantages addressed by, **Sargand, 2009, Esenwa, 2011** and **Rashwan, 2012** 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 ^{O}C as compared with HMA can donate of inadequate drying of the aggregate, thus increase the potential for the moisture damage in the pavement, **Chowdhury** and **Button, 2008**. The significant decreases in Marshall Stability could be detected after moisture damage, moreover the Marshall Flow increases after moisture damage regardless of bitumen content. At lower bitumen content the effect of moisture damage was not important. whereas as the bitumen content increases the decreases in tensile strength because of moisture damage also increases, this perhaps to the truth that, hot aggregates absorb high percentages from 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 moisture damage **Sarsam, 2018**. The aging behavior and performance of several WMA-cutback asphalt roadways causes decreases in the rut depth with ageing **Raab, et al., 2017**.

Kvasnak and **West, 2009** studied moisture susceptibility for plant and laboratory produced WMA as part of project in Alabama. The results show that, moisture damage for WMA from laboratory-produced was higher than WMA from plant-produced and HMA exhibited more satisfactory TSR than WMA. **Goh, 2012** studied developed mixture design framework of WMA through assessing its mechanical characteristics and stated that, the HMA have tensile strength was significantly higher than of the WMA.

The goal of this investigation is to evaluate the influence of implementing cutback asphalt and emulsion asphalt as a binder on the (TSR) and (IRS) through an intensive testing program. Test results will be compared with HMA properties.

2. RESEARCH METHODOLOGY

This research methodology was divided into four stages, the first stage will cover 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 ratio test of the mixtures, while the fourth stage was concerned with index of retained strength test.

3. MATERIALS AND METHODS

3.1 Asphalt Cement

Asphalt cement of penetration grade 40-50 was brought from Al-Dura refinery and used 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, 2015**
Penetration (25^0C, 100 (gm) and 5 sec)	43	1/10,(mm)	ASTM D-5
Ductility (25^0C and 5cm/minute)	156	cm	ASTM D-113
Softening point (ring & ball)	49	^{o}C	ASTM D-36
Absolute Viscosity @ 60 ^{0}C	2150	Poise	ASTM D-2171
Specific gravity (25 ^{o}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 ^{0}C, 50gm, 5h) %	0.220	%	ASTM D-1754
Ductility (25^0C and 5 cm/ minute)	96	cm	ASTM D-113

3.2 Cutback Asphalt

Medium curing cutback asphalt (MC-30) was used as a binder for warm mix asphalt production. The cutback asphalt was obtained from Al-Dura refinery. The tests implemented on the cutback bitumen meet with characteristics complies with **ASTM, 2015**. **Table 2** shows its properties as supplied by the refinery.

Table 2. Physical characteristics of cutback asphalt.

Test	Results	Limits of Specification		**ASTM, 2015** Designation
Viscosity @ 60°C, cSt	40	30	60	ASTM D2170
Water % V (max)	0.2	—	0.2	ASTM D95
Density, kg/m3	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	—	ASTM D2027

3.3 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 its characteristics complies with of the **ASTM, 2015** as shown in the table below. **Table 3** exhibit its properties as supplied by the producer.

Table 3. Physical characteristics of emulsified asphalt.

Test	**ASTM, 2015** Designation	Results	Specification Limits **ASTM, 2015**	
			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	—

3.4 Coarse and Fine Aggregates

The coarse aggregates (crushed) 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 (particle size distribution among sieve No.4 and sieve No. 200). It consists of tough grains, hard, free from loam and deleterious materials. All tests were implemented in the Transportation Lab/civil engineering Department-Baghdad University. The aggregate was tested for physical properties and **Table 4** exhibits the test results.

Table 4. Physical characteristics of fine and coarse aggregate.

Laboratory Test	**ASTM, 2015** Designation	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	ASTM C127	2.61	2.631
Water Absorption, %	ASTM C127	1.471	3.734
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
Percent Wear (Los Angeles Abrasion), %	ASTM C131	19.5	--

3.5 Mineral Filler

Mineral filler used in this study is Portland cement, it was produced by Al-Mas Company and brought from the market. All tests were implemented in the Transportation Lab/civil engineering department-Baghdad University. 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, 2003**
% Passing Sieve No.200 (0.075mm)	98	95
Bulk Specific Gravity	3.1	—
Fineness by Blaine (m^2/kg)	312	≥230

3.6 SELECTION OF AGGREGATES GRADATION

The selected gradation of the aggregates in this work followed **(SCRB, 2003)**, with nominal maximum size 19 (mm). **Fig. 1** presents gradation of the aggregates for binder course.

