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Variation of Asphalt Requirement and Strength Properties among Hot Mix (HMA) and Warm Mix (WMA) Asphalt Concrete

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Abstract— Due to the restrictions for protecting the environment, and the requirements to reduce fuel consumption, research work was started globally for verifying the possibility of implementation of warm mix asphalt (WMA) in pavement construction. Warm mix asphalt enables the production and compaction of asphalt concrete mixtures at temperatures (20-30 °C) lower than that of traditional hot mix asphalt (HMA). In this investigation, two WMA mixtures have been prepared in the laboratory using medium curing cutback (MC-30) and Cationic emulsion. HMA mixture was also prepared for comparison. Marshall specimens of (101.6 mm) in diameter and (63.5 mm) in height were constructed form the mixtures and subjected to indirect tensile strength (ITS) test, Marshall Stability, flow and volumetric properties determination. Test results were analyzed and compared. It was concluded that the stability of WMA is higher than HMA by 17 % and 47.87 % for (cutback and emulsified asphalt) WMA respectively, while the WMA exhibit lower flow than HMA by 34.67 % and 1.33 % when using (cutback and emulsion) WMA respectively. The optimum asphalt content was (20.69 and 32.35) % higher for (cutback and emulsion) WMA than that of HMA. The (ITS) at 25 ^{0}C decreases by (28.58 and 4.51) % when the asphalt content increased and decreased by 0.5 % from optimum asphalt content (OAC) for WMA- emulsion asphalt.

Keywords— Warm mix, emulsion, cutback, marshall volumetric properties, indirect tensile strength.

1. Introduction

Increased environmental awareness regarding emissions of volatiles when producing and placing of hot mix asphalt concrete have led to the development of warm mix asphalt. The high mixing temperatures of regular hot mix asphalt is reduced, while reduction in energy consumption and emission during production and placement could be achieved, [21], therefore recently, the asphalt concrete production industries worldwide have focusing in the incorporation of sustainability in the pavement construction process throughout the use of warm mix asphalt, [3]. One of the biggest advantages of using WMA technologies is that, it can reduce the mixing, placing and compaction temperatures of asphalt mixtures. As the result, their use is becoming prominent in Europe and North America. The general benefit of WMA can be categorized into the following four areas: environmental, economic, paving, and production. The low production and paving temperatures of WMA significantly reduce the emissions and fumes. Thus, greenhouse gases from WMA are lower than that from HMA, [7]. The lower emissions and fumes are beneficial to the construction workers exposed to the fumes produced by the HMA paving process. The economic benefit of WMA is realized by its lower production temperature. Energy consumption of WMA production is typically 60-80% lower than HMA production, [15]. Lower production temperatures can also potentially improve pavement performance by reducing binder aging, providing added time for mixture compaction, and allowing improved compaction during cold weather paving, [17].Warm mix asphalt consists of aggregates of various sizes, mineral filler, and liquid asphalt, was produced at 110°C, and compacted at 100-80°C in the laboratory study by [20]. Asphalt concrete mixture was prepared in the laboratory by [9], and [21] using both of the traditional hot mix and the sustainable alternative of warm mix techniques. It was concluded that higher specific gravity for control mix could be obtained with WMA as compared to that of HMA, [20]. Lower tensile and shear strength of 30% and 19% respectively could be noticed when WMA technique was implemented as compared to those of HMA case. The warm mix exhibits lower viscosity and thus lower resistance to compaction. After compaction, a curing period is required to allow the remaining volatiles of liquid asphalt to evaporate, [1]. 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, [6] and [16]. Another investigation that was conducted by [10] indicated that, the indirect tensile strength exhibit no significant difference between the WMA and the HMA. WMA's disadvantages addressed by [18], [8] and [13] are mainly related to the potential to reduce material durability, and its potential on rutting and moisture susceptibility issues.

The aim of this investigation is to assess the influence of implementing cutback asphalt and emulsion asphalt as a binder on the indirect tensile strength, Marshall Stability and volumetric properties of warm mix asphalt through an intensive testing program. Test results will be compared with HMA properties.

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. **Table (1)** presents the physical properties of asphalt cement.

Table 1: Physical properties of asphalt cement.

