Evaluation of Moisture Susceptibility for Modified Open Graded Friction Course Mixes Used Styrene Butadiene Styrene

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Abstract

Open-graded-fraction-course (OGFC), is a hot asphalt mixture usually utilized as a private purpose wearing course, because of open graded asphalt mixture and aggregates skeleton (stone-on-stone) contact, it contain a relatively high air voids' percentage, after compaction which are permeable to water. In this research one type of gradation was used (12.5 mm) NMAS, to preparing the OGFC asphalt mixtures, penetration grade 40/50, crushed aggregate, asphalt content prepared with 4 % and up to 6 % by weight of mixture with 0.5 % increments. Optimum asphalt content (OAC) was selected based on these criteria, air voids content, asphalt draindown, permeability, and abrasion resistance (aged and un-aged) condition. The mix performance had been investigated by indirect tensile strength and moisture susceptibility (sensitivity) measured according to the (AASHTO T283-14). Results illustrate that the increasing of asphalt binder content leads to a decrease of the air voids content, abrasion loss and permeability values, while draindown increase, conversely, the indirect tensile strength (ITS) had been significantly increased for both conditions and this is a gaod suggestion to resistance alongside moisture susceptibility. It can be decided that the increasing of asphalt binder percent in OGFC asphalt mixture, leads to an increase in the thickness of binder coating around the aggregates. On the other hand, the influence of modifier that prepared with 4% styrene-butadiene-styrene (SBS) on OGFC asphalt mixture tends to improve the mix properties and exhibit higher (TSR) as compared with original asphalt by (31, 27.7 and 24.4) % at asphalt percent (4.8, 5.3 and 5.8) %, respectively. The SBS improved the adhesion between aggregate and asphalt which leads to reduce stripping of HMA, horizontal deformation, and increased the tensile stiffness modulus value.

Keywords: OGFC, Draindown, Cantabro Abrasion Loss, Permeability, Indirect Tensaile Strength And Moisture Sensitivity.

تقيم حساسية الرطوبة لخلطات مفتوحة التدرج المقاومة للاحتكاك محسنه بمادة ال SBS

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الخلاصة

طبقة الاحتكاك ذات التدرج المفتوح (OGFC) هي خلطة إسفلتية ساخنة يستخدم بشكل خاص كطبقة سطحية، وذلك بسبب التدرج المفتوح للخلطة والذي يعتمد على ربط هيكلية الركام المفتوح (ركام على ركام)، ويحتوي على نسبة فراغات عالية نسبياً، بحيث بعد الحدل تبقى الخلطة محافظة على نفاذيتها العاليه للماء. في هذا البحث تم استخدام تدرج ذو مقاس (12.5 ملم) NMAS لإعداد خلطات اسفلتية مفتوحة التدرج، ذات اسفلت ذو درجة اختراق 50/40 و ركام مكسر ، ويمحتوى اسفلت محضر بنسبة 4٪ الى 6٪ من وزن الخلطة مع زيادة بنسبة 0.5 ٪. تم اختيار أفضل محتوى إسفلتي (OAC) بناء على المعاييرالاتية : محتوى الفراغات الهوائية و سيلان الاسفلت والمواد الناعمة والنفاذية ومقاومة التآكل لخلطة (متقادمة بالعمر وغير متقادمة). وقد تم دراسة أداء المزيج عن طريق قوة الشد

غير المباشرة وحساسية الرطوبة المقاسة وفقاً لـ (AASHTO T283-14). أوضحت النتائج أن زيادة محتوى الأسفلت يؤدي إلى تقليل كل من محتوى الفراغات الهوائية وخسارة النموذج للتآكل وقابلية النفاذية، في حين أن سيلان الاسفلت والمواد الناعمة يزداد. على عكس ذلك، تم زيادة قوة الشد غير المباشره (ITS) بشكل كبير لكلا الحالتين وكان هذا مؤشر جيد ضد مقاومة الخلطة لحساسية الرطوبة. تم استنتاج أن زيادة نسبة القير في الخلطة الإسفلتية مفتوجة التدرج يؤدي إلى زيادة سماكة طبقة الاسفلت حول الركام، من ناحية أخرى، ان تأثير معدل المضاف الذي تم تحضيره بنسبة 4٪ من (SBS) على الخلطة الأسفلتية ذات التدرج المفتوح أدى إلى تحسين خصائص المزيج الاسفلتي ويظهر أعلى نسبة مقاومة شد (TSR) بالمقارنة مع الأسفلت الأصلي بنسبة (31 , 27.7 , 24.4) ٪ لمحتوى إسفلت (4.8 , 5.3 , 5.8) ٪ ، على التوالي. كما اثبتت النتائج ان الخلطة ذات التدرج المفتوح المحسنة بمادة SBS أدت الى تحسين الاتصاق بين الركام والأسفلت مما يؤدي إلى التقليل من انسلاخ او تطاير مكونات الخلطة HMA)) وكذلك التقليل من التشوه الافقي وزيادة قيمة معامل صلابة الشد..

