Effect of Styrene Butadiene Styrene on Properties of Open-Graded Asphalt Concrete Mixtures

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Abstract

Open graded asphalt mixture is becoming more widespread where it is applied for various purposes, e.g. drainage of rainwater effectivity, traffic safety (high skid resistance), and controlling pollution noise. However, it has many other disadvantages, of which low stability, high stripping, and moisture sensitivity. The research aims to study the effect of styrene butadiene styrene SBS addition on the volumetric and mechanical properties of open graded mixture. In this research one type of aggregate with gradation (12.5 mm NMAS), asphalt of penetration grade (40/50), and cement as filler were used. Optimum asphalt content was selected based on the criteria of air voids content, asphalt drain down, permeability, and abrasion resistance (for aged and un-aged) samples. Other properties of open-graded mixtures, such as indirect tensile strength (ITS), moisture susceptibility, Marshall stability and flow were evaluated. The results show that addition of polymer (SBS) leads to an enhancement in the properties of the modified mixtures. There is an improvement in Marshall parameters. Also, a slight decreasing is noticed for permeability and air voids. For Cantabro abrasion loss (aging and un-aging condition), the abrasion resistance is increased, the drain down of asphalt is decreased from original mixture by addition of SBS. Finally, the moisture sensitivity is improved indicating that modified mixes becomes more resistant to water damage.

Keywords: Open graded mixture, Permeability, SBS, Stability, Draindown.

تأثير اضافة الستيرين بيوتادايين ستيرين على خصائص الخلطات الإسفلتية مفتوحة التدرج

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الخلاصة:

أصبحت الخلطات الإسفلتية ذات التدرج المفتوح أكثر انتشارًا حيث يتم تطبيقه لأغراض مختلفة ، على سبيل المثال تصريف مياه الأمطار بشكل فعال ، وسلامة المرور (مقاومة عالية للانزلاق)، والتحكم في ضوضاء التلوث. ومع ذلك ، فإنه يحتوي على العديد من العيوب الأخرى ، منها ضعف الثباتية ، والتجريد العالي ، وحساسية الرطوبة. يهدف البحث الى دراسة تأثير اضافة الستيرين بيوتادايين ستيرين على الخواص الحجمية والميكانيكية للخلطات مفتوحة التدرج. في هذا البحث تم استخدام نوع واحد من الحصى المتدرج ذو المقاس الاسمي (١٢,٥ ملم) ، اسفلت ذو درجة اختراق (٤٠/٥٠) والسمنت كمادة مالئة. تم اختيار محتوى الأسفلت الأمثل بناءً على هذه المعايير محتوى الفراغات الهوائية ، وتصريف الأسفلت ، والنفاذية ، ومقاومة التآكل (للنماذج المتقادمة وغير المتقادمة). تم تقييم الخصائص الأخرى للخلطات الإسفلتية ذات التدرج المفتوح ، مثل قوة الشد غير المباشر، وحساسية الرطوبة ، وثباتية مارشال ، والزحف. بشكل عام ، تؤدي إضافة البوليمر (SBS) إلى تحسن في خصائص الخلطات الأسفلتية المحسنة. هناك تحسن في معايير مارشال. أيضا ، لوحظ انخفاض طفيف في النفاذية والفراغات الهوائية. بالنسبة لفقدان تآكل كانتابرو (حالة التقادم وعدم التقادم) ، تزداد مقاومة التآكل بإضافة SBS ، وينخفض تصريف الأسفلت من الخلطة الأصلية. أخيرًا ، تم تحسين حساسية الرطوبة مما يشير إلى ان الخلطات المعدلة تصبح أكثر مقاومة لتلف الرطوبة.

1. Introduction

Recently, the number of vehicles has increased dramatically [1]. This increase in traffic volume and load axles has led to the rapid deterioration of flexible roads, especially with the lack of periodic maintenance work [2]. So there is a constant need to improve asphalt mixtures to enhance their properties and increase their resistance to loads and weather conditions [3][4]. The Open-graded friction course (OGFC) is defined as thin wearing surface of permeable hot mix asphalt (HMA) that is being applied for exceptional purpose of drainage around the world [5][6]. Due to increasing traffic volume combined with the effects of other exterior factors such air temperatures and moisture causing pavement distress [7] and affecting the performance of the asphalt concrete [8], the use of permeable pavement OGFC has been spread due its safety characteristics. These characteristics affect positively towards the driver, and regularly utilized as final riding surface on the high-speed expressways [5][9]. Open-graded asphalt mixture layer that improves drainage when it rains, consist of the high content of coarse aggregate and a low percentage of fine aggregate, which creates a high percentage of air. The aggregate frame (stone on stone) is responsible for the resilience of the pavement [10]. The stone bears the lifting loads where the asphalt holds everything in place [11]. Porous asphaltic mix has high drainage and noise-abrasion properties, however, its performance regarding rutting resistance, fatigue life, and moisture susceptibility is not as efficient as traditional mixes.