Test	Result	Unit	Specification [5]
Penetration (25 ^{0}C, 100 g, 5 sec)	43	1/10 mm	ASTM D 5
Ductility (25 ^{0}C, 5cm/min)	156	cm	ASTM D 113
Softening point (ring & ball)	48	^{o}C	ASTM D 36
Kinematic viscosity	551	135 °C, cSt	ASTM D 2170
	127	165 °C, cSt	
Absolute Viscosity @60 ^{0}C	2150	Poise	ASTM D 2171
Specific gravity at 25 ºC	1.041	—	ASTM D 70
After thin film oven test			
Retained penetration of original, %	67.4	1/10 mm	ASTM D 5
Ductility at 25 ^{0}C, 5cm/min, (cm)	96	cm	ASTM D 113
Loss in weight (163 ^{0}C, 50g, 5h) %	0.220	%	ASTMD 1754

2.2 *Emulsified Asphalt*

Cationic Emulsified asphalt was used as binder for warm mix asphalt production, it was brought from state company for mining industries. Tests conducted on emulsified asphalt confirmed that its properties complies with the SCRB [16]. **Table (2)** exhibit its properties as supplied by the producer.

Table 2: Physical properties of cationic emulsified asphalt.

Test	ASTM [15] Designation	Results	Specification Limits [19]	
			Min.	Max
Particle Charge Test	ASTM D244	Positive	Positive	—
Saybolt Furol viscosity at (50 °C)	ASTM D245	250	50	450
Oil Distillate by Volume of Emulsion (%)	—	85	65	—
Penetration, 25°C, 100 g,5 s	ASTM D5	135	100	250
Ductility, 25°C, 5 cm/min	ASTM D113	187	40	—
Solubility in Trichloroethylene	ASTM D2042	101	97.5	—
Specific Gravity at 25°C	ASTM D70	1.02	—	—
Residue by Distillation, %	ASTM D6997	60	57	—

2.3 *Cutback Asphalt*

Medium curing Cutback asphalt (MC-30) was used as a binder for warm mix asphalt production. It was brought from Al-Dura refinery. Tests conducted on cutback asphalt confirmed that its properties complied with the SCRB [16]. **Table (3)** shows its properties as supplied by the refinery.

Table 3: Physical properties of cutback asphalt.

Test	Results	Limits of Specification		ASTM [5] Designation
Grade	MC-30	Min.	Max.	
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	—
Tests on Residue from Distillation				
Penetration @25°C (100g, 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

3. 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 (4)** exhibit the test results.

Table 4: Physical properties of coarse and fine aggregate.

Laboratory Test	[15] 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	--

4. Mineral Filler

Mineral filler used in this study is Portland cement, it was produced by Al-Mas Company and obtained from the market, and the physical properties of the filler are listed in **Table (5)**.

Table 5: Physical properties of Portland cement.

Property	Test Result	SCRB Requirements [19]
% Passing Sieve No.200 (0.075mm)	98	95
Bulk Specific Gravity	3.1	—
Fineness by Blaine (m^2/kg)	312.5	≥ 230

5. Selection of Aggregate Gradation

The selected gradation in this study followed the [5] specification, with 19 (mm) nominal maximum size. **Table (6)** shows the selected gradation for binder course.

Table 6: Grain size distributions of the design mix.

% Finer By Weight	Sieve Size (mm)
100	25.4
93	19.2
76	12.5
66	9.5
63	4.75
35	2
26	1
20	0.6
14	0.25
10	0.125
7	0.075

6. Preparation of Hot Mix Asphalt (HMA)

The aggregate were sieved and separated to different sizes, then combined to meet the specified gradation for binder course layer, [19]. The combined aggregates were heated to temperature of 110 °C, while the asphalt cement was heated to a temperature of 150°C to produce a kinematic viscosity of (170 ± 20) centistokes. The asphalt cement was added to the heated aggregate to achieve the required amount of asphalt content. The aggregate and the asphalt were mixed in the 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. Specimens were compacted with Marshall hammer using 75 blows on each side as per [5]. 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 indirect tensile strength, and Marshall Stability properties.

7. Preparation of Warm Mix Asphalt (WMA)

The aggregate were sieved and separated to different sizes, then combined to meet the specified gradation for binder course layer as per SCRB, [19]. 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 required amount of asphalt content, and mixed thoroughly by hand using a spatula for two minutes until all aggregate particles 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 volumetric and strength properties. Marshall specimens were subjected to 75 blows on the top and on the bottom of specimen. Specimens were removed from the mold after 24 hours. In case of cutback asphalt mixtures, specimens were collapsed after removal from the mold, then it was decided to use the short term aging technique as prescribed by AASHTO TP4 as cited by [12]. **Figure (1)** shows part of the prepared Marshall specimens and the testing apparatus.