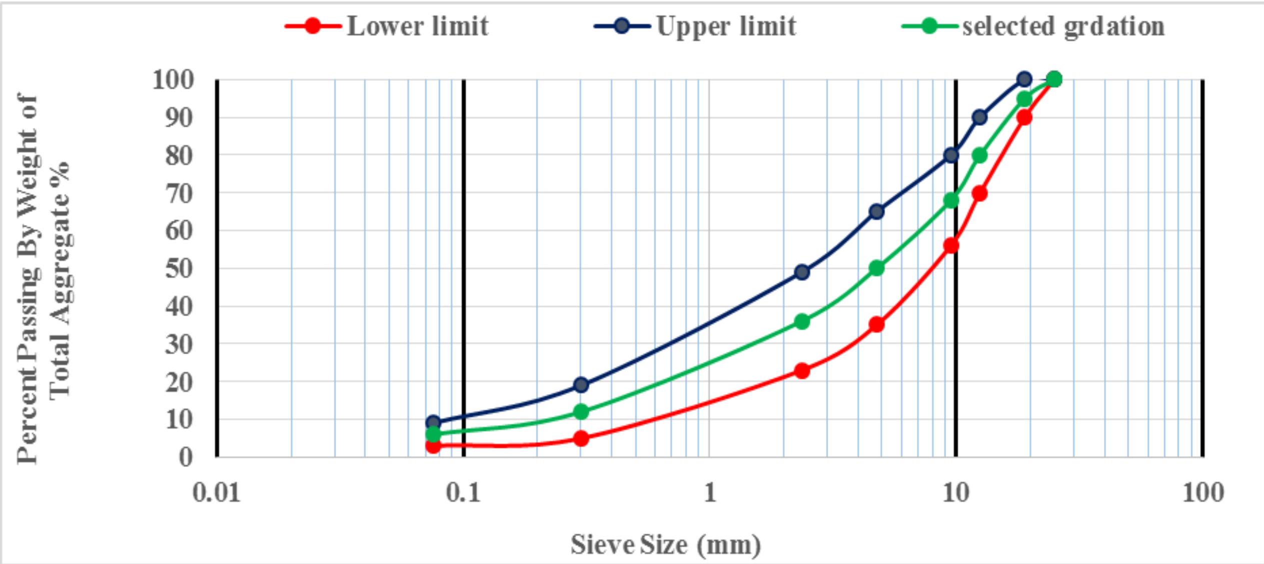

Figure 1. Gradation of the aggregates for binder course layer according to **SCRB, 2003**.

4. PREPARATION OF HMA

The virgin aggregates and filler were sieved and combined in order to meet a specified gradation of the binder course layer, **SCRB, 2003**. 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 reach the required volume of asphalt content. The bitumen and the aggregate were mixed by hand in the mixing bowl on the hot plate for (3-4 minutes) until bitumen 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 D6926 **ASTM, 2015** and the cylindrical specimens of (101.6 mm) in height and (101.6 mm) in diameter were compacted with static compressive strength. 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 TSR and IRS.

5. PREPARATION OF WMA

The virgin aggregates and filler were sieved and combined in order to meet a specified gradation of the binder course layer, **SCRB, 2003**. The combined aggregate was heated to a temperature of (110 ^{0}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 volume of asphalt content, and mixed thoroughly by hand utilized the spatula for (2-3) minutes until all aggregates were coated with 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 TSR and IRS. The procedure of obtaining the optimum asphalt content and the volumetric properties was published elsewhere, **Nihad, 2018**. 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, 2015**. The cylinder specimens of (101.6 mm) in height and (101.6 mm) in diameter were compacted with static compressive strength. 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 to evaporate the volatiles materials which contained in the asphalt components, therefore after several attempts at different times it was decided to implement Short-Term Aging (STA) technique as prescribed by AASHTO TP4 as cited by **Al-Jumaily, 2007**. **Fig. 2** shows group of the prepared cylindrical samples and the testing apparatus.

Figure 2. Part of the prepared cylindrical specimen for indirect tensile strength ratio test and index of retained strength.

