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EVALUATION EFFECT OF PARTICLE SIZE AND CONCENTRATION OF POLYMER STYRENE BUTADIENE STYRENE (SBS) ON THE ENGINEERING PROPERTIES OF ASPHALT MIXTURE

تقيم تأثير الحجم الحبيبي و تركيز بوليمر الستايرين بيوتادين ستايرين على الخواص الهندسية للخلطة الاسفلتية

Mohammed Aziz Hameed Al-Shaybani
Ministry of Education
Email: **mohammedalshaybani@yahoo.com**

ABSTRACT

Scientists and engineers are constantly trying to improve the performance of asphalt concrete pavements by the modification of the asphalt binder. Polymer-modified asphalt mixtures have been used for many years to reduce the amount and severity of distress and extend the service life of hot mix asphalt (HMA) pavements. The polymers have acceptable effects on asphalt mixes in low and high temperature due to increasing the resistance to fatigue cracking, rutting (permanent deformation) and thermal cracking. The major objective of this research is to evaluate the effect of polymer on the properties of the Hot Mix Asphalt (HMA). One asphalt cement grade (40-50) from Al-Daurah refinery, one type of locally available polymer styrene butadiene styrene (SBS) with three various particle sizes. Three sizes are obtained from sieving analysis at sieves (No16 (1mm), No9 (2mm) and No5 (4mm)) have been used with three percentages for each size. These percentages are (1, 2.5 and 4) % for SBS by weight of asphalt cement. Each size of polymer is blended with asphalt cement by wet process of blending times 60 minutes for a suitable range of temperatures at (180ºC). The experimental works showed that all polymer-modified mixtures have (stability, indirect tensile strength and rutting resistance) higher than control asphalt mixtures, in about (50-107) %, (11-32) % and (33-47) %), respectively, dependent on different particle sizes of polymer and polymer concentration under predicted suitable blending time. It can be concluded that the small particle sizes of styrene butadiene styrene (SBS No16) give better properties of pavement. Therefore, the addition of (2.5% SBS No16) to asphalt mixtures showed better improvement on the performance properties of pavement modified with polymer, in which the referred percentage represents the optimum percent of concentration for blending polymer.

KEY WORDS

Asphalt, particle sizes, asphaltic pavement, HMA performance, polymer.

الخلاصة

إن الكثير من الباحثين والمهندسين يحاولون باستمرار تحسين أداء التبليط بخرسانة الاسفلت واحد الحلول المناسبة هو تحسين خواص المواد الإسفلتية باستخدام المضافات مثل اللدائن (البوليمر)، ان الخلطات الاسفلتية المعدلة بالبوليمر استخدمت لعديد من السنوات لتقليل تأثير شدة العيب او التشوه ولتمديد العمر الخدمي للتبليط بالخرسانة الاسفلتية الحارة(HMA). حيث ان البوليمرات يكون لها اثار مقبولة على خلطات الاسفلت في درجة الحرارة المنخفضة والمرتفعة، من خلال زيادة المقاومة لتشقق الكلل، التخدد(التشوهات الدائمة) و التشقق الحراري. ان الهدف الرئيسي من هذا البحث هو تقييم تأثير حجم الحبيبات المختلفة للبوليمر ونسبة تركيز البوليمر على خصائص خلطات الخرسانة الاسفلتية الحارة (HMA)، حيث تم استخدام نوع واحد من الاسفلت ذو اختراق (40-50) من مصفى الدورة، استخدام نوع واحد من البوليمر المتوفر محليا الستايرين بيوتادين ستايرين حيث تم استخدام ثلاث حجومٍ مختلفة لحبيبات البوليمر مكتسبة بواسطة التحليل المنخلي للبوليمر وهيه (منخل رقم 16

(1مليمتر)، منخل رقم 9 (2مليمتر) ومنخل رقم 5 (4 مليمترِ)) و استعمل بثلاث نِسَب مئويةِ لكُلّ حجم حبيبات للبوليمر وهذه النسب هي كالاتي (4,2.5,1) % كنسب وزنية من الاسفلت وجرى خلط كل نسبة من البوليمر مع الاسفلت باستخدام الطريقة الرطبة وبزمن خلط (60) دقيقة ودرجة حرارة محددة (180) درجة مئوية اظهرت النتائج المختبرية ان جميع الخلطات المعدلة بالبوليمر تمتلك (قوة ثبات، مقاومة شد غير مباشر ومقاومة للتخدد (مقاومة التشوهات الدائمة) اعلى من الخلطات الاسفلتية الاعتيادية التقليدية الغير معدلة تتراوح من (50-107)%، (11-32) % و (33-47) % على التوالي، حيث يعتمد ذلك على حجم الحبيبات للبوليمر وتركيز البوليمر تحت زمن خلط متوقع ومناسب، ويمكن استنتاج ان الحبيبات صغيرة الحجم من الستايرين بيوتادين ستايرين SBS تعطي خصائص افضل للتبليط المعدل بهذا لبوليمر، وان اضافة (SBS No16 2.5%) للخلطات الاسفلتية تعطي افضل نتائج في خصائص الاداء للتبليط المعدل بهذه البوليمرات، وان هذه النسبة المشار لها تمثل النسبة الامثل لخلط هذا البوليمر.