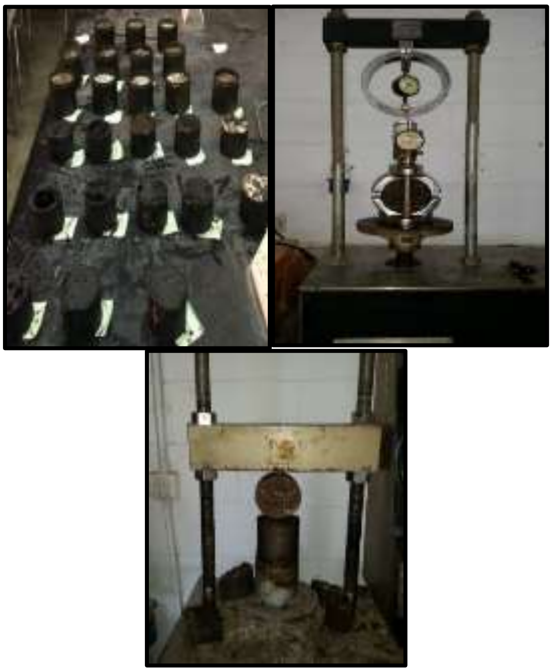


Figure 1: Part of the prepared specimens and the test apparatus.

8. Short Term Aging (STA)

The loose mixture of cutback -aggregate was placed in a pan and spread to an even thickness ranging between 25 and 50 mm, the mixture in the pan was placed in the conditioning oven for 4 h ± 5 min. at 135 ± 3°C as cited by [18] 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 subjected to 75 blows on the top and on the bottom of specimen with specified compaction hammer. This procedure was carried out in accordance with AASHTO TP4 as cited by [12]. The total number of prepared Marshall specimens were 63 specimens.

9. Marshall Test

The volumetric properties of the specimens were obtained as per ASTM, [5]. Marshall Stability and flow records were performed on each specimen according to procedure [5].

9.1 *Indirect Tensile Strength Test*

The test followed the procedure of ASTM [5]. Marshall specimens were used in this test, and percent air voids for specimens were the same as for Marshall Test.

10. Results and Discussion

10.1 *Effect of Asphalt Content on Marshall Properties of the all Mixtures*

Five percentages of asphalt content were used for each type of asphalt by weight of aggregate to determine the OAC of asphalt mixtures. An average of the following values was considered:

1- Asphalt content at maximum unit weight.

2- Asphalt content at maximum stability.

3- Asphalt content at 4 percent air voids.

Other properties such as flow, voids in total mixture (Vv %), voids in mineral aggregate (VMA %) and voids filled with asphalt (VFA %) are considered to confirm the required limits by [5]. **Figure (2, 3, and 4)** show the relationship between asphalt content and Marshall volumetric properties for HMA, WMA-cutback asphalt and WMA-emulsified asphalt respectively. **Table (7)** exhibit a summary of the marshal properties of the three mixtures under investigation. The data which can be seen in **Table (7)** indicate that, Marshall Test results of binder layer are within the limits of the Iraqi specification requirements, [19]. It also indicate that the optimum asphalt content was (20.69 and 32.35) % higher for (cutback and emulsion) WMA than that of HMA.

Table 7: Marshall properties for the all types of mixtures at the optimum asphalt content.

Marshall Test Properties	Type of Asphalt Concrete Mixture			SCRB [5] Specification Limit
	HMA	WMA-Cutback Asphalt	WMA-Emulsified Asphalt	
OAC %	4.6	5.8	6.8	—
Stability (kN)	9.4	11	13.9	≥ 7
Flow (mm)	3.75	3.70	2.45	2 - 4
Bulk Density (gm/cm3)	2.294	2.311	2.306	—
Vv (%)	4.10	4.40	4.12	3 - 5
VMA (%)	16.8	17	17.9	≥ 13
VFA (%)	75	74.8	77.4	—

