Warm Mix Asphalt / Low temperature asphalt

ASSESSING WARM MIX ASPHALT CONCRETE (WMAC) AS A GREEN PAVEMENT

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Abstract

Warm mix asphalt concrete (WMA) is considered as one of the finest choices of green and sustainable materials in asphalt concrete paving operation. The temperatures decline in the mixing, handling, and compaction of the mix gets in saving energy, cutting emissions and significant cuts in construction costs. The fundamental concept of the WMA is to decrease the blending and compaction temperatures of the mixture and to manufacture mixture which have the same durability, performance and strength as hot mix asphalt concrete HMA. As the result of decreased temperature of WMA, it shows less aging of asphalt mixture. It is known that, asphalt oxidation lead to stiffen or harden of the binder and may result various pavement distresses. In this work, the temperature susceptibility of two types of warm mix have been compared with those of HMA. Cylindrical specimen of 63.5 mm in height and 101.6 mm in diameter have been prepared using medium curing cutback and cationic emulsion in case of warm mix and asphalt cement in case of hot mix. Specimens were tested for indirect tensile strength ITS at 5 and 20 °C. It was concluded that WMA are less susceptible to temperature than HMA. The temperature susceptibility at optimum asphalt content are (24, 17 and 19) kPa/°C for the HMA, WMA-emulsified asphalt and WMA-cutback asphalt respectively. The temperature susceptibility of WAC was lower than that of HMA by (20.8 and 29.2) % for emulsified and cutback asphalt mixes respectively. WMA exhibit higher ITS at 25 ^{0}C than HMA by 30.59% and 23.9 % when using cutback asphalt and emulsified asphalt with WMA respectively, on the other hand, WMA exhibit higher ITS at 5 ^{0}C than HMA by 11.77% and 4.14 % when using cutback asphalt and emulsified asphalt with WMA respectively.