1. Introduction

Open graded friction courses (OGFC), is as exceptional purpose thin surface of hot mixture asphalt (HMA), pavement that is increasingly being utilized around the world owed to its security aspects and driver friendly. The OGFC regularly applied as final riding surface on interstate and high speed expressways low volume, permeable layer of asphalt mixture improves surface drainage during rainfall, the rainwater drains perpendicularly through the OGFC asphalt mixture to an impermeable underlying layer and then laterally to the margin of the pavement. The others application of open graded asphalt mixtures are to provide skid resistance in addition, reduces splash and spray potential, mainly in the wet season, which is obviously better than dense-graded asphalt pavement, which reduced the potential of aquaplaning, and improved visibility of marking roads. This mixture contain a small percentage of fine aggregate which produces a large percent of air voids, the pavement consists primarily from coarse aggregate with a high asphalt binder content. Aggregate skeleton (stone-on-stone), is responsible for the pavement ability, to resist trucks and carry the loads resulting from traffic loading without exposing pavement to cracking and permanent deformetion, the load is carried by the stone while the asphalt keeps everything in place. Over 70 % of the states reported an OGFC asphalt pavement service life of 8 or more years [1]. Because of the open structure of the layer, however, environmental forces such as moisture and asphalt oxidation have been a negative impact on durability (due to the ingress of air, water, heat and ultra-violet radiation), improved that by using of modified- polymer asphalt binder [2]. The voids content, also absorb sound energy as tires roll over the OGFC pavement, by 5 decibels (dBA) [3]. The higher air voids in mixture leads to reduce contact area between aggregate particles, hence leading to its lowered ITS. Though, the use of modified asphalt significantly increases ITS values of mixture by 18.1 % as compared with asphalt mixtures without modifiers [4].

2. Methodology

The methodology adopted for this study includes the selection of local materials that are widely used in the asphalt paving industry in Iraq. According to [5], gradation was selected; while optimum asphalt content choice based on these criteria, air void content, draindown, cantabro abrasion and permeability for varying asphalt binder contents. marshall specimens prepared and compacted using optimal asphalt content and were checked for moisture sensitivety to evaluate the performance of OGFC asphalt mixture.

3. Materials Properties

The material used in this research has been tested according to the ASTM standard and compared to the results achieved by the Iraqi Standard Specification [6].

3.1 Aggregates

The local aggregates used in this research consist of crush quartz, obtained from "Al-Nibae quary" which is commonly utilized for asphalt mix. in Iraq. The fine and coarse aggregates used in this research must be washed, sieved and recombained in the appropriate proportions to met the specification of wearing course as essential by [6], Table (1) demonstrate that.

3.2 Filler

Material pasing through sieve number # 200 (0.075 mm) is called as filler. One type of mineral fillers applied in this research, which was "Ordinary Portland Cement Type I" from mass Iraq corporation for cement production. Table (2) demonstrat the physical propertis of cement Filler.

3.3 Asphalt Binders

Asphalt binder with "40/50" penetration grade, had been utilized in this study, obtained from the (Dura refinery), southwest of Baghdad. A set of ASTM tests were conducted for identification of the physical propertis of asphalt binder, as presented in Table (3), The results were in accordance with the requirement of [6].

3.4 Asphalt Binder Modified with Styrene-Butadiene-Styrene (SBS) Modified

Styrene-Butadiene-styrene is a thermoplastic polymer produced by (KRATON® D1192 E Polymer), company in France, the poly-butadiene block provides elastecity and the poly-styrene block provides plastic assets that improves the performance of asphalt pavement by increasing the stability, stiffness and elasticity of asphalt binder. SBS soften under high temp. therefore, it can be simply added and blended. 4 % SBS was added with asphalt binder. Table (4) presents the SBS properties.