In the past few years, there has been an increase of using polymer-modified binders into hot mix asphalt (HMA) [12][13]. Several types of polymers are currently used in asphalt binders to enhance their properties [14][15]. SBS is commonly used in pavement construction for dense graded mixtures [16] [17]. The porous asphalt mix consists almost of 85% coarse aggregate by weight, and the voids between them result in an open and hollow structure that increases the surface ability to allow water to flow vertically or horizontally. The Australian Asphalt Pavement Association (AAPA) specifications [18] for porous asphalt aggregate are shown in (Table 1) [19].

The goal of this research is to investigate the influence of adding different percentages of SBS polymer on properties of open-graded asphalt concrete mixtures in terms of air voids, permeability, Cantabro abrasion loss, draindown, indirect tensile ratio, and Marshall parameters, and make a comparison between modified and control mixtures due to its volumetric and mechanical properties.

2. Materials

Local materials that are often used in the asphalt paving industries in Iraq are used in this study. The open-graded asphalt mixture includes asphalt binder, (fine and coarse) aggregates, filler, and additives.

Table (1): Porous Asphalt mix Criteria Based on AAPA Specification [17].

Property	Criteria
Stability	>5 kN
Flow	(2-6) mm
Air void	(18-25) %
Permeability	>0.01 cm/sec
Cantabro loss unaged	< 20 %
Cantabro loss aged	< 30 %
Draindown	< 0.3 %
Indirect tensile ratio	< 0.8 %

In this work, asphalt cement with penetration grade (40-50) is utilized, it was obtained from the Central Refinery Company (Al- Daura refinery), southwest of Baghdad. Table (2) displays the physical characteristics of the utilized asphalt cement. The results of the tests carried out on the asphalt cement showed that its properties conform to the Iraqi specifications [20] and ASTM standards [21].

The crushed aggregates used in this study were obtained from Al-Nibaie Quarry. Table (3) shows the physical properties of the coarse aggregate (retained on sieve No.4), while two kinds of fine aggregates are utilized in this study: 75% crushed sand and 25% river sand by the total weight of aggregate. Table (4) shows the physical properties of fine aggregates.

Mineral fillers utilized in this work are Ordinary Portland Cement obtained from the local markets. Table (5) shows the physical properties of Ordinary Portland Cement.

The **s**tyrene-butadiene-styrene SBS was brought from local markets in Baghdad city. SBS polymer is a white tri-block particle with a small size. SBS has a significant effect on the results of the ductility test at both (4 and 25 ºC), in which modified asphalts tend to have a little ductility, while SBS polymer improves the performance of asphalt mixture by increasing the stiffness, stability, and elasticity of asphalt binder [17]. Three different percentages of Styrene-butadiene-styrene contents (2, 3, and 4) % were added to the optimum asphalt content. The method of mixing the polymer with bituminous binder used in this study is the wet method, in which the polymer is added to the bituminous binder before introducing it in the asphalt concrete mixture, with blending time of 60 minute at the temperature of mixing (170 - 190) °C [16]. Some of the physical and mechanical properties for SBS are revealed in Table (6).

3. Aggregate Gradation

The selected gradation follows (ASTM D-7064) [22] for open-graded asphalt pavement mixtures. In this study, one trial blend was used of aggregate gradation having (19 mm) maximum aggregate sizes (MAS), the gradation is shown in Table (7) and Figure (1).

Table (2): Physical Properties of Asphalt Binder

Tests	ASTM Specif.	Value	SCRB Specif.
Penetration (0.1mm)	D5-13	43	(40-50)
Ductility (cm)	D113-07	145	< 100
Flash point (°C)	D92-16b	295	< 232
Fire points (°C)	D92-16b	305	……
Softening point (°C)	D36-14	51.5	(51-62)
RV 135 °C	D4402-15	0.432	……
RV 165 °C		0.118	
Specific gravity	D70-08	1.048	(1.01-1.05)

Retained penetration; % of original	D5	88	> 55
Ductility of residue (25 °C - 5 cm/min)	D113	130	> 25

Table (3): Physical Properties of Coarse Aggregates

Property	ASTM Specif.	Coarse Aggregate			
Specific gravity	C127-128	sieve size (mm)	G_{sb}	G_{sa}	Abs. %
		12.5	2.65	2.67	0.32
		9.5	2.58	2.59	0.09
		4.75	2.57	2.58	0.18
Los Angeles abrasion	C131	21.72% (30 % Max)			
Fractured pieces	D5821	98 (95% Min)			
Flat and elongated Particles	D4791	Flat	0.9%		
		Elongate	2.5% (10 % Max)		

Table (4): Physical Properties of Fine Aggregates

Property	ASTM Specif.	Fine Aggregate			
Specific gravity	C127-128	sieve size (mm)	G_{sb}	G_{sa}	Abs. %
		2.36 , 0.075	2.58	2.77	2.6
Clay content	D2419	51% (45%Min)			

Table (5): Physical Properties of Ordinary Portland Cement

Properties	**Results**
% Passing sieve No. 200	97%
Bulk specific gravity	3.20

Table (6): Physical and Mechanical Properties for SBS polymer.