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1. INTRODUCTION

Increased environmental awareness regarding emissions of volatiles when producing and placing of HMA have led to the development of the WMA. WMA has been used in Europe since 1997 and the United States since 2002. This results in reduced carbon footprints in the construction of asphalt pavements, (Sarsam, 2018). Reduce fossil fuel use at the hot mix asphalt plant, decrease emissions at the plant, and decrease worker exposure to emissions during placement. The decrease in emissions provides better working conditions and has an influence in reducing impacts to the environment, (Herrick et al., 2007). WMA was developed in response to needs for reduced energy consumption and stack emissions during the production of asphalt concrete, improved workability and compaction after long hauls and when using lower placement temperatures, and better working conditions for plant and paving crews, (Hurley and Prowell, 2006). One of the important advantages of using WMA is that it can decrease the mixing and compaction temperatures of bitumen mixtures. The low production and paving temperatures of WMA meaningfully decrease the emissions and fumes, (D'Angelo et al., 2008). WMA technology is good for the environment because it produces asphalt at temperatures 20–40° C lower in comparison to Hot Mix Asphalt. The temperature reduction achieved by WMA comes from the use of various technologies that have been developed in recent years, and which can be classified in the following three groups: organic additives, chemical additives, and water-based or water-containing foaming processes, (Rubio et al., 2012). (Schlosser et al, 2016) conducted a study to assess whether warm mix asphalt (WMA) use would result in significant emission reductions throughout the District and identify and address any barriers to adoption. It was concluded that using WMA instead of hot mix asphalt (HMA) results in lower temperatures required for production, storage, and transport which can lead to less fuel consumption, resulting in potential cost savings and emissions reductions. (Abouabid et al, 2017) reviewed and evaluated the mechanical and performance characteristics of the Warm Mix Asphalt (WMA) binder and surface course pavement layers against HMA. The air void contents reported varied significantly and were found to be higher than expected which may indicate that these asphalt materials could be susceptible to increased oxidation and permeability. WMA air voids were found to be higher than HMA. WMA rut depth was found to be slightly higher than HMA which could be attributed to higher air voids. The samples tested for moisture susceptibility showed ITSR values for all the binder course mixtures exceeded 70% indicating adequate resistance to water damage of the mixtures. A comparative study of different WMA technologies was carried out by (Baptiste et al., 2016), the study looked at both the mechanical and the environmental performances of the 3 different WMA technologies comparatively to a traditional equivalent HMA. The extensive laboratory evaluation seems to show that the 4 asphalt mix configurations tested lead to similar and very satisfying level of performances. The on-site measurements show some limited differences between the different sections as one of the WMA section is not as well compacted as the other ones probably due to the application conditions. Moreover, the stiffness modulus measured on extracted cores is a bit higher for the HMA section compared to all the WMA sections. (Garg et al., 2018) investigated the performance of HMA and WMA under high Aircraft tire pressure and temperature, it was concluded that HMA and WMA exhibit comparable performance in rutting, the rutting performance of HMA/WMA is more sensitive to temperature than tire pressure. (Tutu and Tuffour, 2016) reviews several studies in the context of pavement sustainability. It was noted that warm-mix asphalt provides substantial sustainability benefits like or, in some cases, better than conventional hot-mix asphalt. Sustainability benefits include lower energy use, reduced emissions, and potential for increased reclaimed asphalt pavement usage. It was concluded that there are concerns over some aspects of warm-mix asphalt such as lower resistance to fatigue cracking, rutting and potential water-susceptibility problems, particularly with mixes prepared with water-based technologies, which require further research to address. It was stated by (Jones, 2014) that the use of warm mix asphalt has clear benefits when compared to hot mixes. These include significant reductions in, or even elimination of, smoke and odors, lower emissions, improved workability, better working conditions, and better performance on projects with long hauls or where mixes are placed under cool conditions. The slightly higher costs of using warm mix technologies are outweighed by these benefits. (Rondón-Quintana et al., 2015) stated that the main failure modes in the measurement of WMA's resistance are the moisture susceptibility and rutting. The durability and resistance of WMA mixtures measured in the laboratory and in situ are not finalized. WMA mixtures experience a lower level of aging and oxidation in the short term of the asphalt binder, mainly due to the lower temperatures during the manufacturing, extension, and compaction processes. This lower level of aging in the short term can result in a mixture that is less fragile and more resistant to phenomena such as cracking by thermal fatigue. However, this advantage of WMA mixtures can reduce their resistance to permanent deformation and to fatigue in thick layer. (Martinho et al., 2017) compared several warm-mix asphalt (WMA) blends and hot mix asphalt (HMA) in terms of their resistance to permanent deformation (wheel-tracking tests), fatigue performance and stiffness modulus (four-point bending tests), and water sensitivity (indirect tensile strength ratio). The results showed that the level of mechanical performance of WMA was, globally, satisfactory and like the obtained for the HMA used as reference. Nevertheless, the warm mix with additive revealed high sensitivity to temperature. A significant variation of stiffness and resistance to fatigue could be anticipated, leading to the alert that construction and compaction conditions should be very well set and implemented in order to avoid very different porosities when compared with the mix design study. (Singh and Gupta, 2016) studied the variation in the physical properties between HMA and WMA, it was concluded that lower marshal stability, flow and voids in mineral aggregates are associated with WMA as compared with HMA. (Gamez A., 2012) conducted a performance evaluation addressing different 'curing' periods of the WMA to determine the evolution of the complex modulus over time, and to identify the optimum time for opening WMA paved surfaces to traffic. The effect of curing time on the short-term performance of the WMA was investigated. It was concluded that WMA exhibited lower tensile strengths than the control mix within the first 12 hours of curing time after compaction. While the tensile strength of the control mix remained relatively constant, the WMA tensile strength increased during the first seven days and was like that of control mix after the curing period. It was stated by (Raghavendra et al, 2016) that the low viscosity of liquid asphalt will furnish the required perfect coating of aggregates and the workability for compaction, whereas the curing period will provide the increase in mechanical strength, and durability during traffic exposure. WMA's disadvantages addressed by (Sargand et al, 2009), (Esenwa et al, 2011) and (Rashwan, 2012) are principally related to the potential of decrease material durability, and potential for rutting and moisture susceptibility cases. The significant decreases in Marshall Stability could be detected for WMA as compared to that of HMA regardless of asphalt content., this was attributed to the fact that hot aggregates absorb high percentages of liquid asphalt through the mixing process, then the excess volatiles evaporate, leaving more voids when compared to low liquid asphalt content, the excess voids will be more susceptible to the reduction in the strength property, (Sarsam and Nihad, 2018). The aging behavior and performance of several WMA-cutback asphalt roadways causes decrease in the rut depth with ageing as reported by (Raab et al., 2017). It was stated by (Goh, 2012) that the HMA exhibit higher tensile strength than that of the WMA. In a study of WMA, emulsified asphalt properties were compared with HMA and find that the temperature susceptibility for WMA-emulsified asphalt is less than HMA (Shifa et al., 2009). The WMA- emulsified asphalt has improved properties of asphalt mixture over HMA, including decrease in the temperature susceptibility and rate of the aging, (Sun et al., 2014).