Table (1): Properties of aggregate

Property	Specification	Coarse aggregate	Fine aggregate	SCRB 2003
Bulk specific gravity	ASTM C127-128	2.611	2.658	....
Apparent specific gravity	ASTM C127-128	2.662	2.733	....
Percent of water absorption	ASTM C127-128	0.52	0.73	....
Los Angeles abrasion	ASTM C131	17.72	....	30% Max
Percent flat and elongated	ASTM D-4791	5		10% max
Fractured pieces	ASTM D5821	98	....	90% Min
Clay content by Sand equivalent	ASTM D2419	....	53	45% Min

Table (2): Physical propertis of cement filler

Physical properties	
Passing Sieve No 200 , %	97
Bulk Specific gravity	3.14
Surface Area (m2 / kg)	355
Fineness (cm^2/gm)	3050

Table (3): The physical properties of the asphalt binder (Dura Refinery**)**

Test	Unit	Specification	Value of test	S.C.R.B 2003 specification
Penetration (25 ℃-100g 5sec) (0.1mm)	1/10 mm	(ASTM D5)	43	(40-50)
Ductility (25 ℃, 5 cm/min)	cm	(ASTM D113)	140	> 100
Flash point (cleave land open cup)	℃	(ASTM D92)	296	> 232
Fire points	℃	(ASTM D92)	326	....
Softening point R&B (4±1) °C/min.	℃	(ASTM D36)	53	(51-62)
Solubility in trichloroethylene	%	....	99.7	> 99
RV 135 °C	Pas.sec	(ASTMD-4402)	0.52	....
RV 165 °C			0.31	
Specific gravity at 25 ℃	....	(ASTM D70)	1.04	(1.01-1.05)
Residue After Thin-Film Oven Test (ASTM D1754)				
Retained penetration; % of original	%	(ASTM D5)	88.4	> 55
Ductility of residue (25 ℃ - 5 cm/min)	cm	(ASTM D113)	105	> 25

Table (4): The physical properties of modify asphalt 4 % SBS

Test	Unit	Specification	Value of test
Penetration (25 ℃-100g 5sec) (0.1mm)	1/10 mm	(ASTM D5)	35
Ductility (25 ℃, 5 cm/min)	cm	(ASTM D113)	110
Flash point (cleave land open cup)	℃	(ASTM D92)	323
Fire points	℃	(ASTM D92)	368
Softening point R&B (4±1) °C/min.	℃	(ASTM D36)	72
Solubility in trichloroethylene	%	....	99.3
RV 135 °C	Pas.sec	(ASTM D-4402)	1.34
RV 165 °C			0.74
Specific gravity at 25 ℃	....	(ASTM D70)	0.96
Residue After Thin-Film Oven Test (ASTM D1754)			
Retained penetration; % of original	%	(ASTM D5)	80
Ductility of residue (25 ℃ - 5 cm/min)	cm	(ASTM D113)	85

3.5 Gradation

The gradient was selected according to [5] for OGFC paving mixtures. The sieve size from 3/4 in (19 mm) to No. 200 (0.075mm). In this study, one kind of OGFC gradation had been used (19 mm) maximum aggregate sizes (MAS), Table (5) and Figure (1) illustrate that.

Table (5): Aggregate gradation of OGFC asphalt mixture

Sieve Size mm	NMAS 12.5 mm (Coarse Gradation)	
	ASTM D7064−13 % Passing	Selected % Passing
3/4 inch (19.0 mm)	100	100
1/2 inch (12.5 mm)	(85 - 100)	93
3/8 inch (9.5 mm)	(35 - 60)	48
No. 4 (4.75 mm)	(10 -25)	20
No. 8 (2.36 mm)	(5 -10)	8
No.200 (0.075mm)	(2 -4)	4