الكلمات الدالة:الاسفلت، الحجم الحبيبي، التبليط الاسفلتي، اداء الخلطة الإسفلتية الحارة، البوليمر.

1- INTRODUCTION

Hot mix asphalt concrete (HMA) generally is composed of two materials, aggregate and asphalt binder. About (94% to 96%) by weight of the mix consists of the aggregate, and the remaining (4% to 6%) by weight of the mix consists of the asphalt binder. Although the percentage of the asphalt binder is relatively small, they greatly influence pavement performance more than the aggregate because environmental factors, such as heat and sun radiation, affect the asphalt binder more than aggregate, (Al-Dubabe, 1996). The increase in road traffic and high pavement temperature in summer during the last four decades in combination with an insufficient degree of maintenance has caused an accelerated deterioration of road structures in many countries. In Iraq, within about one year after construction, rutting distress was observed at several locations in the highways due to the high axle loading and the hot summer days, (Yassoub, 2005). To minimize the deterioration and thereby to increase the long term durability of a flexible pavement, the asphalt layers should be improved with regard to performance-related properties, such as resistance to permanent deformation, low temperature cracking, load-associated fatigue, wear, stripping and ageing.

2- OBJECTIVES

This study has two main objectives:

1. Evaluate the effect of polymer on the properties of asphalt mixtures (stability, tensile strength, resistance to permanent deformation and fatigue cracking), and compare these properties with those of a virgin unmodified asphalt mixture.
3. Evaluate modified binders provide better properties and the amount of modifiers should be used for getting good performance.
2. Evaluate the effect of particle size should the polymer be mixed with the asphalt binder to obtain a good property of polymer asphalt.

3- MATERIALS USED

3-1 Aggregates

The coarse aggregate used in this study is crushed aggregate from Al- Najaf quarry. This aggregate is widely used in the middle and south areas of Iraq for asphalt pavement. The particles tend to off white in color with angular surfaces. The fine aggregate obtained from Karbala quarry. The coarse and fine aggregates used in this work are sieved and recombined in the proper proportions to meet the wearing coarse gradation as required by the SCRB specification (SCRB, R/9. 2004) .Routine tests are performed on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the SCRB are summarized in Table 1. The selected gradation with specification limits are presented in Table 2.

3-2 Asphalt Binders

The typical asphalt binders used for construction of pavements in Iraq are PG 70-16, (Abbas, 2009). The physical properties and tests of asphalt cement are presented in Table 3.

3-3 Polymer

Styrene butadiene styrene (SBS) is used to modify binders with various practical sizes, three sizes are obtained from sieving analysis at sieves (No16 (1mm), No9 (2mm) and No5 (4mm). Two PG 70-16 binder (SBS modified and unmodified binders) used in this study were prepared by a supplier from the same base asphalt. The modified asphalts were prepared by adding (1, 2.5 and 4) % SBS by weight of asphalt binder.

4-LABORATORY SPECIMEN PREPARATION AND TEST METHODS

4-1 Specimen Preparation

Duplicate test specimens of controlled air void contents were prepared in the laboratory. For the wheel track apparatus (WTA) test, specimens 150 mm in diameter x 60 mm in height with 4% air void contents are prepared using the compaction apparatus. For the indirect tensile strength (ITS) test and Marshall test, specimens 100 mm in diameter x 60 mm in height is prepared using the compaction apparatus to have 4% air void contents.

4-2 Binder Mixing

The binder mixing used in this study is the wet process, in which the polymer is added to the asphalt binder before adding it in the asphalt concrete mixture. The polymer is added to the asphalt binder at a blending speed of 2620 rpm, the recommended speed should not be less than 2500 rpm (Al-Dubabe, 1996). Depending on the Marshall stability, the best time is selected. It is (60 minutes) for SBS in order to get a suitable predicted time of blending at specified temperature at (180°C), (Hamid et al, 2008).