The aim of this work is to implement medium cutback and cationic emulsion as a binder in the preparation of WMA. The moisture and temperature susceptibility of WMA will be assessed through the indirect tensile strength test of the mixtures to present the WMA as a possible green pavement alternative.

2. MATERIALS AND METHODS

2.1. Bitumen

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

Table 1. Physical Properties of Bitumen.

Test	Result	Unit	Specification (ASTM, 2015)
Penetration (25ºC, 100 gm, 5 sec)	43	1/10, (mm)	ASTM D-5
Ductility (25ºC and 5cm/minute)	156	cm	ASTM D-113
Softening point (ring & ball)	49	ºC	ASTM D-36
Absolute Viscosity @ 60 ºC	2150	Poise	ASTM D-2171
Specific gravity (25 ºC)	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 ºC, 50gm, 5h) %	0.220	%	ASTM D-1754
Ductility (25ºC and 5 cm/ minute)	96	cm	ASTM D-113

2.2. Cutback Bitumen

Medium curing cutback bitumen (MC-30) was implemented as a binder for warm mix asphalt production. The cutback was obtained from Dura refinery. Table 2 exhibit its properties as supplied by the refinery.

Table 2. Physical Characteristics of Cutback Bitumen.

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/m^3	0.91	0.91	0.93	—
Test on the Residue from Distillation				
Penetration@25°C, 100 g, 0.1mm, 5sec	150	120	250	ASTM D2027
Ductility @ 25 °C	100	100	—	ASTM D2027
Solubility in Trichloro Ethylene% wt.	99	99	—	ASTM D2027

2.3. Emulsified Bitumen

Cationic Emulsified bitumen was used as a binder for warm mix asphalt production, it was obtained from the state company for the mining industries. Table. 3 exhibit its properties as supplied by the producer.

Table 3. Physical Characteristics of Emulsified Bitumen.

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	—

2.4. Coarse and Fine Aggregates

Crushed coarse aggregates retained on sieve No.4 were obtained from AL-Nibaee quarry. Such aggregates are for asphalt concrete mixture. Natural and crushed sand were implemented as fine aggregates (passing sieve No.4 and retained on sieve No. 200). The aggregates were tested for physical properties and Table. 4 exhibits the test results.

Table 4. Physical characteristics of Fine and Coarse Aggregate.

Laboratory Test	(ASTM, 2015) Designation	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	ASTM C127	2.610	2.631
Water Absorption, %	ASTM C127	1.4	1.7
Emulsion Absorption, %	ASTM D4469	1	1.4
Cutback Absorption, %	ASTM D4470	0.6	0.9
AC (40-50) Absorption, %	ASTM D4471	0.4	0.6
% Wear (Los Angeles Abrasion)	ASTM C131	19.5	--

2.5. Mineral Filler

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

Table 5. Physical Characteristics of the Ordinary 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

2.6. Selection of Aggregates Gradation

Dense gradation following (SCRB, 2003) specification for binder course with nominal maximum size of 19 (mm) was adopted in this study. Figure 1 presents the combined gradation of the aggregates.