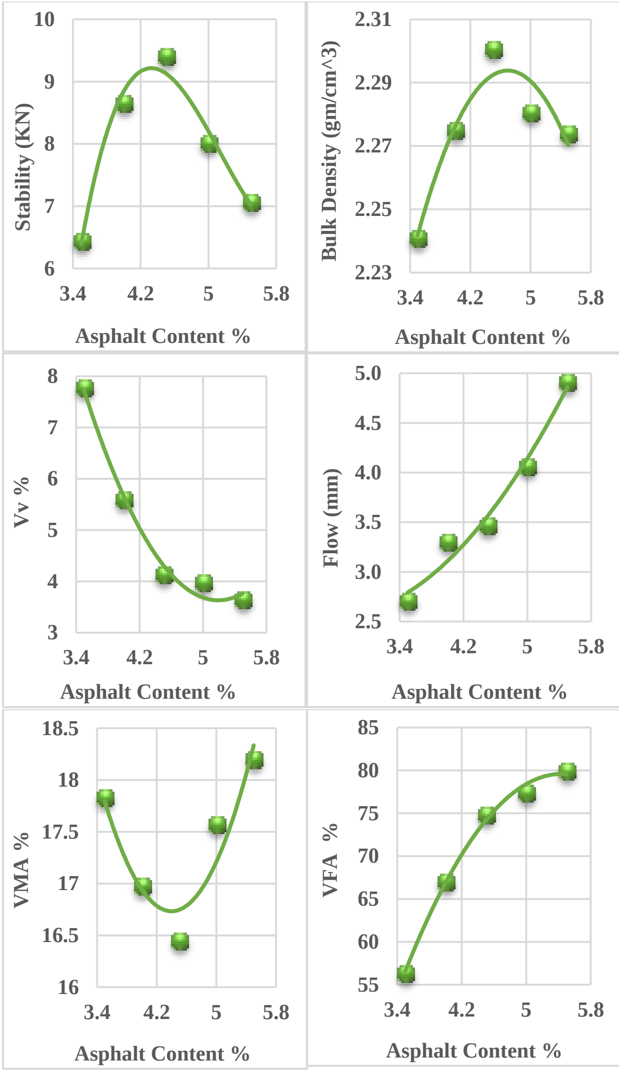
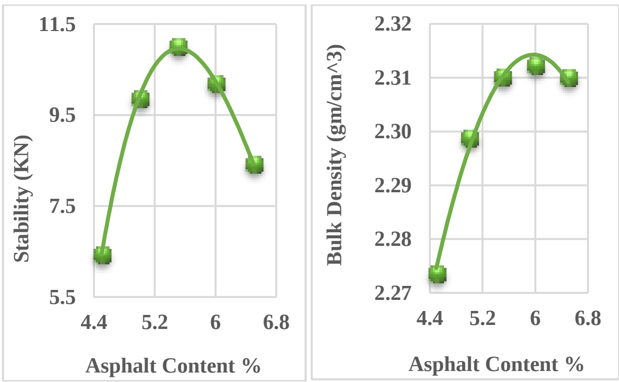


Figure 2: Marshall test results for HMA.



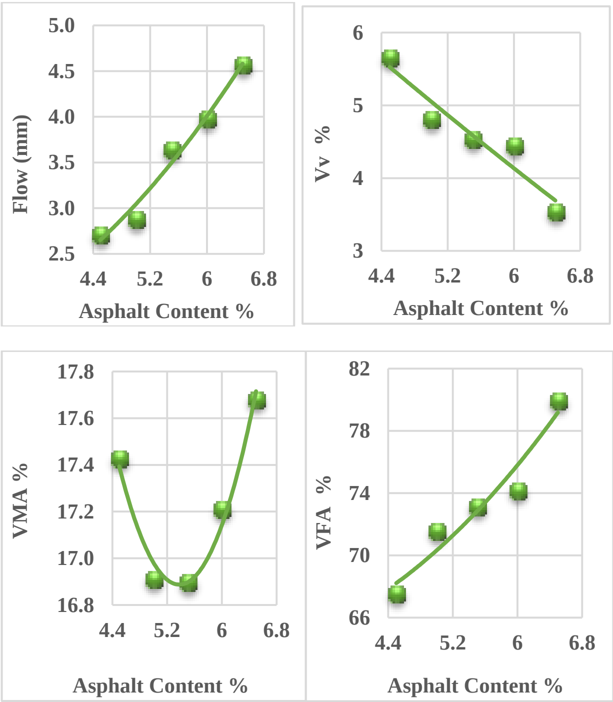


Figure 3: Marshall test results for WMA-cutback asphalt.