Typical Properties	**Unit**	**Value**
Specific gravity	---	940
Tensile strength (σt)	MPa	32 min
Melting point	°C	180
Elongation	%	88
Density	Kg/m³	1242

Table (7): Gradation of the Open-Graded Asphalt Mix

Sieve Size	ASTM (D7064−13)	Trial Blend
3/4 inch	100	100
1/2 inch	85 - 100	93
3/8 inch	35 - 60	48
No. 4	10 -25	18
No. 8	5 -10	8
No. 200	2-4	3

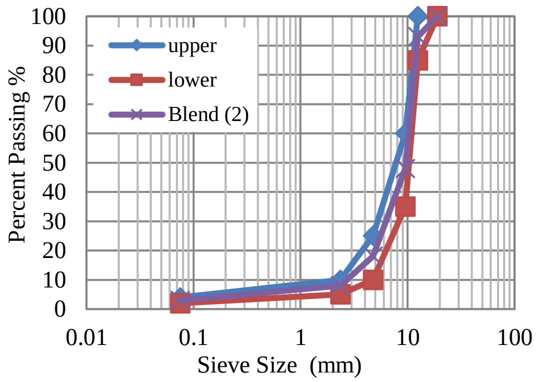

Figure (1): Gradation of Combined aggregate (12.5 mm NMAS)

4. Preparation of Marshall Specimens

Marshall specimens are made according to (ASTM D6926−10) [23], a diameter of (101.5) mm and a height of (63.5) mm. Open-graded asphalt mixture was equipped by blending aggregates with five different asphalt binders (4, 4.5, 5, 5.5 and 6%). Aggregates, cement filler and asphalt were blended in a steel container. The mold assembly was placed on the compaction base and 50 blows were applied on the top and the bottom of the specimen with a specified 4.535 kg compaction hammer, which sliding weight and a free fall in 18 in (457.2 mm). The specimen is leaved in the mold to cool at room temperature for 24 hours, then it is extracted from the mold using a mechanical lever. The weight of the sample is 1200 gm. Figure (2) show some of the prepared specimens.

Figure (2): Some of the Prepared Marshall Specimens

5. Mixing and Compaction Temperature

The Asphalt Institute [24] recommends that the laboratory mixing and compaction temperatures for asphalt binder should be determined where the viscosity-temperature line crosses the viscosity ranges of 0.17 ± 0.02 Pa-s (mixing temperature range) and 0.28 ± 0.03 Pa-s (compaction temperature range). Rotational viscometer (RV) or Brookfield viscosity is used to determine the viscosity of the asphalt binder at two temperatures (135° C and 165 °C) to ensure that the asphalt binder has a sufficient fluidity for pumping and mixing. The results display that the temperature of mixing approximately (155 °C), and temperature of compaction approximately (144°C).

6. Optimum Asphalt Content Selection

Five different percentages of asphalt contents (4, 4.5, 5, 5.5 and 6 %) are used to find the optimum asphalt content using Marshall mix design method according to ASTM (D7064–13). Figures (3) to (7) show Marshall mix design curves for optimum asphalt content and it is found (5.2 %), it is determined by averaging the values shown below:

- Air Void: The best value of the bitumen content is (5) %.
- Cantabro Abrasion Loss: The best value of the bitumen content is (5.5) %.
- Draindown: The best value of the bitumen content is (5) %.
- Permeability: The best value of the bitumen content is (5) %. The optimum asphalt content (5.2%) will be used for the control mix and modified mixes with SBS.

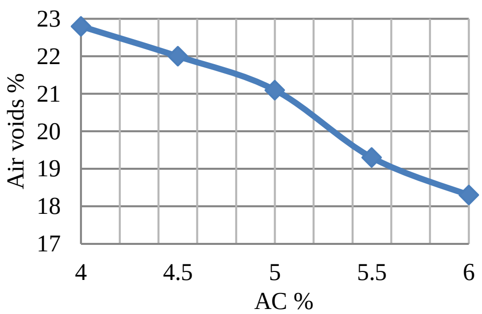

Figure (3): Relationship between air voids and asphalt content

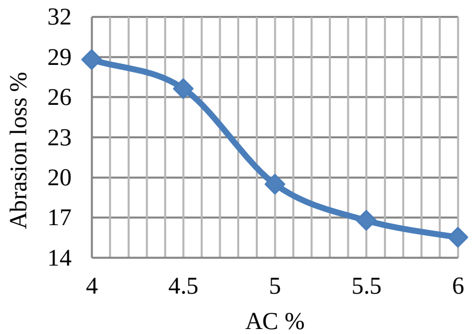

Figure (4): Relationship between abrasion and asphalt content for un-aged samples