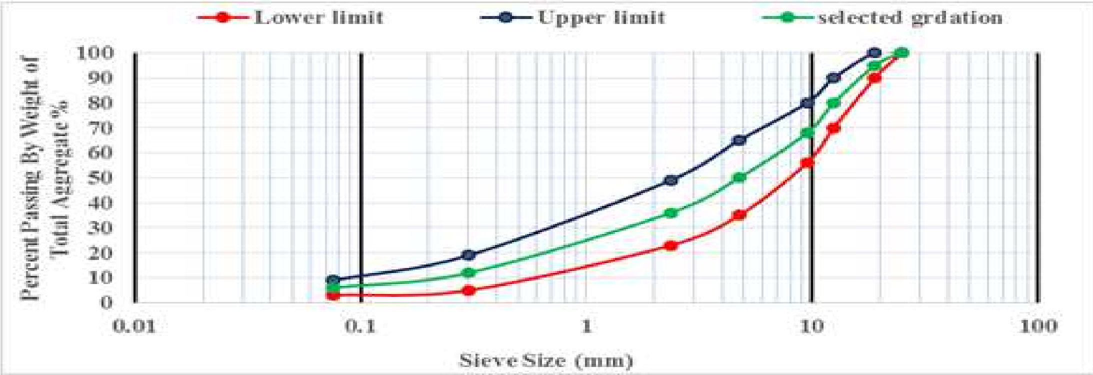

Figure 1. Gradation for Binder Course Layer According to SCRB, [21]

2.7. Preparation of HMA

The aggregates and filler were sieved and combined in order to meet a specified gradation of the binder course layer as specified by (SCRB, 2003). The combined aggregates were heated to a temperature 160 °C, while the bitumen was heated to temperature 150°C to produce a kinematic viscosity of (170 ± 20) centistokes, then the bitumen was added to the preheated aggregate to the required percentage of aggregate. The bitumen and the aggregate were mixed by hand in the mixing bowl on the hot plate for 3 minutes until the bitumen had adequately coated the surface of the aggregate, while the mixing temperature was maintained at 150 °C, specimens were compacted with Marshall Hammer using 75 blows on each side, according to (ASTM, 2015). Mixtures with 0.5 % of bitumen above and below the optimum have also been prepared to verify the impact of bitumen content on the temperature susceptibility.

2.8. Preparation of WMA

The aggregates and filler were sieved and combined in order to meet a specified gradation of the binder course layer according to (SCRB, 2003). The combined aggregate was heated to a temperature of (110 ºC), then the optimum requirement of liquid asphalt (6.8 and 5.8) % for the WMA-emulsified bitumen and WMA-cutback bitumen respectively at 20°C was added to the preheated aggregate to reach the desired amount of bitumen content, and mixed thoroughly by hand by the spatula for 3 minutes until all aggregates were coated with thin layer of liquid bitumen. Mixtures with 0.5 % of liquid asphalt above and below the optimum have also been prepared to verify the impact of binder content on the temperature susceptibility and moisture damage. The procedure of obtaining the optimum bitumen content (OBC) and the volumetric properties was published elsewhere, (Nihad and Sarsam, 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 as per (ASTM, 2015). Specimens were removed from the mold after 24 hours. In case of cutback asphalt mixtures, specimens were collapsed after removal from the mold because there was not enough time for evaporation of the volatile's materials contained in the asphalt components. Therefore, after several attempts using different curing periods and based on the literature, (National Academies of Sciences, Engineering, and Medicine, 2011), (Gamez A., 2012) and (Behl et al., 2014), it was decided to implement Short-Term Aging (STA) technique as prescribed by (AASHTO, 2013). Figure 2 shows part of the prepared cylindrical samples.