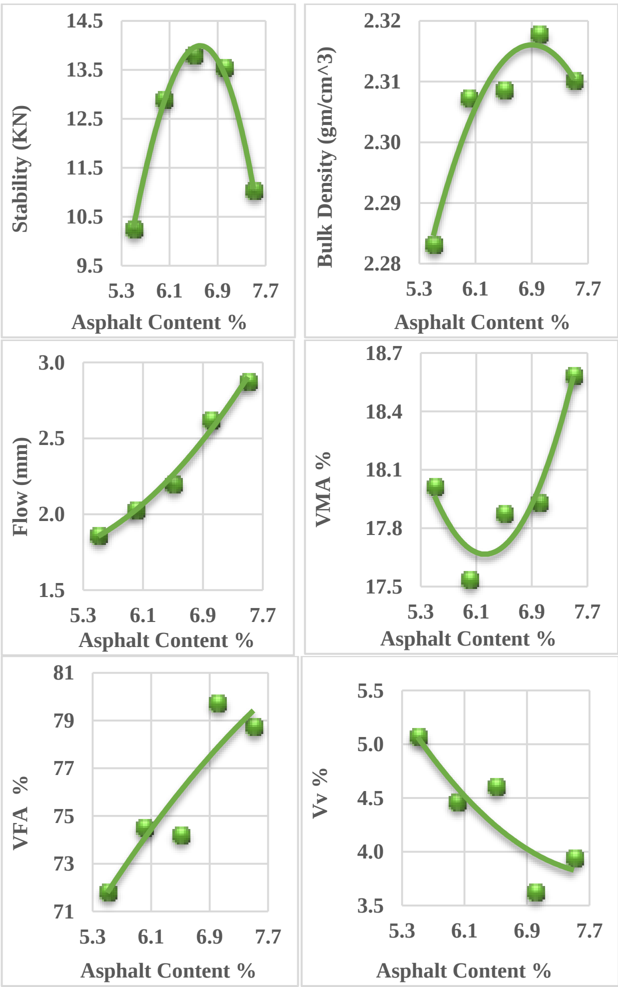


Figure 4: Marshall test results for WMA-emulsified asphalt.

10.2 ***Effect of Mixture Type on the Marshall Stability***

Stability is an important property of the asphalt mixture. Marshall Stability gives the indication about the resistance of asphalt mixture to rutting, a high value of Marshall Stability indicates increased Marshall Stiffness and the high stiffness of asphalt mixture means good resistance to traffic loadings but it also indicates lower flexibility which is required for long term performance. High stiffness values are not recommended due to thermal cracking expected to occur. **Figure (5)** show the effect of mixture type on Marshall Stability. It is noted that, the Marshall stability was increased by (17 and 47.8) % for WMA when using cutback asphalt and emulsion respectively as compared to HMA. Such behavior may be attributed to the fact that For WMA-emulsified asphalt, part of its water was evaporated and another part interact with filler (Portland cement) to give more stiff and stable mixture, therefore better able to resist distortion and displacement. It also indicates lower flexibility which is required for long term performance. Such behavior comply with the findings by [2]. The short term aging (STA) for WMA-cutback asphalt increase the Marshall stability, increment related to the fact that, due to aging the viscosity increase thus leading to increase the strength of bond between the components of asphalt mixture [12].

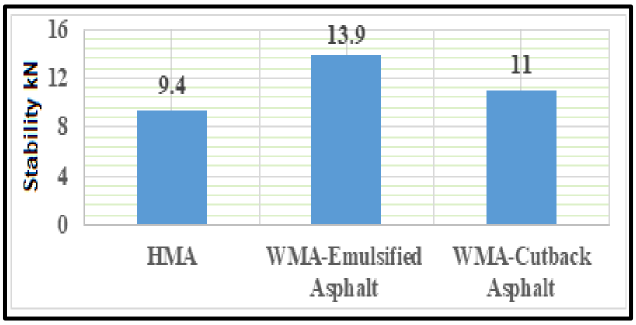


Figure 5: Effect of mixture type on the Marshall stability.

10.3 ***Effect of Mixture Type on the Marshall Flow***

Generally, high flow value indicate a plastic mix that is more prone to rutting problem under traffic loads, whereas low flow values may indicate a mix with higher than normal voids and insufficient asphalt for durability and could result in premature cracking due to mixture brittleness during the life of the pavement. **Figure (6)** show the effect of mixture type on the Marshall Flow. It can be observed that the Marshall flow was decreased by (1.33 and 34.6) % when using emulsified asphalt and cutback asphalt respectively as compared to HMA. Such behavior may be attributed to the stiffer mixture obtained after the loss of volatiles due to short term aging in case of cutback asphalt. Such behavior of materials comply with the findings of [12].