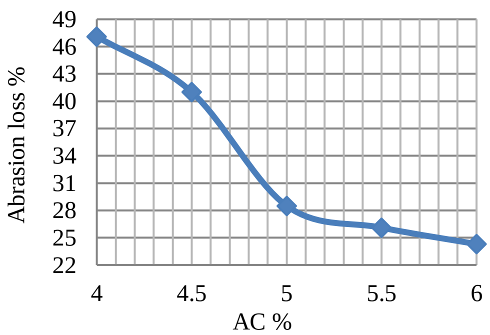

Figure (5): Relationship between abrasion and asphalt content for aged samples

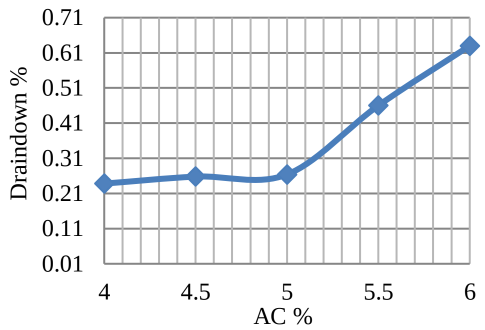

Figure (6): Relationship between draindown and asphalt content for un-aged samples

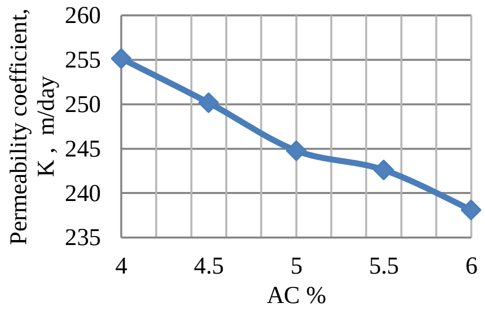

Figure (7): Relationship between permeability and asphalt content

7. Properties of Open-Graded Asphalt Concrete Mixtures

- **Air Voids (Va)%**

The percentage of air voids were calculated for compacted open-graded mixtures according to test method ASTM (D3203-11) and (D 7064-13). The percentage of air voids is determined by using the following equation.

$$Va = 100 \times (1 - \frac{Gmb}{Gmm}) \quad \text{........(1)}$$

Where:
Va = percentage of air voids,
G_{mb} = Bulk specific gravity, of the compacted open-graded pavement mixtures, were determined using the geometric measurements of specimens, according to the ASTM test method (D3203-11),
G_{mm} = Theoretical maximum specific gravity, of the un-compacted mixtures, were determined according to (ASTM D2041-11).

- **Cantabro Abrasion Loss**

According to (ASTM D7064-13), the Cantabro abrasion loss test is carried (un-aged and aged samples) and the purpose of this test is to determine the abrasion resistance of the Marshall compacted sample. The specimens for each binder content were divided into two groups of three so that the average void content was similar for each group. One group was tested in the unaged condition using the Los Angeles machine test method (ASTM C131-14) and the other was aged for 7 days at 140˚F (60˚C). After 7 days, the aged group was allowed to cool at room temperature for 24 hours before the test. To measure the abrasion resistance of the open-graded specimens, the initial mass of a sample was measured and then the sample was placed in a clean LA Abrasion drum without any steel charge at 300 pm at a rate of (30-33) rpm at 77 °F (25 °C). After 300 revolutions, the specimen was taken out from the drum, brushed and then weighed again.

Figure (8) illustrates specimens before and after abrasion loss test (before and after test). Abrasion loss was calculated using Equation. Where Ai and Af are the initial and final masses of the specimen, respectively.

$$Abrasion\ loss\ \% = \frac{Ai - Af}{Ai} \times 100 \quad ....(2)$$

Figure (8): Specimen before and after Loss test

- **Draindown Test**

According to (ASTM D6390-11) un-compacted samples were prepared (the mass of the sample is 1200 ± 200 g) so that the maximum permissible draindown should not exceed 0.3 %. Then, it is placed the in the oven at the temperature that anticipated plant production temperature as well as 150°C for one hour ± 5 min. After the specified time, it was removed from the oven and cooled to room temperature, as shown in Figure (9). The draindown percentage is calculated using the following equation:

$$\boldsymbol{Draindown}\ \% = \frac{\boldsymbol{D-C}}{\boldsymbol{B-A}} \times \boldsymbol{100} \quad ....(3)$$

Where:
A= mass of the empty wire basket gm,
B= mass of the wire basket and sample gm,
C= mass of the empty catch plate gm, and
D= mass of the catch plate plus drained material gm.