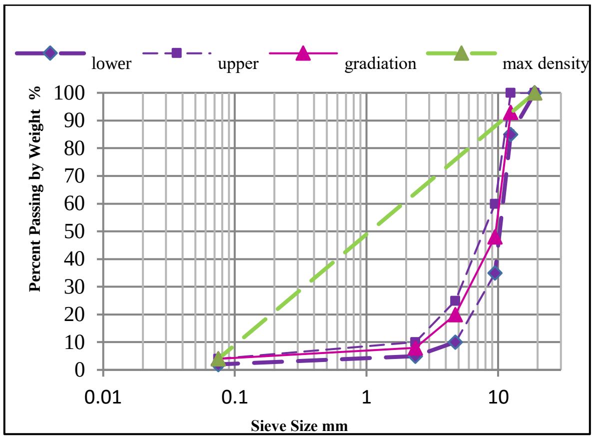


Figure (1): Gradations of combined aggregate (NMAS 12.5 mm) used in this work

4. Experimental Works and Laboratory Investigation

4.1 Preparation of Marshall Molds and Specimens

Marshall specimen was prepared according to [7], that involves of a diameter shall be 4 inch (101.5 mm) and 2.5 inch (63.5 mm) in nominal height. Open graded asphalt mixture were equipped by blending aggregates with five different asphalt binder (4, 4.5, 5, 5.5 and 6%), aggregates, cement filler and asphalt were blended in a steel container to products the samples, the weight of sample approximetely about 1200 gm. The loose mixture were conditioned for (volumetric mixture design) in an oven for two hrs. at compaction temp., and 4 hrs.; at 135 °C for short term aging (mechanical property testing). The frame rally placed on the compaction base and "75 shocks", on each face (top and botom) of sample, was done exhausting the standard marshall hammer. The specimen was left to cool at ambient temp. previous to consequent testing, Plate (1) illustrate that.

4.2 Mixing and Compaction Temperatures

The visco. of asphalt binder 40-50 "penetration grade" was determined consuming a Brokfield Rotational Viscometer and accompanied conferring to [8]. [9] commends perfect asphalt binder mixing and compaction viscosities coresponding to (0.17±0.02 Pa.sec and 0.28±0.03 Pa.sec), respectively. Figure (2) shows the semi-logarithmic correlation between temperature and viscosity, and two temp. (135 and 165) °C adopted. From the slope lines, the mixiing and compaction temperatures were found to be in the range of (157 to 163°C) and (142 to 150°C), respectively. Based on these outcomes, the essential mixing and compaction temp. were 163 °C and 150 °C, respectively; which were utilized in this investigations.

Plate (1): Prepared specimens

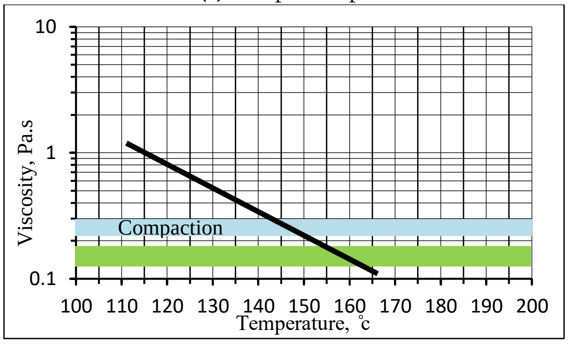


Figure (2): Viscosity-temperature chart for asphalt 40/50

4.3 Volumetric properties

4.3.1 Theoretical Max Specific Gravity (G_{mm})

Maximum theoretical specific gravity, is a virtual value demonstrating a compressed sample without air void percent, that was obtained according to [10].

4.3.2 Bulk Specific Gravity of Mix (G_{mb})

Bulk specific gravity, of the competed mixture has been determined by using the geometric measurements of specimens, according to [11].

4.3.3 Air Voids (Av%)

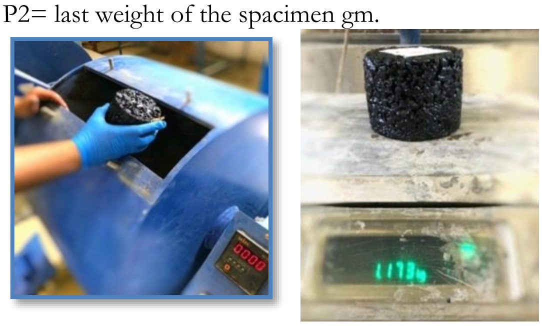
According to test method [11], air voids percent was found for compacted OGFC bituminous paving mixtures, and can be defind as the full size of small air sacks between the covered particles aggregate throughout a compacted asphalt mix.