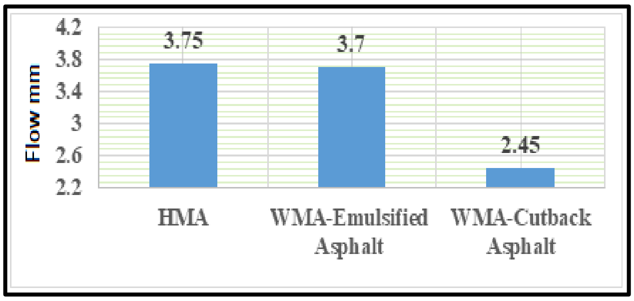


Figure 6: Effect of mixture type on the Marshall flow.

10.4 ***Effect of Mixture Type on the Bulk Density***

The density varies with asphalt content in such a way that, it increases with increasing asphalt content in the mixture, the density reaches a peak and then begins to decrease because additional asphalt cement produces thicker films around the individual aggregates, and tend to push the aggregate particles further apart subsequently resulting in lower density. The effect of mixture type on bulk density is illustrated in **Figure (7)**. It indicates that, the bulk density was increased by (0.74 and 0.52) % when using emulsified asphalt and cutback respectively as compared to HMA. Such behavior of materials comply with the findings by [8]. Lower viscosity exhibit in case of emulsion and cutback asphalt mixture, therefore, less compaction effort is required to achieve same HMA density and with application of similar compaction, higher density can be achieved as the WMA-emulsified asphalt remains workable over greater time than the HMA mixture.

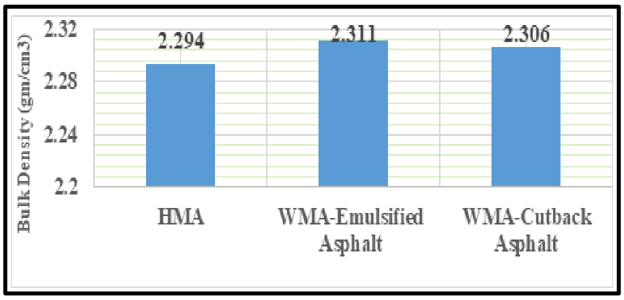


Figure 7: Effect of mixture type on the bulk density.

10.5 ***Effect of Mixture Type on the Voids in Total Mixture (Vv %).***

Air void in the mixture is an important parameter because it permits the properties and performance of the mixture to be predicted for the service life of the pavement, and percentage of air voids is related to durability of asphalt mixture. Air void proportion around 4% is enough to prevent bleeding or flushing that would reduce the skid resistance of the pavement and increase fatigue resistance susceptibility. The asphalt mixtures with high percent of air void is considered to be less durable. The effect of mixture type on (Vv %) is illustrated in **Figure (8)**, it indicates that, the (Vv %) was increased by (7.32 and 0.5) % when using emulsified asphalt and cutback WMA as compared to HMA. Such behavior of materials comply with the findings of [11]. The relation between air voids and binder content follows the same trends observed for HMA, more binder is added into the mixture more voids are filled with binder and therefore the percentage of air voids decreases. The reason for the higher percentage of voids in cutback asphalt mixture may be attributed to the loss of volatiles with age, such behavior of materials comply with the findings of [4].

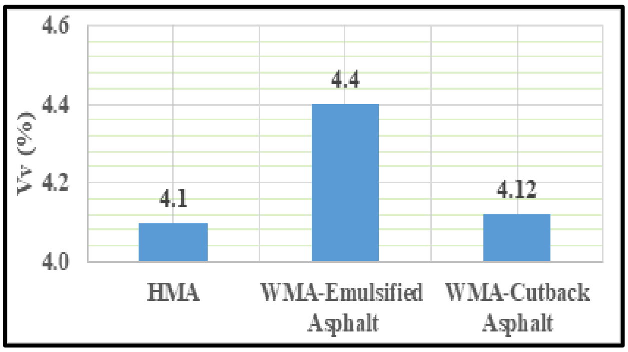


Figure 8: Effect of mixture type on the voids in total mixture (Vv %).