Figure 2. Part of the prepared cylindrical specimen for temperature susceptibility

2.9. Short Term Aging (STA)

The loose mixture of cutback-aggregate was placed in the pan and spread to a thickness of 30 mm, then stored in a conditioning oven for 4 hours ± 5 min. at 135 ± 3°C. The mixture was stirred every 1 hours throughout the (STA) process in order to obtain a homogeneous aging process. At the end of the aging period, the mixture was cooled to the compaction temperature of 100°C and poured into the mold and subjected to 75 blows on the top and bottom of the specimen with Marshal compaction hammer. This procedure was implemented in accordance (AASHTO, 2013). This aging signifies to the aging which occurs in the field among mixing and placement which allows for absorption of the asphalt into the pores of aggregate and evaporation of the volatiles of a binder.

2.10. Test for moisture damage and Indirect Tensile Strength

The indirect tensile strength ratio test TSR has been utilized for assessing the moisture damage potential of the WMA. The moisture susceptibility test detects the stripping in the mixture. The test procedure followed (ASTM D-4867, 2015). A set of six specimens was prepared, three samples were tested for ITS at 25° C, the average value of ITS for these samples were considered and labeled (unconditioned). The other three specimens were conditioned by placing in the flask filled with water at 20˚C, then a vacuum of 30 mm (Hg) was applied for 10 minutes. The saturated specimens were covered by the plastic film and put in the plastic bag containing 10 ± 0.5 mL of water and sealed, then the bags were put in a freezer at (-18 ± 3°C) for 24 hours. After 24 hours, the plastic bag and film were removed from each specimen and could thaw for two hours at the room environment, then tested for ITS. This test was implemented at the rate of 50.8 mm/min till a maximum load is achieved and the sample fractures, then the load was recorded. Figure 3. Exhibit the conditioning process. The indirect tensile strength test followed the procedure of (ASTM, 2015). Marshall Specimens were used in this test, and percent air voids for specimens were the same as for Marshall Test at optimum binder content. Test was conducted at (5 and 25) °C.

Figure 3. Wrapping the specimen with a plastic sheet, storage in freezer and testing apparatus

3. RESULTS AND DISCUSSIONS

3.1. Impact of Bitumen Type and Content on Temperature Susceptibility

The Temperature Susceptibility results exhibited in Table 6 showed that the HMA was more influenced by temperature than WMA. The temperature susceptibility of HMA is higher than that of WMA by (26.3 and 41.1) % for cutback and emulsion treated mixtures respectively at optimum bitumen content, such behavior of materials comply with the findings of (Mortono, 2008) and (Behl et al., 2014). This may be attributed to the lower binder content in WMA mixture and the hardening of the asphalt after aging in case of cutback which lead to mixture of less susceptibility to temperature variation. It can also be observed that WMA-Emulsified bitumen exhibits the lowest temperature susceptibility among other tested mixtures at various asphalt percentages. The cutback treated mixture was sensitive to the change in asphalt content, specimens with ± 0.5 asphalt rather than OBC collapsed during the test. Similar findings have been reported by (Suresha and Kumar, 2018) and (West et al., 2014). Table 7 summarizes the ITS test results at OBC and two testing temperature which furnishes the data for temperature susceptibility calculation.

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

HMA		**WMA-Cutback Bitumen**		**WMA-Emulsified Bitumen**	
Bitumen content %	Temperature Susceptibility (kPa/ ^{o}C)	Bitumen content %	Temperature Susceptibility (kPa/ ^{o}C)	Bitumen content %	Temperature Susceptibility (kPa/ ^{o}C)
OBC-0.5	26	OBC-0.5	Failed	OBC-0.5	9
OBC	24	OBC	19	OBC	17
OBC+0.5	32	OBC+0.5	Failed	OBC+0.5	24