6. SHORT TERM AGING

The loose mixture of cutback-aggregate is placed in the pan and spread to a thickness among (25-50) mm, then put it 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 a particular compaction hammer and the cylinder specimens (101.6 mm) in height and (101.6 mm) in diameter were compacted with static compressive strength. This procedure was implemented in accordance AASHTO TP4 as cited by **Al-Jumaily, 2007**. This aging signifies to the aging which occurs in the field among mixing and placement which allows for absorption of the bitumen into the pores of aggregate and evaporation the volatiles of a binder.

7. INDIRECT TENSILE STRENGTH RATIO TEST

The indirect tensile strength ratio test has been utilized in a number of bitumen mixture evaluations and roadway analyses. The moisture susceptibility test utilized to assess mixture for stripping in a design aggregate blend and bitumen binder content since the loss of bond or stripping caused by the existence of moisture among a bitumen and the aggregate. The procedure followed of ASTM D-4867. The set of six samples was prepared, three samples were tested for ITS (unconditioned samples) and the average value of ITS for these samples were computed and three samples were conditioned through placing in the flask wall glass which filled with water at 20˚C then a vacuum of 30 mm (Hg) was applied from 5 to 10 minutes. The partially saturated samples are conditioned through covered the specimen by the plastic film and put in the plastic bag containing 10 ± 0.5 mL of water and sealed, then the bags are put in a freezer at (-18 ± 3°C) for 24 hours. After 24 hours, the plastic bag and film is removed from each sample, and were allowed to thaw for two hours at the room environment, then tested for ITS. This test implemented at the rate of 50.8 mm/min till a maximum load is achieved and the sample fractures, then a load is recorded. **Fig. 3** presents wrapped the specimen with a plastic film, storage in freezer and the test apparatus. A similar procedure was reported by **Sarsam, 2016**. The (TSR) calculated by Eq. (1):

$$TSR = \frac{s11}{s1} * 100 \quad (1)$$

Where:

TSR = Indirect Tensile Strength ratio, %.

SI= Average ITS for unconditioned specimens, kPa.

SII = Average ITS for moisture-conditioned specimens, kPa.

Figure 3. Wrapping the specimen with a plastic sheet, storage in freezer and the test apparatus (indirect tensile strength ratio test).

8. INDEX OF RETAINED STRENGTH

This test implemented to determine the loss of cohesion resulting from the action of water on compacted asphalt mixture, it follows the ASTM D1075 **ASTM, 2015.** The set from six samples were prepared, three samples were stocked at room temperature for 2 hours after remove from the mold, then tested for compressive strength and three samples were stocked in a water bath at 60ºC for 24 hours and three samples were stocked in another water bath at 25ºC for 2 hours then tested for compressive strength. The test was implemented through apply a compressive load at a constant rate of 5.08 mm/min for determine the maximum resistance load at fracture. The Sample was placed in vertical position so that, the axial load was subjected on the surface area of the sample as shown in **Fig. 4** until it fractures. The (IRS) calculated by Eq. (2):

$$IRS = \frac{s11}{s1} * 100 \quad (2)$$

Where:
IRS = Index of retained strength (%).
SII = Average compressive strength of conditioned samples, kPa.
SI = Average compressive strength of unconditioned samples, kPa.

Figure 4. Part of the prepared specimens and the test apparatus (index of retained strength).

9. RESULTS AND DISCUSSION

9.1 Impact of Asphalt Content on Indirect Tensile Strength under Moisture Damage

The effect of asphalt content on ITS value under moisture damage for HMA and WMA mixtures were shown in the **Fig. 5**. The Results for HMA was shown that, ITS was decreased by (31.51 and 27.91) % when the bitumen content increased and decreased by 0.5 % from (OAC) respectively. The Results for WMA-cutback asphalt show that, the ITS test at (OAC) equal to 1023 kPa and when the bitumen content increased and decreased by 0.5 % from (OAC) specimens was fractured. The Results for WMA-emulsified asphalt show that, ITS was decreased by (38.66 and 11.29) % when the bitumen content increased and decreased by 0.5 % from (OAC) respectively, this behavior of materials conform with the results of **West, et al., 2014**. When the bitumen content increases, the tensile strength also increases reached to peak value at OAC then begin decreases. This is attributed to the truth that, hot aggregates absorb the high percentages of liquid asphalt through the mixing, then the excess volatiles evaporate leaving more voids when compared to low liquid bitumen content. The excess voids will be more susceptible to moisture damage. In (OAC) have higher values of (ITS) may be because the percentage of asphalt content at (OAC) is the appropriate percentage for coating and durability, such behavior of materials comply with the findings of **Sarsam, 2018**.