Figure (9): Asphalt Draindown test

8. The Experimental Tests

- **Hydraulic Conductivity Test (Permeability)**

Permeability is one of the most important features used in the evaluation of the open-graded asphalt mixtures. The minimum coefficient of permeability of the asphalt is 100 m / day (according to the NCAT report and ASTM D7064-13). In this research, the falling-head test apparatus was used to determine the rate of flow water, conducted through the Marshall specimen. Figure (10) shows apparatus. The coefficient of permeability (K) of the compacted paving mixture was calculated based on Darcy's law, using the following equation:

$$\boldsymbol{K} = \frac{\boldsymbol{a.l}}{\boldsymbol{A.t}} \boldsymbol{ln\ ln} \left(\frac{\boldsymbol{h1}}{\boldsymbol{h2}}\right) \times \boldsymbol{tc} \quad ....(4)$$

Where:
k= coefficient of water permeability, cm/s
a= inside cross-sectional area of inlet standpipe,
l= thickness of test specimen, cm,
A= cross- sectional area of test specimen, cm^2,
t= average elapsed time of water flow between timing marks, sec.,
h1= hydraulic head on specimen at time t1, cm,
h2= hydraulic head on specimen at time t2, cm,
ln = natural logarithmic function and
tc= temperature correction for viscosity of water

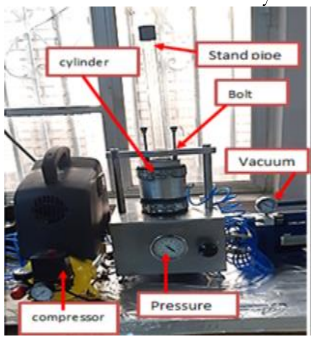

Figure (10): Hydraulic conductivity apparatus

- **Indirect Tensile Test (IDT)**

Indirect tensile test (IDT) is utilized to evaluate the resistance of moisture susceptibility of asphalt mixture when results are obtained on both moistures conditioned and unconditioned specimens according to AASHTO T-283. Marshal hammer was used for compacted two groups of specimens for each percentage of asphalt binder. After compaction of the first three samples without any conditioning, which were considered as (dry un-conditioned samples) and other three samples were subjected to vacuum saturation followed by an optional freeze cycle. Figure (11) exhibits details of the indirect tensile test. Indirect Tensile Strength (ITS) was calculated using the following equation:

$$\boldsymbol{ITS} = \frac{\boldsymbol{2000\ P}}{\boldsymbol{\pi\ t\ D}} \quad ....(5)$$

Where:
ITS = indirect tensile strength, kPa
P = maximum load to failure, N
D = diameter of specimen, mm
t = thickness of specimen immediately before test, mm

Then the following equation is used to calculate the ratio of the indirect tensile strength (TSR).

$$\boldsymbol{TSR} = \frac{\boldsymbol{ST\ (conditiones\ samples)}}{\boldsymbol{ST\ (control\ samples)}} \quad ....(6)$$

Where:
TSR= indirect tensile strength ratio, %
ST (control samples) = average of the indirect tensile strength of dry un-conditioned, kPa ,and
ST (condition samples) =average of the indirect tensile strength of wet conditioned, kPa.

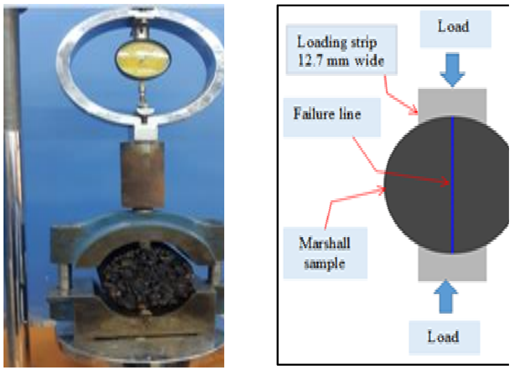

Figure (11): Details of indirect tensile test

9. Results and Discussions

- **Effect of SBS polymer on Air Voids**

Figure (12) explains that the addition of the SBS polymer to mixture causes a reduction in air voids. The results indicated that the air voids of the specimens containing (2, 3, and 4%) Styrene Butadiene Styrene (SBS) is decreased by (1.7, 3, and 3.5%) respectively.

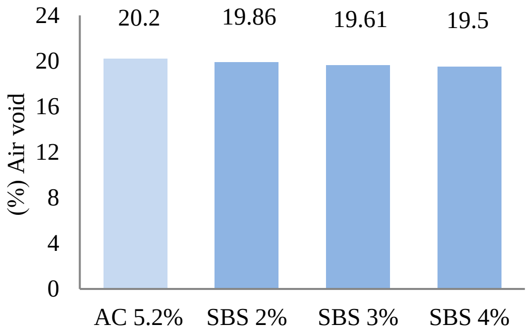

Figure (12): Effect of the SBS polymer on Air voids

- **Effect of SBS polymer on Cantabro Abrasion Loss**

The SBS polymer offered an important effect on the abrasion loss aging and un-aging of the modified open-graded mixtures. Generally, increasing the percentage (SBS polymer) leads to a decreasing in abrasion loss aging and un-aging. For example, (4.0%) SBS causes aging and un-aging to decrease by (11.2%) and (10.9%) from original, as shown in Figures (13) and (14).