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

HMA		**WMA-Cutback Bitumen**		**WMA-Emulsified Bitumen**	
Bitumen %	ITS kPa	Bitumen %	ITS kPa	Bitumen %	ITS kPa
OBC at 25 ^{o}C	912	OBC at 25 ^{o}C	1191	OBC at 25 ^{o}C	1130
OBC at 5 ^{o}C	1402	OBC at 5 ^{o}C	1567	OBC at 5 ^{o}C	1460

3.2. Influence of Testing Temperature on ITS

As demonstrated in Figure 4, the indirect tensile strength (ITS) values at OBC and 25 ^{o}C increased by (30.59 and 23.9) % when cutback bitumen and emulsion were implemented respectively as compared to mixtures of HMA. On the other hand, The ITS values at OBC and 5 ^{o}C increased by (11.77 and 4.14) % when cutback and emulsion were implemented respectively for WMA as compared to those of HMA. Such behavior of materials complies with the findings by (Behl, and Chandra, 2017). The reduction in ITS is significant when increasing the testing temperature since the increase of temperature causes reduction in the cohesion between aggregate particles and its adhesion with the binder of asphalt concrete mixtures due to the reduction in viscosity of bitumen.

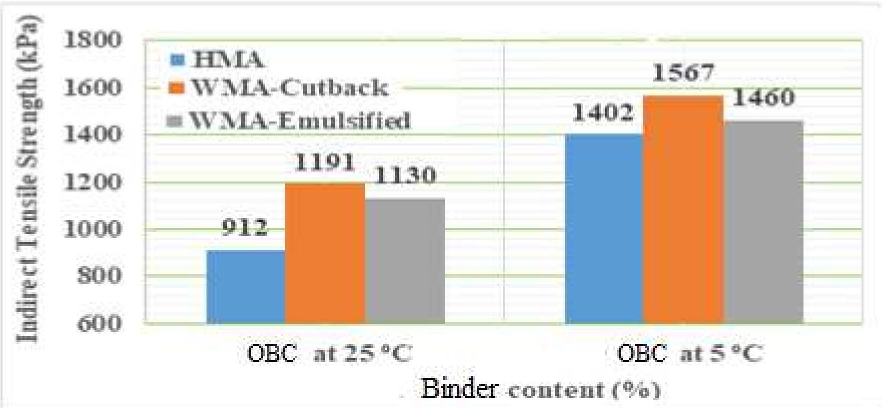

Figure 4. Effect of Testing Temperature on ITS according to the Asphalt binder Type.

3.3. Effect of Bitumen Content and Testing Temperature on ITS

Figure 5 demonstrates the ITS test results at 5 ºC. It can be observed that for HMA, the ITS was decreased by (6 and 13.62) % when the bitumen content increased or decreased by 0.5 % from OBC respectively. On the other hand, the results of WMA-cutback bitumen at 5 ºC show that the ITS was decreased by 5.68 % when the binder content decreased by 0.5 % from OBC, while when the binder content increased by 0.5 % from OBC, specimen was fractured. The results of WMA-emulsified bitumen at 5 ºC show that the ITS was increased by 5.96 % and decreased by 13.7 % when the binder content increased or decreased by 0.5 % from OBC respectively. The increase in the binder content by 0.5 % from OBC negatively affect the ITS due to the increment in the bitumen content which produces thicker films around the individual aggregate particles, therefore tend to thrust the aggregate further separately subsequently. The reduction in the bitumen content below OBC increases the stiffness of the mixture, that causes reduction in the required cohesion between asphalt and aggregate which leads to weaken the tensile strength.