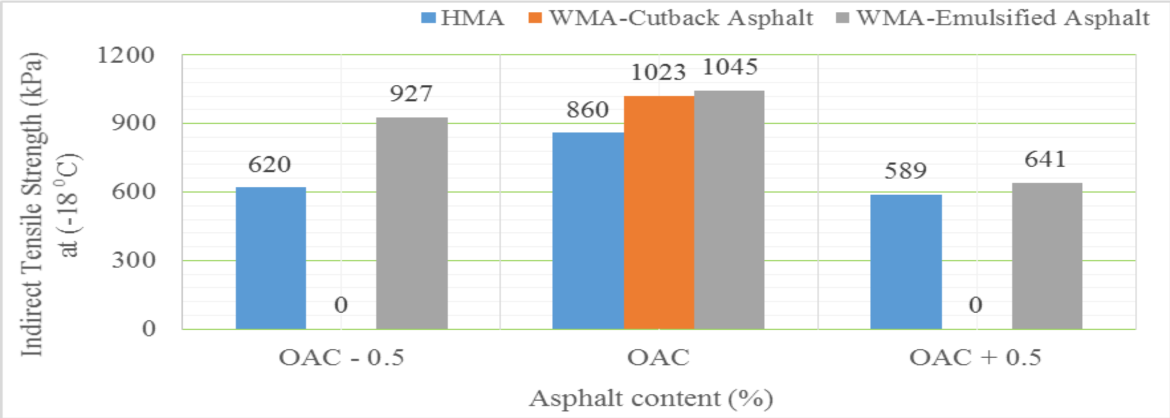

Figure 5. Effect of asphalt content on the indirect tensile strength under moisture damage.

9.2 Effect of Asphalt Type and Content on Indirect Tensile Strength Ratio

The purpose of conducting this test is to study the effect of asphalt type and content on the (TSR) for HMA and WMA mixtures as presents in the **Table 6** and **Fig. 6**. The (TSR) test results showed that, the HMA was less influenced to moisture damage than WMA, at (OAC), the (TSR) for HMA higher than WMA-cutback asphalt by 8.51 %, such behavior of materials does not comply with the findings of **Esenwa, 2011.** The possible cause was that aging improvemed resistance to moisture for the WMA-cutback asphalt that refer to the asphalt mixture after exposed to oxidation would causes increases in the hardness which lead to increases the resistance to tensile strength, however it remained less than HMA. The WMA-cutback asphalt give Av % more than HMA because of difficult compaction age materials**.** the (TSR) for HMA higher than (TSR) for WMA-emulsified asphalt by 2.13 %, such behavior of materials comply with the findings of **Shifa, 2009** and **Zhang, 2010**.

Table 6. Effect of asphalt type and content on the indirect tensile strength ratio.

HMA		WMA-Cutback Asphalt		WMA-Emulsified Asphalt	
Asphalt content %	Indirect Tensile Strength Ratio %	Asphalt content %	Indirect Tensile Strength Ratio %	Asphalt content %	Indirect Tensile Strength Ratio %
OAC-0.5	88	OAC-0.5	Failed	OAC-0.5	86
OAC	94	OAC	86	OAC	92
OAC+0.5	86	OAC+0.5	Failed	OAC+0.5	79