10.6 ***Effect of Mixture Type on the Voids Filled with Asphalt (VFA %)***

The purpose for having high (VFA %) is to secure a durable asphalt mixtures. **Figure (9)** show the effect of mixture type on the (VFA %). It indicates that (VFA %) was decreased by 0.27 % when using emulsified asphalt and it was increased by 3.2 % when using cutback asphalt WMA. The higher percentage of VFA in case of cutback asphalt may be attributed to the lower viscosity of binder which can allow more voids to be filled. Such behavior of materials comply with the findings of [11].

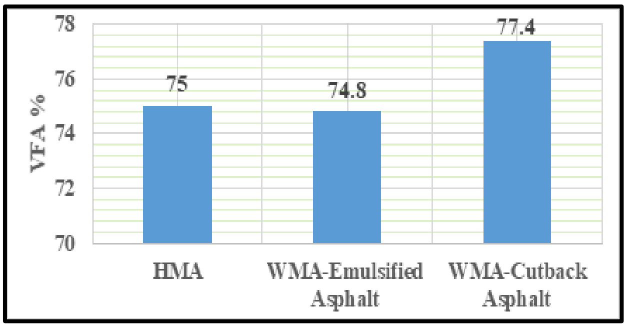


Figure 9: Effect of mixture type on the voids filled with asphalt (VFA %).

10.7 ***Effect of Mixture Type on the Voids in Mineral Aggregate (VMA %)***

The voids in the mineral aggregate is the total available volume of voids between the aggregate particles in the compacted paving mixture that includes the air voids and the voids filled with effective asphalt content expressed as a percent of the total volume. It is significantly important for the performance characteristics of the mixture, the (VMA %) must exceed the minimum requirement to support the durability and air space. If the (VMA %) is too small, there will be no space for the asphalt cement required to coat around the aggregates and this subsequently results in durability problems, on the other hand, if (VMA %) is too large, the mixture may suffer stability problems. **Figure (10)** show the effect of mixture type on (VMA %). It is clear that, the (VMA %) was increased by (1.2 and 6.55) % when using emulsified asphalt and cutback WMA respectively as compared to HMA. such behavior of materials comply with the findings of [20].

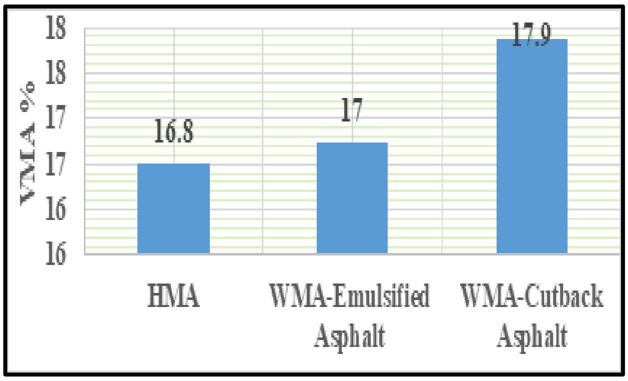


Figure 10: Effect of mixture type on the voids in mineral aggregate (VMA %).

10.8 *Indirect Tensile Strength Test*

Figure (11) exhibit the impact of asphalt content and mixture type on the variation in indirect tensile strength. At optimum asphalt content, (ITS) increased by (30.59 and 23.9) % for cutback asphalt and emulsion WMA respectively as compared to HNA. For mixtures with asphalt content was 0.5 % above or below the optimum requirement, the (ITS) was decreased by (25.10 and 23.14) % when the asphalt content increased or decreased by 0.5 % from OAC respectively for WMA with emulsion. This behavior may indicate low susceptibility to the change in asphalt content. Such behavior of materials comply with the findings by [14]. On the other hand, for WMA-cutback asphalt, it was found that, the specimens with 0.5 % asphalt above or below the optimum requirements collapsed during the test indicating high susceptibility to the change in asphalt content.

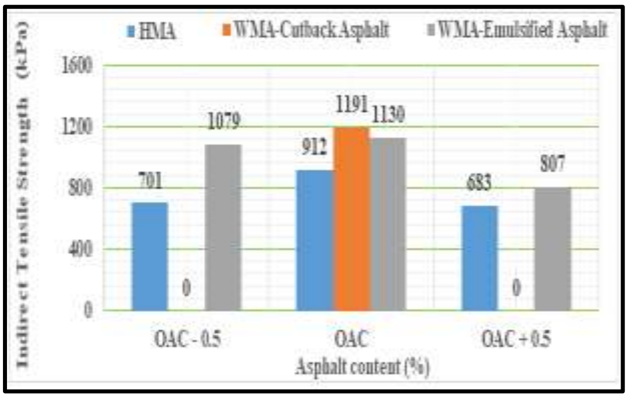


Figure 11: Effect of asphalt content on the indirect tensile strength at 25 ^{o}C.