4-3 Marshall Test

This test is carried out according to the (ASTM D-6927, 2006), which covers the measurement of the resistance to plastic flow of a cylindrical specimen of bituminous paving mixture loaded on the lateral surface of the specimen by means of Marshall apparatus. Prior to stability test, all specimens are weighted in the air and submerged in water. The bulk specific gravity and density (ASTM D-2726, 2002), theoretical specific gravity (ASTM D-2041, 2002) and percent of air voids (ASTM D-3203, 2002) are determined for each specimen. Standard method of Marshall is used to find the optimum asphalt content for compact asphalt concrete specimens. The results of Marshall tests show almost typical relationships between Marshall properties and asphalt content. Four different percentages (4.2, 4.8, 5.4 and 6) % of Daurah PG (70-16) asphalt cement are used with ordinary Portland cement (filler) and one gradations of aggregate for (12.5) mm nominal maximum size of aggregate for dense mix in accordance with the SCRB specification (R9), for wearing course type (A), (SCRB, 2004). The optimum asphalt content (O.A.C) of the various mixes is determined from the following Marshall curves, (stability, flow and 4% of air voids) are shown in Figure 1, the optimum asphalt is (4.8) %.

4-4 Indirect Tensile Strength (ITS) Test

Indirect tensile strength (Fatigue Cracking Analysis). This test is depended in analyze mixtures for fatigue cracking resistance. For intermediate analysis, test temperature are used at 20°C or less for fatigue cracking analyses. Lower the temperature of the environmental chamber to the test temperature with (± 0.2°C) is achieved, allow each specimen to remain at the test temperature from (3±1) hours prior to testing. In this test, the specimen is loaded at a constant deformation rate of 2 inches per minute (50 mm per minute) of vertical ram movement. The specimen is loaded until failure, peak load is measured throughout the test, (AASHTO: T 322, 2005).

4-5 Wheel Track Apparatus (WTA) Test

Wheel track apparatus test is conducted dry to 6000 passes (3000 cycles) at 50˚C in which the rut depth is measured continuously. This test is conducted on two cylindrical samples at one time and compacted with standard Marshall compacter. In case that wheel is a completion of the 6000 passes at 50˚C, the testing was manually stopped and rut depth is recorded, (AASHTO: T324, 2005).

5- LABORATORY TEST RESULTS AND DISCUSSION

5-1 Results of Marshall Tests

The results are shown in Table4 for Marshall test. The test results presented in the following articles are revealing the effect three various practical sizes and different concentrations of polymer (SBS).

5-1-1 Bulk Density

The bulk density of the control asphaltic mixtures is higher than the modified asphalt concrete mixtures, regardless of practical sizes for polymers, and its concentration. The differences in bulk density are marginal and not significant due to different practical sizes of polymers and concentration. The asphalt concrete mixture modified with (SBS No16) has higher bulk density than mixtures modified by (SBS No9 and SBS No5), which means that the particle which has small size gives more density than particle with large size, as shown in Table 4

5-1-2 Stability

Stability is an important property for the performance of asphalt mixture in the surface course design. It shows the ability to resist shoving and rutting under traffic. The stability of modified asphalt concrete mixtures and regardless of practical sizes for polymers and concentration is higher than the control asphalt concrete mixtures (9.53 KN) at blending time higher than 15 minutes, due to modifier addition. Three different particle sizes of SBS are selected to evaluate their effects on stability. The highest stability is recorded for modified mixtures using small particles size modifier (SBS No16) rather than mixtures modified by (SBS No9 and SBS No5) at the same optimum percent of concentration. The stability of modified mixtures by styrene butadiene styrene (SBS) is increasing when the particle size is smallest for the same weight of modifier (2.5%). The stability is decreased when increasing percentage of this polymer, as shown in Figure 2, because the surface area occupied by the softer grains is larger than the space occupied by coarse-grained and this in turn will increase the entanglement molecular polymer granules with asphalt and improves the performance by increasing the stability of the mixture and reduces the mixing time, (Morgan, 1995).

5-1-3 Marshall Flow

The flow of the polymer asphalt mixtures and regardless of practical sizes for polymers or its concentration at the time of blending more than 60 minutes is higher than the control asphalt mixture, as shown in Table 4.

5-1-4 Marshall Stiffness

Marshall stiffness represent the ratio of stability to flow, and according to this test, modified specimens which met the SCRB specifications (flow= (2-4) mm) exhibited a higher Marshall stiffness or resistance to shear stress, permanent deformation and hence rutting.