4.4 Cantabro Abrasion Loss Test.

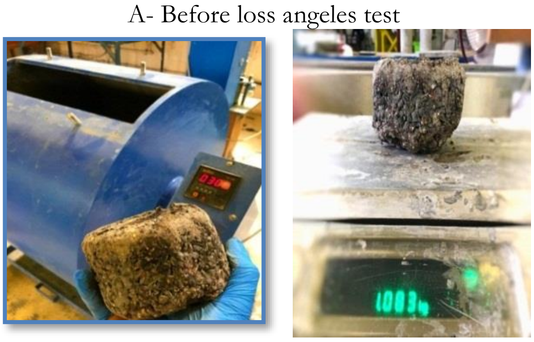
This test was carried out on Marshall sample in an un-aged and aged conditions according to [5], to obtained the abrasion loss of samples equipped with "4 to 6 %" asphalt binder percent consuming the "Loss Angales" container without the charge of steal spheres, machine was revolved (300) revolutions at speed of (30-33) rpm, 18 samples were prepared. The cantabro abrasion test for un-aged compacted mixture was maintained at the test temp.(25 °C) for at minimum 6 hours. The average abrasion loss for set of samples should not exceed 20%. For second condition accelerated laboratory aging was used to simulated the samples that prepared at lab to field. The compacted samples were placed in a forced draft oven, set at 60 °C (140 °F) for 168 hr. (7days). Then, the sample was cooled to 25 °C (77 °F) and stockpiled for 4 hour before implementing the cantabro test. The average abrasion loss for set of samples should not exceed 30%. Plate (2) illustrate specimens before and after abrasion loss test (Before and After Test). The outcome of the experiment test was determined by using the succeeding equation.

$$\mathbf{P = [(P1 - P2)/P1] \times 100}$$

Where:
P = cantabro abrasion %.
P1= original weight of the spacimen gm.
P2= last weight of the spacimen gm.



A- Before loss angeles test



B- After loss angeles test
Plate (2): Sample before and after cantabro abrasion test

4.5 Draindown Test

Draindown features of un-compacted asphalt mixture was evaluated using basket drainage. The draindown test was accomplished to estimate the draining of asphalt binder or fine aggregate from the loose mixture samples as temperature increases. The loose, un-compacted mix was taken and transferred to the drainage basket and assembly were placed into the oven at 170 ˚C for 1 hour ± 5 min. Pre-weighed plate was kept below the drainage basket to collect the drained out binder drippings as shown in Plate (3). The percent of material that drainage had been calculated by using the following equation. The max. allowable draindown should not surpass (0.3) % accordance with [12], 18 samples were prepared.

$$\text{draindown } \% = \frac{(D - C)}{(B - A)} \times 100$$

Where:
A= mass of the unfilled basket gm.
B= mass of the basket and specimen gm.
C= mass of the empty hook bowl gm.
D= mass of the hook bowl plus exhausted material gm.

Plate (3): Asphalt draindown test

4.6 Permeability

Permeability (K) is the greatest influancing factor afecting the stability and long term functionality / performance of OGFC aphalt pavement. Two different methods can be carried out to determined permeability in asphalt mixture, namely the "constant head" or "falling-head" tests. In this research, faling-head test apparatus was used to determine the rate of flow water, that conducted through Marshall specimen, with (150 mm) diameter and (150 mm) height at optimum asphalt content; conferring to the FDOT [13]. Eighteen (18) samples were prepared, and each sample tested a minimum of 3 times and the average was determined. Plate (4) and (5) shows apparatus and prepared samples, respectively. The coeff. of permeability (K) of the compacted asphalt mixture was calculated depend on "Darcy law", using the succeeding equation.

$$K = \frac{a \times l}{A \times t} \ln\left(\frac{h1}{h2}\right)$$

Where:
k= coeff. of permeability cm/s.
a= inside cross sectional area of standpipe cm2.
l= thickness of test sample cm.
A= cross- sectional area of test specimen cm2.
t= avarege lapsed time of water flow between timing marks sec.
h1= hydraulic head on sample at time t1 cm.
h2= hydraulic head on sample at time t2 cm.
ln = natural logarithmic function.