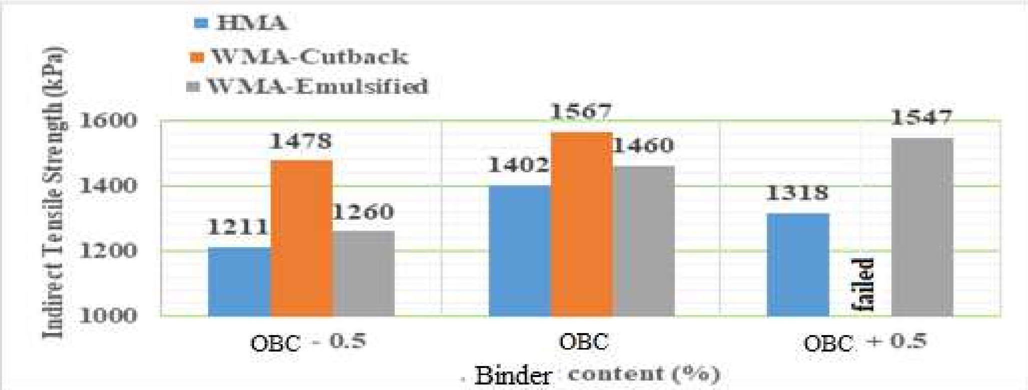

Figure 5. Effect of Asphalt Content on The Indirect Tensile Strength at 5 ºC.

3.4. Influence of Bitumen Type and Content on Indirect Tensile Strength

Various percentages of bitumen content have been tried, namely OBC ± 0.5 % in order to study the impact of the variation in bitumen content on the ITS value tested at 25°C for different mixtures as shown in Figure 6. The test results of HMA show that the ITS decreased by (25.10 and 23.14) % when the bitumen content increased or decreased by 0.5 % from OBC respectively, this gives an indication that at the OBC, the asphalt concrete mixture has good resistance to ITS, such behavior of materials comply with the findings by (Sarsam, 2016). The results of WMA-cutback bitumen show that the ITS at OBC equal to 1191 kPa and when the cutback content increased or decreased by 0.5 % from OBC, specimens were fractured. Such finding indicates the sensitivity of WMA to the variation in cutback content. The results of WMA- emulsified bitumen show that the ITS was decreased by (28.58 and 4.51) % when the emulsified bitumen content increased or decreased by 0.5 % from OBC respectively.

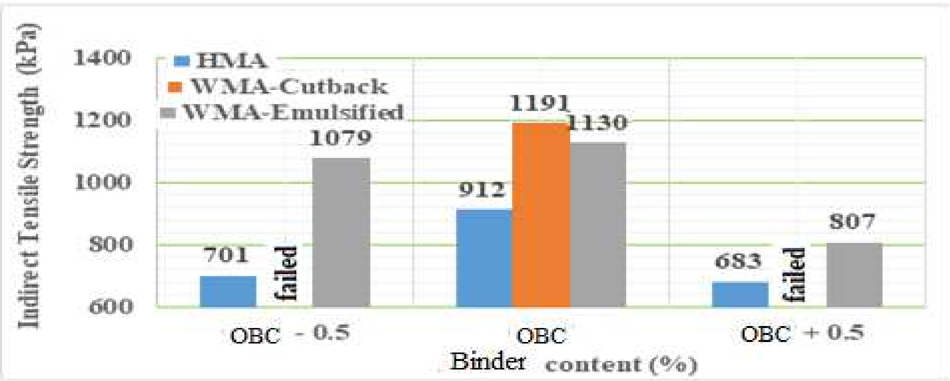

Figure 6. Effect of Binder Content on the ITS at 25 ºC.