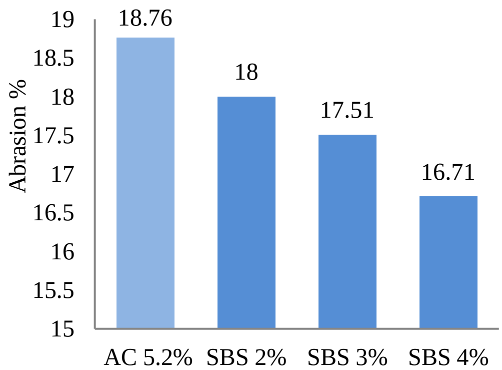

Figure (13): Effect of SBS polymer on un-aged samples

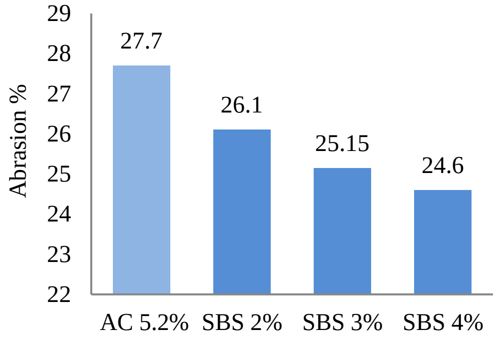

Figure (14): Effect of SBS polymer on aged samples

- **Effect of SBS polymer on Draindown**

In the case of the (2%, 3%, 4%) SBS adding for asphalt binder, the value of the draindown is decreased by (16.5%, 38.25%, and 43.51%) respectively, as presented in Figure (15).

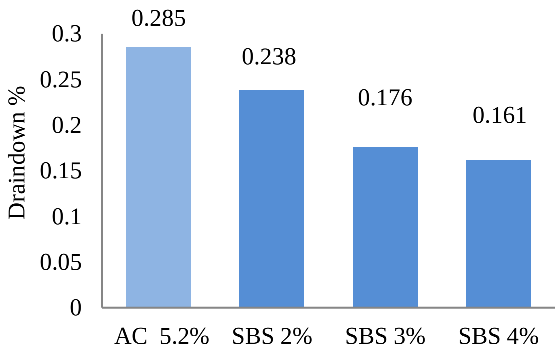

Figure (15): Effect of SBS polymer on Draindown

- **Effect of SBS polymer on Permeability**

The falling head test method was used to assess the permeability of open- graded asphalt. Most researches and specifications specify the permeability coefficient to a maximum value of 100 m/day (ASTM D7064–13). The addition of SBS polymer (2%, 3%, 4%) leads to reduce the coefficient of permeability, it is decreased by (1.42%, 2.1%, and 4.2%) respectively from the control asphalt mix value, as shown in Figure (16).

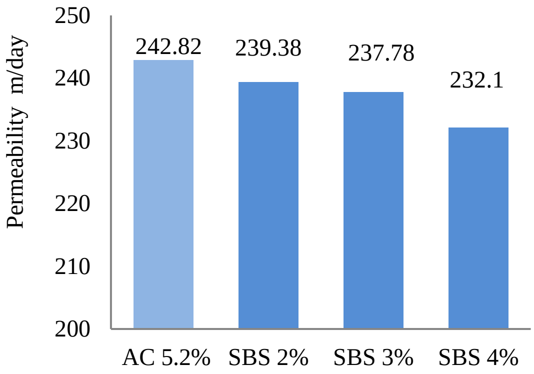

Figure (16): Effect of SBS polymer on Permeability

- **Effect of SBS polymer on Indirect Tensile Strength Test (ITS)**

Figures (17) and (18) show the results of the value of the indirect tensile strength (ITS dry) at temperature 25 °C and the results of the value of the indirect tensile strength (ITS wet) at temperature 60 °C respectively. It can be seen that the loss in ITS for modified mixtures is lower than unmodified mixtures.

On the other hand, Figure (19) illustrates the relationship between the indirect tensile strength ratio (TSR) and the content of the SBS additive. The value was (70.26%) for the open-graded asphalt mixture, then the ratio rises by (84.58% and 87.8%) for the SBS polymer content (3.0% and 4.0%) respectively. In the case of (2.0%) SBS polymer, the TSR values of the mixture did not show any obvious difference.