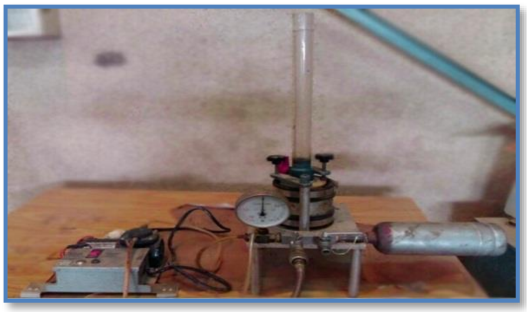


Plate (4): Hydraulic conductivity apparatus

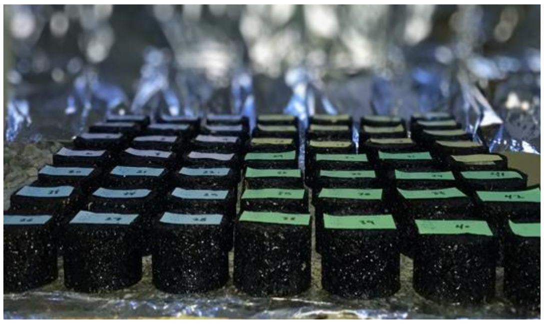


Plate (5): Specimens for permeability test

5. Determined of Optimum Asphalt Binder Content (OAC %)

According to [5], several Marshall specimens were prepared at various asphalt contents from (4 to 6) % (by weight of total mix.) with periods of increase equal to (0.5) %, (150 samples was prepared). In order to determine the opt. asphalt content OAC %. A sequences of tests such as: cantabro abration test (aging and un-aging), draindown test, air void content and permeability were caried out for the selected (OAC) for the mixture. The average percentage of asphalt was taken according to the four criterias as shown in Figure (3) and Table (6).

6. Indirect Tensile Strength Test (ITS)

The ITS test was vastly utilized to determine the relative quality and spliting strength of hot asphalt mixtures (HMA), and test was directed according to the [12], techniques using the marshall loading method. Plate (6) shows details of indirect tensile test and sample tested. Applied a perpendicular compressive load until the max. load was extended, record the max. load (peak load at failure). Three samples for each mixture were tested and the average results stated. The ITS was calculated consuming the succeeding equation.

$$\mathrm{ITS} = \frac{2000 \times P}{\pi \times t \times D}$$

Where:
ITS = indirect tensile strength kPa.
P = max. load to failure N.
D = diameter of sample mm.
t = thickness of sample before test mm.

7. Moisture Susceptibility (Sensitivity) TSR

This test method covers the variation of diametrical tensile strength resulting from the effects of water saturation and accelerated water condition with frees/thaw cycle of compacted asphalt mixture. Traffic loading and climatic conditions may cause tensile stresses that developed within the pavement and results two kinds of cracks may be exhibited, called fatigue cracking and thermal or shrinkage cracking, respectively. [14], used to estimate moisture sensitivity of OGFC asphalt mixture. Two subsets of test specimens were produced. Samples were compacted in Marshall hammer. One subset of 3 specimens was tested in a dry condition. The other subgroup of the 3 samples was considered wet condition subgroup exposed to vacuum permeation followed by a freeze sequence at minimum 16 hrs. at -18°C followed by a 24 hrs. thaw cycle at 24 hrs. at 60°C, after acclimatizing both subsets were tested for indirect tensile strength, an average value of ITS for dry set (Sd) and for wet (Sw) were computed. This was achieved by tester machine head by applying the load to the specimen with a constant rate 50.8 mm / minute (2in/min) the max load at failure was recorded. Minimum tensile strength ratio 80 %. The succeeding equation was utilized to computed the (TSR).

$$\mathrm{TSR} = \frac{\mathrm{Sw}}{\mathrm{Sd}} \times 100$$

Where:
TSR= indirect tensile strangth ratio %.
S_d = avarege of indirect tensile strength of dry unconditioned kPa.
Sw= avarege of indirect tensile strength of wet conditioned kPa.

Plate (6): Details of indirect tensile test and sample tested

8. Test Results and Discussion

8.1 Selection of Optimum Asphalt Content

As soon as the design gradation was determined, then numerous specimens prepared at several asphalt percentages in order to determine the opt. asphalt content (OAC). Five asphalt percent were estimated (4, 4.5, 5, 5.5 and 6%); these designated percentages depend on enginering best practice after conversation with municipal and secretive sector authorities. The samples were estimated based on: air void analysis, cantabro abrasion loss (un-aging and aging), draindown test and permeability. The results for each were employed to determine the optimum asphalt content was (5.3) %, as shown in Figure (3) and Table (6)

8.2 Evaluation of Moisture Sensitivity

Figures (4) and (5) illustrate the results of ITS for both conditions which used original and modified asphalt, while Figure (6) demonstrate the mean tablet diagram of indirect tensile ratio (TSR) for OGFC (original and modified) asphalt mixture. The result indicates that when asphalt content increased, the TSR increases for both asphalts. Based on the test results, this due to excessive asphalt content that increases the thickness of asphalt coating.