5-1-5 Air Void

An 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. The air void content of the modified mixture has not differed from that of the non-modified 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.

5-2 Results of ITS Tests

The results of this test are shown in Table 5, and Figures 3. ITS for 2.5% SBS modified content is higher than control mixture (conventional mixture without modifiers) and The fine grained particle sizes of (SBS No16) having higher indirect tensile strength because the surface area occupied by the softer grains is larger than the space occupied by coarse-grained and this in turn will increase the entanglement molecular polymer granules with asphalt and improves the performance by increasing the indirect tensile strength of the mixture and reduces the mixing time.

5-3 Results of WTA Rut Tests

Results presented in Table 6 indicate that the polymerized asphalt mix has a higher resistance to permanent deformation (rutting depth) than the control mixtures (control mixture is the conventional mixture without modifiers). The effects of particle sizes and percentage concentrations of polymer are shown in Figure 4. The modified mixtures by (2.5 % SBS No16) have rutting depth at 50 Cº (3.39mm), lower than asphalt concrete mixtures modified by (2.5% SBS No 9 and 2.5% SBS No5). Also, these mixtures have rutting depths lower than mixtures modified by (1% and 4% of SBS No 16, SBS No 9 and SBS No5) as shown in Figures 4. The fine grained particle sizes of SBS have rutting depth lower than coarse grained sizes at the same percentage of SBS polymer, thus increasing of concentration for SBS causing increasing the rutting depth. Therefore, the best particle sizes of SBS are softer (SBS No16) with 2.5% concentration, because it has high resistance to permanent deformation caused from good interaction and bonded of softer particles with asphalt binder at blending to produce modified asphalt mixtures.

6- CONCLUSIONS

Based on the research findings, the following conclusions are presented:

1. Using of small particle sizes of styrene butadiene styrene (SBS No16) to mixtures give better performance properties from other particle sizes, the modified mixtures with (2.5% SBS No16) have higher stability (107%), also higher indirect tensile strength (35%) and lower rutting depth (47%) than control asphalt mixtures.
2. Best values of stability, tensile strength and resistance to permanent deformation, can be obtained from modified mixtures with 2.5% SBS by weight of asphalt.
3. The flow of the polymer asphalt mixtures and regardless of practical sizes for polymers or its concentration at the time of blending more than 60 minutes is higher than the control asphalt mixture.

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Table 1: Physical Properties of Aggregate.

Property	ASTM Designation	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127 C-128	2.53	2.63
Apparent Specific Gravity	C-127 C-128	2.67	2.68
% Water Absorption	C-127 C-128	3.15	2.8
% Wear (Los Angeles)	C-131	28 Max 35%	-----
Angularity	D 5821	95%	-----

Table 2: Asphalt Mixture Grading for Surface (Wearing) Course, Type A.

Sieve		(% Passing by Weight of Total Aggregate + Filler)	Specification limits for wearing coarse (SCRB),Type IIIA
Opening (mm)	Size (in)		
19	3/4	100	100
12.5	1/2	95	90-100
9.5	3/8	83	76-90
4.75	No.4	59	44-74
2.36	No.8	43	28-58
300 um	No.50	13	5-21
75 um	No.200	7	4-10
Asphalt Cement (% weight of total		4,8	4 - 6

Table 3: Physical Properties of Asphalt Cement.

Tests	Units	Penetration grade (40-50)	S.C.R.B Specification
Penetration (25 ^{0}C), 100 gm, 5sec) ASTM D-5	1/10 mm	46	(40-50)
Kinematic Viscosity at 135 ^{0}C ASTM-2170	cst	385	-----
Ductility (25 ^{0}C, 5 cm/min) ASTM D-113	cm	107	>100
Flash Point ASTM D-92(Cleveland open cup)	^{0}C	339	min. 232
Specific Gravity at 25 ^{0}C ASTM D-70	……	1.04	(1.01-1.05)

Table 4: Marshall Test Results for Control Mixture and Asphalt Mixtures Modified by Styrene Butadiene Styrene (SBS) with Three Different Particle Sizes.