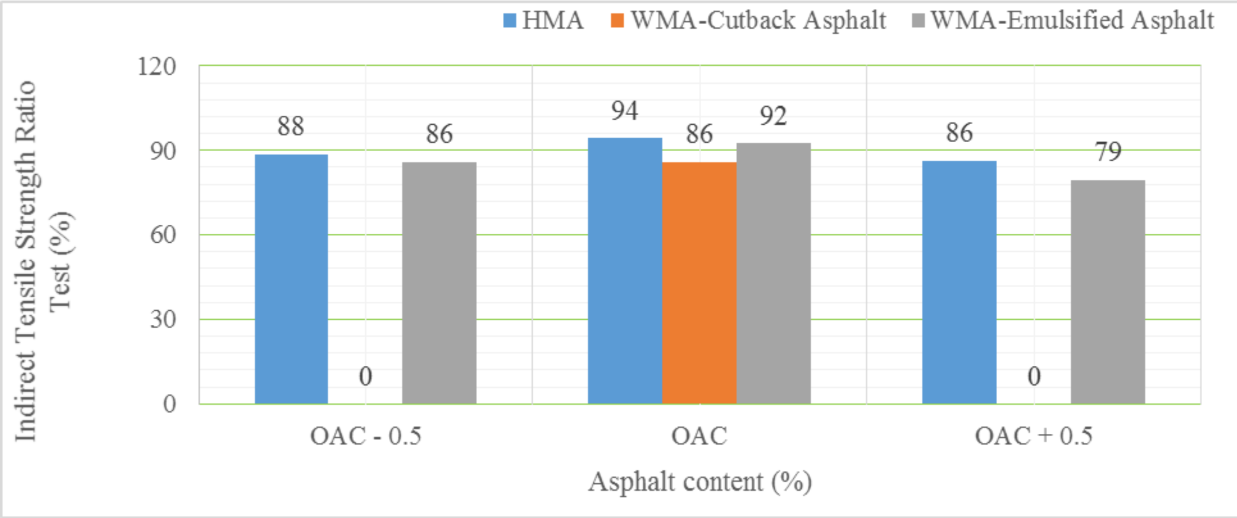

Figure 6. Effect of asphalt type and content on indirect tensile strength ratio.

Exposed of WMA-cutback asphalt to aging lead to an increase in hardness of asphalt because of stiffening by aging, which increases the resistance to tensile, but the same time give Av % more than HMA because of difficult compaction the age materials therefore give less (TSR) value than HMA, **Esenwa, 2011**. The low viscosity of emulsified asphalt affects in a better distribution of asphalt and decreases the number of uncoated aggregates, which contribute towards better stability, but since the emulsified asphalt content water and some percentage from water interact with filler (Portland cement), therefore, give mixture stiff and less moisture susceptibility, but the same time give Av % more than HMA because of some percentage from water was evaporated from mix and leaving behind a percentage of air voids, therefore give less (TSR) than HMA **Suresha** and **Kumar, 2018**. The WMA-emulsified asphalt have (TSR) higher than WMA-cutback asphalt may be because the effect of cement filler during the hydration process was interaction with water in emulsified asphalt and the development of the products from hydration to fill voids and decreasing water absorption, resultant in little water impact on WMA-emulsified asphalt.

9.3 Impact of Asphalt Types on Index of Retained Strength under Different levels of Stress

The (IRS) is a reference to mixture resistance to water damage. According to **SCRB, 2003** the acceptable value of the IRS is (70%) or above. The results in **Table 7** and **Fig. 7** show that, at (OAC) and the stress level at 10 psi, the (IRS) decreased by 16.1% when used WMA-emulsified asphalt instead of HMA and the specimen for WMA-cutback asphalt was fractured. The Results at (OAC) and the stress level at 20 psi, show that, the IRS decreased by 10.26% when used WMA-emulsified asphalt instead of HMA and the specimen for WMA-cutback asphalt was fractured. The Results at (OAC) and the stress level at 30 psi, show that, the (IRS) when used HMA equal to 73% and the specimens for WMA-cutback asphalt and WMA-emulsified asphalt were fractures.

Table 7. Effect of mixture types on the index of retained strength at different levels of stress.

HMA		WMA-Cutback Asphalt		WMA-Emulsified Asphalt	
Asphalt content %	Index of Retained Strength%	Asphalt content %	Index of Retained Strength%	Asphalt content %	Index of Retained Strength%
OAC at 10 psi (0.069 MPa)	87	OAC at 10 psi (0.069 MPa)	Failed	OAC at 10 psi (0.069 MPa)	73
OAC at 20 psi (0.138 MPa)	78	OAC at 20 psi (0.138 MPa)	Failed	OAC at 20 psi (0.138 MPa)	70
OAC at 30 psi (0.21 MPa)	73	OAC at 30 psi (0.21 MPa)	Failed	OAC at 30 psi (0.21 MPa)	Failed