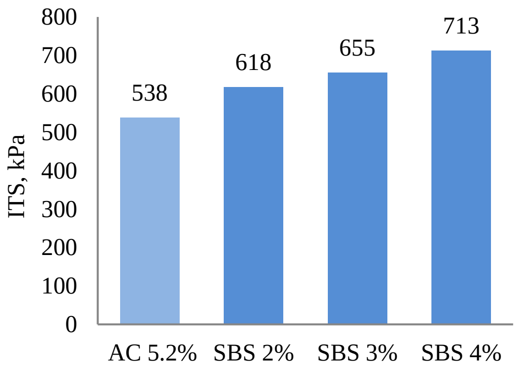

Figure (17): Effect of SBS polymer on ITS (Dry condition) @ 25°C

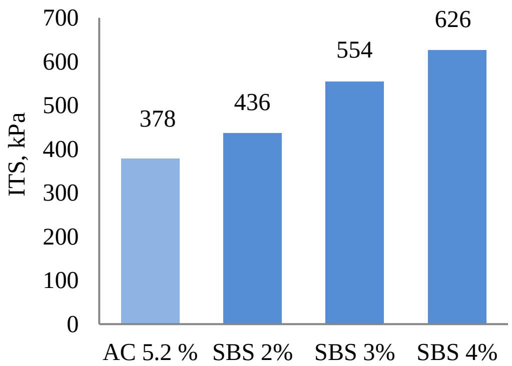

Figure (18): Effect of SBS polymer on ITS (Wet condition) @ 60°C

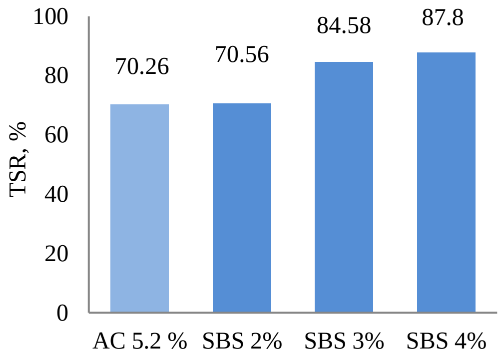

Figure (19): Effect of SBS polymer on Tensile strength ratio

- **Effect of SBS polymer on Marshall Stability and Flow**

Three open-graded asphalt mixtures specimens of unmodified and modified binders were prepared at the optimum asphalt content of 5.2% to determine Marshall properties. From Figure (20), it can be seen that the addition of SBS polymer at (2, 3 and 4 %) increases Marshall stability by (9.3, 18.7, and 31.1%) of the control asphalt content, respectively. While a decrease in flow value was observed with the addition of the same SBS polymer content by (15.5, 22.2, and 26.6%) respectively, from the control asphalt content, as can be seen in Figure (21).

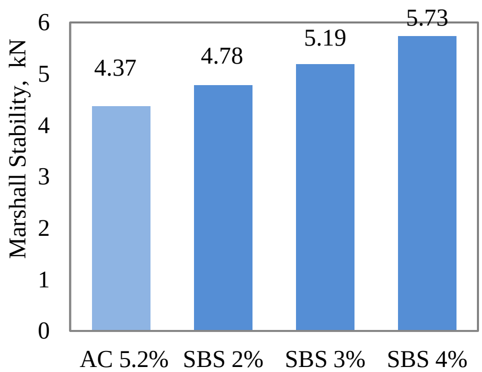

Figure (20): Effect of SBS polymer on Marshall stability

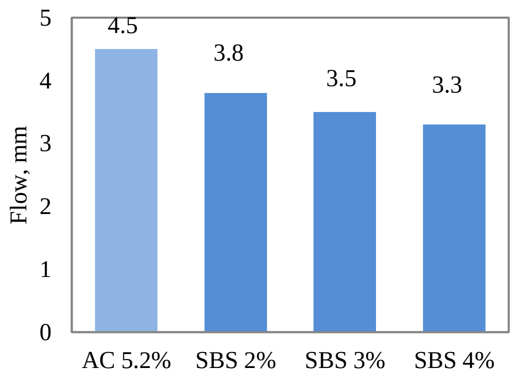

Figure (21): Effect of the SBS polymer on flow

10. Conclusions

1- Comparing with traditional open-graded asphalt mixture, the air voids is decreased as SBS content increased, it can be attributed to the SBS increment leads to increasing the asphalt film thickness around the aggregate particles leading to voids filling between aggregate particles.

2- Draindown results show an improvement after incorporating SBS polymer. It is means that SBS increases the asphalt viscosity and enhance the adhesion between asphalt and aggregate particles in the mix.

3- Cantabro abrasion loss is decreased for mixtures containing SBS polymer in comparison to traditional open-graded asphalt mixtures that means SBS increases the bond between asphalt and aggregate particles.

4- Permeability coefficient is decreased slightly when increasing SBS polymer content, it can be attributed to decreasing air voids leading to reducing the porosity.

5- Marshall stability is increased after addition to SBS polymer means that modified mixes showed an improved strength, high stiffness and had a beneficial effect to bond aggregates together compared to the control mix. Whereas, the decrease in flow value is observed with the addition of this modifier.

6- The indirect tensile strength ITS for modified mixtures is higher than control mixtures, indicating that SBS could stiffen the mixture and increase its strength against moisture effect. Also, it is observed that mixtures tested at 25°C having higher ITS compared to samples tested at 60°C, it may due to high temperature reduces the viscosity and cohesion of the binder result in poor tensile strength.

7- Tensile Strength Ratio (TSR) is generally increased; it reaches the maximum value up to 87.8% at 4% SBS. However, most mixtures with SBS are satisfied with the 80% minimum specification requirements.

11. References:

[1] H. H. Joni, A. A. Mohammed, A. A. Shakir, Classification of Traffic Accidents datasets between 2003 -2017 in Iraq, 2019, Data in Brief, 28:104902, DOI:10.1016/j.dib.2019.104902.

[2] K.H. Hassan, “Common Defects and Distresses in Flexible Pavements in the Middle part of Iraq and their Main Reasons” in Engineering and Technology Journal, 2013, Volume 31, Issue 21, Pages 50-62.