11. Conclusions

Based on the testing program, the following conclusions could be drawn:

1- Warm mix asphalt concrete with medium curing cutback or cationic emulsion satisfies the requirement of the local SCRB specification. The optimum asphalt content was (20.69 and 32.35) % higher for (cutback and emulsion) WMA than that of HMA.

2- WMA have stability higher than HMA by (17 and 47.87) % when using cutback and emulsified asphalt with WMA respectively, while the WMA have lower flow than HMA by (34.67 and 1.33) % when using cutback and emulsified asphalt with WMA respectively.

3- WMA have higher VFA than HMA by 3.2 % when using cutback asphalt and lower than HMA by 0.27 % when using emulsified asphalt, on the other hand, WMA have (VMA %) higher than HMA by (6.55 and 1.2) % when using cutback asphalt and emulsified asphalt with WMA respectively.

4- WMA exhibit higher (ITS) than HMA of (30.59 and 23.9) % when using cutback and emulsified asphalt with WMA respectively.

5- The ITS at 25 ^{o}C was decreased by (25.10 and 28.58) % and by (23.14 and 4.51) % when the asphalt content increased and decreased by 0.5 % from OAC for HMA and WMA- emulsion asphalt respectively.

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تباين متطلبات الإسفلت وخصائص القوة بين الخرسانة الإسفلتية الساخنة والخرسانة الإسفلتية الدافئة

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الخلاصة – نظرًا للقيود المفروضة على حماية البيئة ومتطلبات تقليل استهلاك الوقود ، بدأ العمل البحثي على مستوى العالم للتحقق من إمكانية تنفيذ الخلطة الاسفلتية الدافئة في إنشاء الطرق الاسفلتية. يتيح الإسفلت ذو المزيج الدافئ إنتاج، مزج وحدل الخلطات الخرسانية الإسفلتية في درجات حرارة (20-30 درجة مئوية) أقل من تلك بالخاصة الخلطة الاسفلتية الساخنة. في هذا البحث ، تم تحضير خلطتين من الخلطات الاسفلتية الدافئة في المختبر باستخدام الاسفلت السائل والاسفلت المستحلب الكاتيوني كما تم تحضير الخلطة الاسفلتية الساخنة أيضًا لغرض المقارنة. تم تحضير عينات من هذه الخلطات والتي تتضمن عينات مارشال بقطر (101.6 مم) وارتفاعه (63.5 مم) من مختلف الخلطات لاختبار مقاومة الشد غير المباشرة، وخصائص مارشال لهذه الخلطات. تم تحليل نتائج الاختبار ومقارنتها، وتم استنتاج إلى أن ثباتية الخلطة الاسفلتية الدافئة أعلى من الخلطة الاسفلتية الساخنة بنسبة 17٪ و 47.87٪ عند استخدام الأسفلت السائل والمستحلب مع الخلطة الاسفلتية الدافئة على التوالي، في حين التدفق للخلطة الاسفلتية الدافئة أقل من الخلطة الاسفلتية الساخنة بنسبة 34.67٪ و 1.33٪ عند استخدام الأسفلت السائل والمستحلب مع الخلطة الاسفلتية الدافئة على التوالي. كان محتوى الإسفلت الأمثل اعلى بنسبة (20.69 و 32.35)٪ بالنسبة للأسفلت السائل والمستحلب مع للخلطة الاسفلتية الدافئة على التوالي مقارنة مع المحتوى الاسفلتي الامثل للخلطة الاسفلتية الساخنة. تنخفض مقاومة الشد غير المباشرة عند 25 درجة مئوية بنسبة (28.58 و 4.51)٪ عندما يزداد محتوى الإسفلت وينخفض بنسبة 0.5٪ من محتوى الإسفلت الأمثل للأسفلت المستحلب مع خلطة الاسفلتية الدافئة

الكلمات الرئيسية – المزيج الدافئ، الاسفلت المستحلب، الأسفلت السائل، خصائص اختبارات مارشال الحجمية، قوة الشد غير المباشرة.