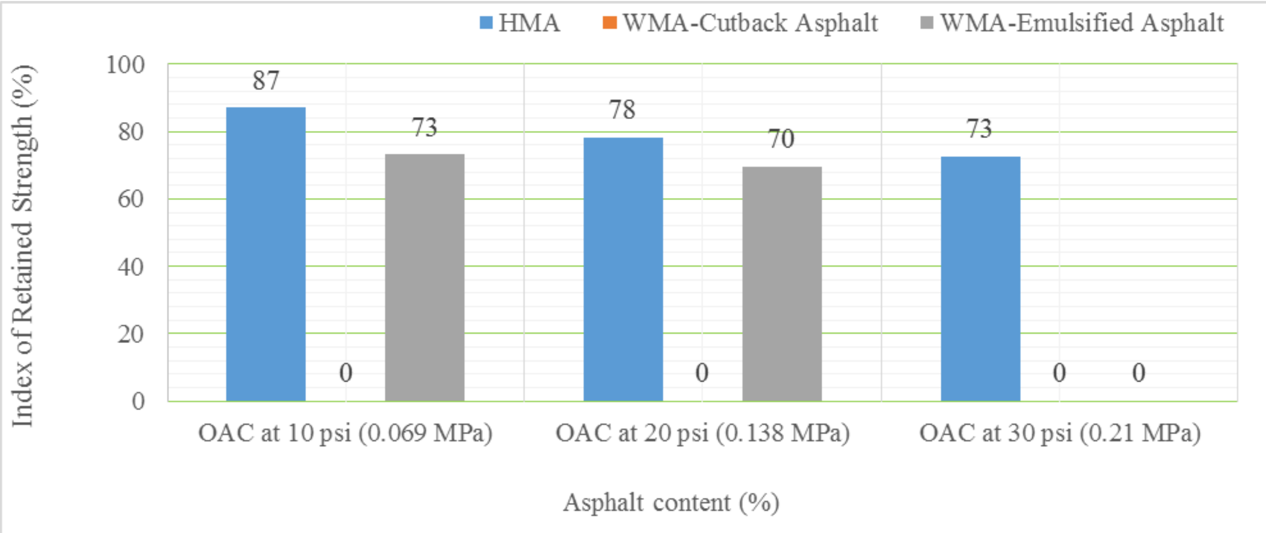

Figure 7. Effect of mixture types on the index of retained strength at different levels of stress.

The (IRS) for HMA was higher than WMA that indicates, the HMA was less prone to water damage than WMA, because of the effect of viscosity for HMA asphalt binder gave better coating of aggregates. The WMA-emulsified asphalt has (IRS) higher than WMA-cutback asphalt may be because of the effect of cement filler which during the hydration process was interaction with water in emulsified asphalt and the development of the products from hydration to fill voids and decreasing water absorption, resultant in little water impact on WMA-emulsified asphalt. When the WMA-cutback asphalt exposed to aging, lead to an increase in hardness of asphalt because of stiffening by aging, which increases the resistance to tensile, but the same time give (Vv %) more than HMA because difficult compaction the age materials, therefore give less (IRS) value than HMA. From **Fig. 7** can conclude that, when stress, increasing the (IRS) decreasing furthermore, when stress is increasing from 10 to 20 psi would decrease higher than when stress increasing from 20 to 30 psi. The increases of stress level will causes possess extra tensile stress, which the mixture was unable to accommodate moreover, the stress level of 10 psi will not be adequate for mixture to show its real (IRS) property.

10. CONCLUSIONS

Based on limitations of materials and test conditions, the conclusions could be addressed as follows:

1- The WMA mixture was more prone to moisture damage than of the HMA mixture. The (TSR) are (92 and 86) % for (emulsion and cutback) WMA respectively. Both were lower than HMA by (2.13 and 8.51) % respectively.
2- The increment of asphalt content lead to increase the tensile strength ratio reached to peak value at (OAC) then begin decreases.
3- The WMA has less (IRS) than HMA at (OAC) and stress level 20 psi, the (IRS) are 70% and 78% for the WMA-emulsified asphalt and HMA respectively and for WMA-cutback asphalt specimen was fractured. As the stress level increase, the (IRS) decrease furthermore, when stress increases from 10 to 20 psi the (IRS) decrease higher than when stress increase from 20 to 30 psi.
4- WMA-emulsified asphalt has (IRS) and (TSR) higher than WMA-cutback asphalt, the (IRS) was 70 % for the WMA-emulsified asphalt and for WMA-cutback asphalt, the specimen was fractured. The (TSR) were (92 and 86) % for the WMA-emulsified asphalt and WMA-cutback asphalt respectively.

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