[3] H.H. Joni, H. H. Zghair, A. A. Mohammed, “Rutting Parameters of Modified Asphalt Binder with Micro and Nano-Size of Metakaolin Powder”, Journal of Engineering Science and Technology, Vol. 15, No. 5 (2020) P. 3465 – 3480.

[4] H.H. Joni, R.H. Al-Rubaee, M.A. Al-Zerkani. “Rejuvenation of aged asphalt binder extracted from reclaimed asphalt pavement using waste vegetable and engine oils”, Case Studies in Construction Materials 11, e00279.

[5] Qureshi, N. A., Farooq, S. H., and Khurshid, B. (2015). "Laboratory evaluation of durability of open-graded friction course mixtures", Int. J. Eng. Techno, volume. 7, no.3, PP. 956-964.

[6] M. M. Namaa, Z.I. Qasim, and Karim Hadi, "Study of the Properties of Open Graded Asphalt Mixtures with the addition of SBS", IOP Conference Series Materials Science and Engineering, vol.1090, 2021, doi:10.1088/1757-899X/1090/1/012002.

[7] K. H. Ibrahim Al Helo, Z. I. Qasim, and M. A. Abdulhussein, Effect of laboratory aging on moisture susceptibility of polymer-modified bituminous mixtures, BCEE4, IOP Conf. Series: Materials Science and Engineering 737 (2020) 012131, doi:10.1088/1757-899X/737/1/012131.

[8] M. Y. Fattah, K. H. Al Helo, and Z. I. Qasim, Prediction Models for Fatigue Resistance of Local Hot Mix Asphalt, Road Materials and Pavement Design, (2015), DOI: 10.1080/14680629.2015.1119711.

[9] D.A. Khalaf; Z.I. Qasim.; and K. H. Al Helo, “Effect of Modified Asphalt Cement of the Performance of Stone Matrix Mixtures”, in Engineering and Technology Journal, 2020, Volume 38, Issue 5, Pages 789-800. doi: 10.30684/etj.v38i5A.489.

[10] Kandhal, P. S. (2002). "Design, construction, and maintenance of open - graded asphalt friction courses", National asphalt pavement association information series 115.

[11] H. F. Talal, “Selecting the Optimum Graphical Method to Find Aggregate Blend Proportions in the Production of HMA” in Engineering and Technology Journal, 2015, Volume 33, Issue 7, Pages 1636-1655.

[12] A. H. Abed, Z. I. Qasim, H. M. Al-Mosawe, and H. H. Norri, “The Effect of Hybrid Anti-Stripping Agent with Polymer on the Moisture Resistance of Hot Mix Asphalt Mixtures”, Cogent Engineering 6 (1), 2019, DOI: 10.1080/23311916.2019.1659125.

[13] S. Amirkhanian, F. Xiao, D. Herndon, The Evaluation and Specification Development of Alternate Modified Asphalt Binders in South Carolina, Report No. FHWA-SC-14-03, South Carolina Department of Transportation, 2014.

[14] A. Behnood, J. Olek, Rheological properties of asphalt binders modified with styrene butadiene styrene (SBS), ground tire rubber (GTR), or polyphosphoric acid (PPA), Constr. Build. Mater. 151 (2017) 464–478, doi:http://dx.doi.org/10.1016/j.conbuildmat.2017.06.115.

[15] H.H. Joni; M.M. Hilal; and D.S. Helan, “Effect of Polymer Additives on Permeability of Asphalt Concrete Mixtures” in Engineering and Technology Journal, 2018, Volume 36, Issue 1, Pages 75-83.

[16] Shirini, B., & Imaninasab, R. (2016). Performance evaluation of rubberized and SBS modified porous asphalt mixtures. Construction and Building Materials, 107, 165-171.

[17] King G et al. (1999). "Additives in asphalt." J Assoc Asphalt Paving Technol A 1999; 68:32– 69.

[18] AAPA, (2004). "Open graded asphalt design guide". Australian Asphalt Pavement Association, Victoria, Australia.

[19] Eka Putri, E., & Vasilsa, O. (2019, March).

Improve the Marshall stability of porous asphalt pavement with HDPE addition. In MATEC Web of Conferences (Vol. 276, p. 03005). EDP Sciences.

[20] SCRB (2003). State Commission of Roads and Bridges, Standard specifications for Roads and Bridges. Hot mix asphalt concrete pavements, Section R9. Iraq, Ministry of Housing and Construction, Department of Planning and Studies, R9.

[21] ASTM, Annual Book of standards of American Society for testing and materials, volume 03.04, USA, 2020.

[22] ASTM-D7064 (2013). Standard Practice for Open-Graded Friction Course (OGFC) Mix Design. Annual book of ASTM standards.

[23] ASTM-D6926 (2010). Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus1. Annual Book of ASTM Standards.

[24] Asphalt Institute, (2003). "Performance Grade Asphalt Binder Specification and Testing". Manual Series No.1, (SP-1), Asphalt Institute, Lexington, Kentucky.