3.5. Influence of Bitumen Content on Resistance to Moisture Damage

The purpose of conducting this test is to study the influence of binder type and content on the tensile strength ration (TSR) for HMA and WMA mixtures which is an indication of the resistance to moisture damage. The (TSR) test results demonstrated in Figure 7 showed that, the HMA was less influenced by moisture damage than WMA at (OBC). The (TSR) for HMA is higher than WMA-cutback bitumen by 8.51 %, such behavior of materials does not comply with the findings of (Esenwa, 2011). The possible cause of such behavior was that the short-term aging process had improved the resistance to moisture damage for the WMA-cutback bitumen. WMA mixture after being exposed to oxidation would practice increment in the stiffness which lead to increase the resistance to tensile stress. The WMA-cutback bitumen could have more air voids than HMA after the loss of volatiles with age. It can be observed that (TSR) for HMA is higher than (TSR) for WMA-emulsified bitumen by 2.13 %, such behavior of materials complies with the findings of (Shifa, 2009) and (Zhang, 2010). The low viscosity of emulsified bitumen influence the better distribution of binder and decreases the number of uncoated aggregates, which contribute towards better stability, but since the emulsified bitumen contains water which may interact with filler (Portland cement), therefore, exhibit stiffer mixture with low moisture susceptibility. The evaporation of water with age would exhibit more voids than the case of HMA, therefore exhibit lower (TSR) than HMA. Similar finding was reported by (Suresha and Kumar, 2018). The WMA-emulsified bitumen exhibits higher (TSR) than WMA-cutback bitumen. This may be attributed to the effect of cement filler hydration process when got interaction with water in emulsion and filling the voids and decreasing water absorption. This could exhibit low water impact on WMA-emulsified bitumen mixture.

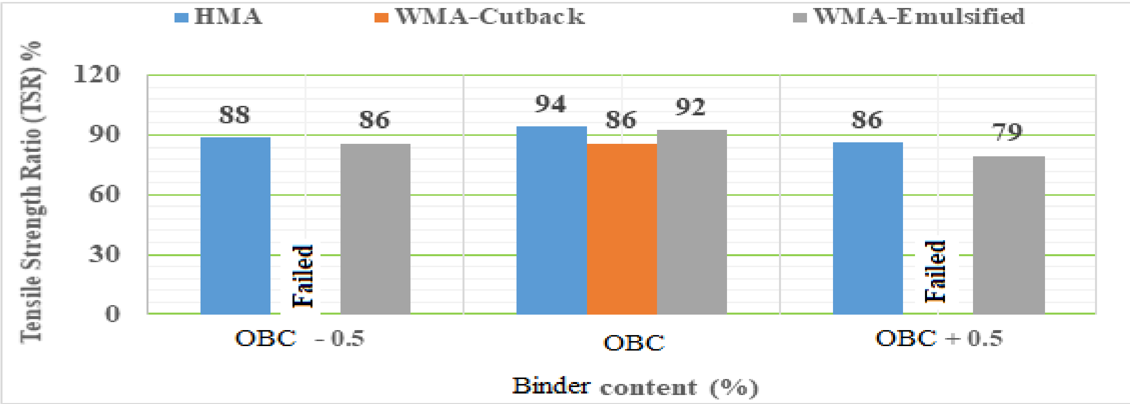

Figure 7. Effect of Binder Content on the TSR %

4. CONCLUSIONS

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

1- WMA mixtures are less susceptible to temperature variation than HMA, the temperature susceptibility values were (17 and 19) kPa/°C for the WMA-emulsified bitumen and WMA- cutback bitumen respectively, which are lower than that of HMA by 29.17% and 20.83% respectively.

2- WMA exhibit higher ITS at 25 ºC than HMA by 30.59% and 23.9 % when using cutback and emulsion binders respectively, on the other hand, WMA have higher ITS at 5 ºC than HMA by 11.77% and 4.14 % when using cutback and emulsion respectively as compared to HMA.

3- The ITS at 25 ºC decreases by (25.10 and 28.58) % and by (23.14 and 4.51) % when the binder content increased or decreased by 0.5 % from OBC for HMA and WMA- emulsion bitumen respectively. For WMA-cutback bitumen, the ITS value at OBC equal to 1191 kPa and it exhibit sensitive behavior to the variation in binder content.

4- The ITS values at 5 ºC of HMA decreased by (6 and 13.62) % when the binder content increased or decreased by 0.5 % from OBC respectively, while for WMA-cutback bitumen, the ITS decreased by 5.68 % when the binder content decreased by 0.5 from OBC.

5- 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.

6- Warm mix asphalt concrete prepared with medium curing cutback or cationic emulsion binders can be presented as a green and sustainable pavement due to its lower susceptibility to temperature variation and its satisfactory resistance to moisture damage as well as lower mixing, handling and compaction temperature.

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