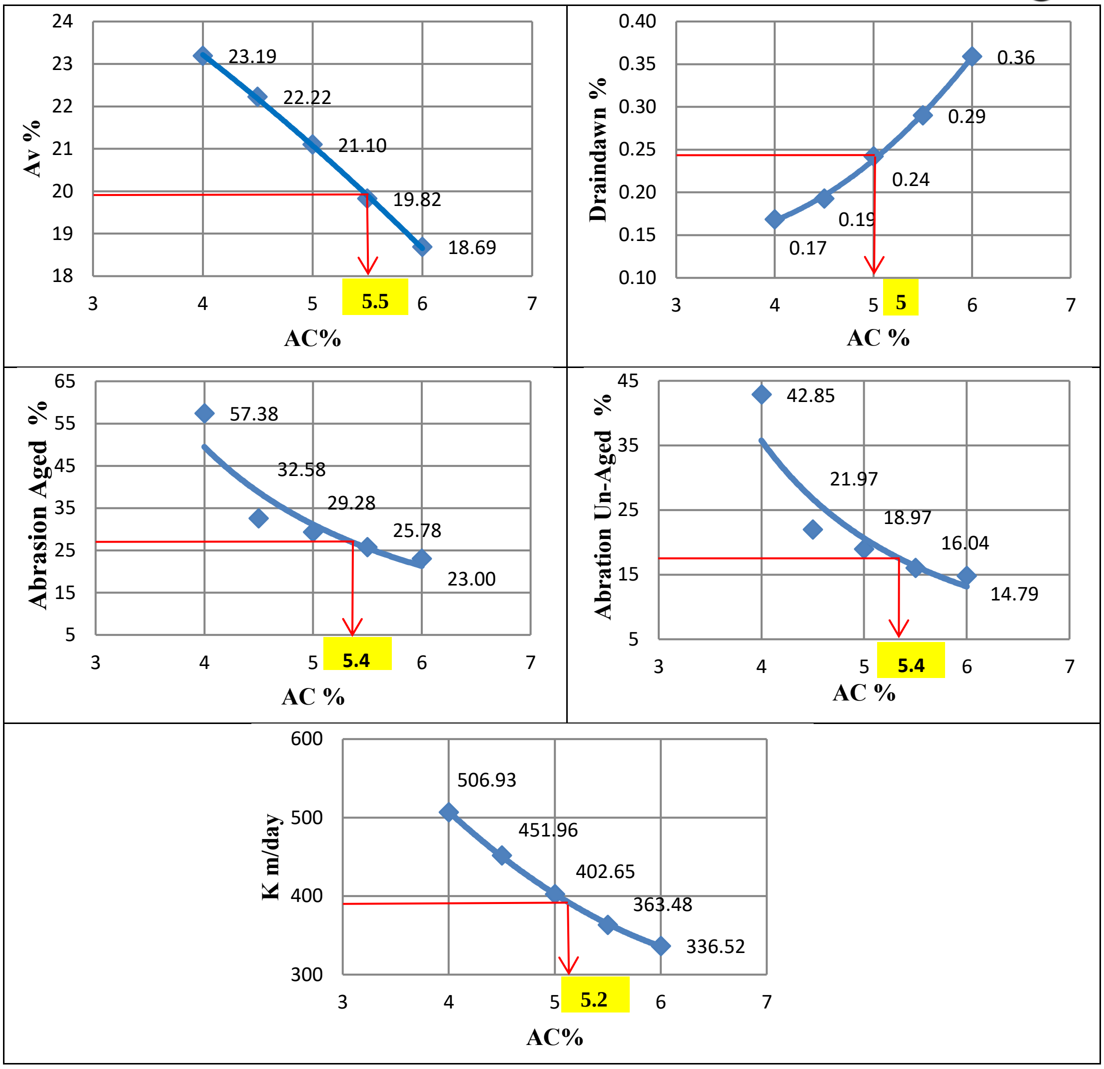


Figure (3): Asphalt binder ratio with criteria

Table (6): Experimental tests results of marshall specimen to find optimum asphalt content (NMAS 12.5 mm).

AC %	Air void	Draindown %	Abrasion Un-Aging %	Abrasion Aging %	Permeability
4.0	23.19	0.17	42.85	57.38	506.93
4.5	22.22	0.19	21.97	32.58	451.96
5.0	21.10	0.24	18.97	29.28	402.65
5.3	20.70	0.267	16.50	26.40	377.00
5.5	19.82	0.29	16.04	25.78	363.48
6.0	18.69	0.36	14.79	23.00	336.52

On other hand, the use of modified asphalt leads to improve moisture susceptibility (TSR), it is recommended to use 4 % SBS in open graded asphalt mixtures because these percent resistance to moisture damage and exhibit highest (TSR) with (31, 27.7 and 24.4)% increases as compared with the original asphalt, at asphalt content (4.8, 5.3 and 5.8)%, respectively. The SBS increases adhesion between the asphalt and aggregates and decreases the attraction between water and pavement. Subsequently, SBS also improves hot mix asphalt properties.

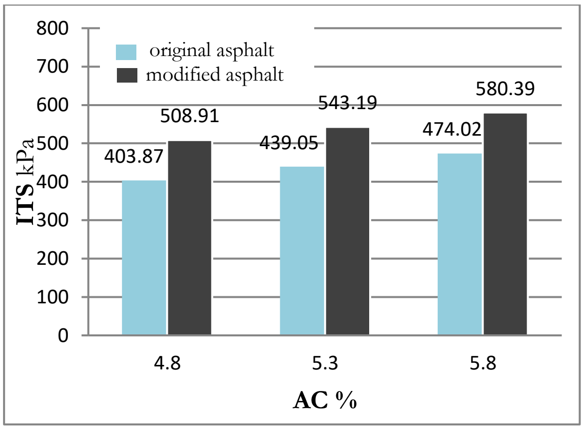


Figure (4): Effect of modified asphalt binder content on its 25°C.

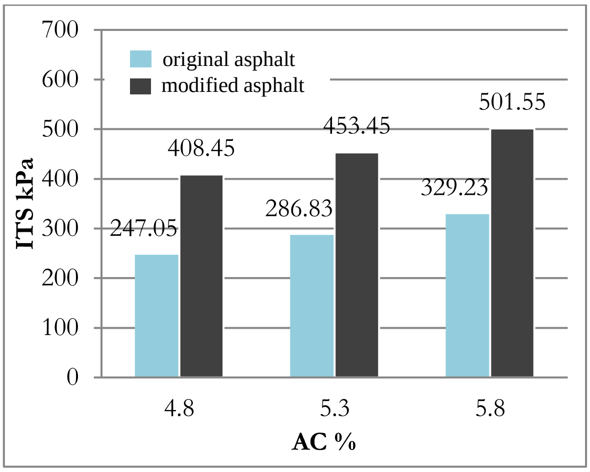


Figure (5): Effect of modified asphalt binder content on its 60°C after 24 hr. (frees/thaw)

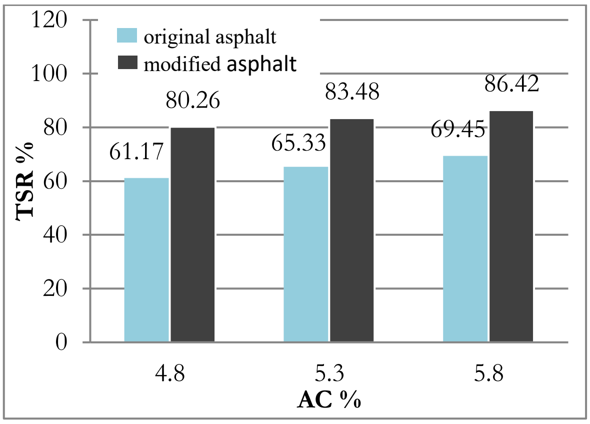


Figure (6): Effect of modified asphalt binder content on TSR%

9. Conclusions

It is evident that all dry condition samples display greater ITS as compared to wet condition samples, value has increased when asphalt content increases the asphalt content by approximately 4.8% in dry condition by (8.7 and 17.4) % for original asphalt and by (6.7 and 14) % for modified asphalt, while in wet condition value increses by (16 and 33)% for original asphalt and by (11 and 23)% for modified asphalt at asphalt percent (5.3 and 5.8)%, respectively. However, this increasing have caused decreasing in air voids content which resultes declining in coff. of permeability and cantabro abrasion %, while asphalt draindown increase. Test results indicate the main role is to improve TSR due to used polymer-modified asphalt with (4 % SBS) instead of unmodified asphalt binder which increases moisture damage resistance (mixture resistance to high temperatures) and exhibit highest (TSR) with (31, 27.7 and 24.4) % increases as compared with original asphalt at asphalt content (4.8, 5.3 and 5.8)%, respectively, as well as asphalt modifiers can assist in promoting adhesion, between the asphalt and the aggregate, then improving the mixture stiffness.

10. References

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