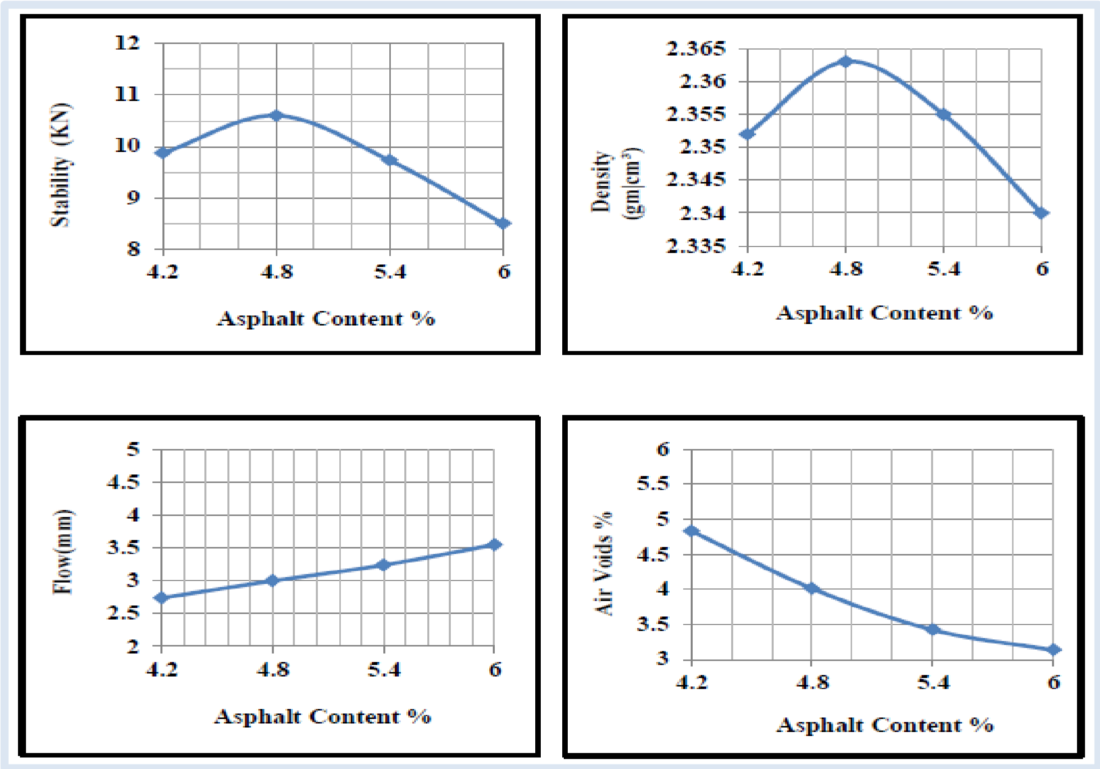
Sample	Polymer percent (%)	Stability (KN)	Flow (mm)	Bulk density (gm/cm³)	Air voids (%)	Stiffness (KN/mm)
Control `Unmodified	0	9.53	2.07	2.38	3.8	4.59
Modified with SBS No 16	1	15.21	3.22	2.31	4.02	4.72
	2.5	18.51	3.17	2.36	3.28	5.83
	4	19.75	3.95	2.38	5.11	5.00
Modified with SBS No 9	1	15.18	3.26	2.32	4.10	4.66
	2.5	18.22	3.23	2.34	3.31	5.64
	4	17.19	4.01	2.35	5.01	4.28
Modified with SBS No 5	1	14.34	3.25	2.30	4.32	4.41
	2.5	17.11	3.27	2.32	3.35	5.32
	4	18.92	4.32	2.37	5.41	3.38

Table 5: Indirect Tensile Strength Test Results for Control Mixture and Asphalt Mixtures Modified by Styrene Butadiene Styrene (SBS) With Three Different Particle Sizes.

Sample	Polymer percent (%)	ITS = (2p\(πDT) Mpa
Control `Unmodified	0	2.25
Modified with SBS No 16	1	2.72
	2.5	2.98
	4	2.61
Modified with SBS No 9	1	2.68
	2.5	2.83
	4	2.57
Modified with SBS No 5	1	2.59
	2.5	2.88
	4	2.51

Table 6: Wheel track Test Results at 50 C° for Control Mixture and Asphalt Mixtures Modified by Styrene Butadiene Styrene (SBS) With Three Different Particle Sizes.

Sample	Polymer percent (%)	Rut depth(mm) at (50˚C) after (6000) passes
Control `Unmodified	0	6.36
Modified with SBS No 16	1	3.52
	2.5	3.39
	4	3.90
Modified with SBS No 9	1	3.57
	2.5	3.46
	4	4.07
Modified with SBS No 5	1	3.96
	2.5	3.78
	4	4.21



igure 1: Marshall Mix Design Curves for Optimum Asphalt Content.

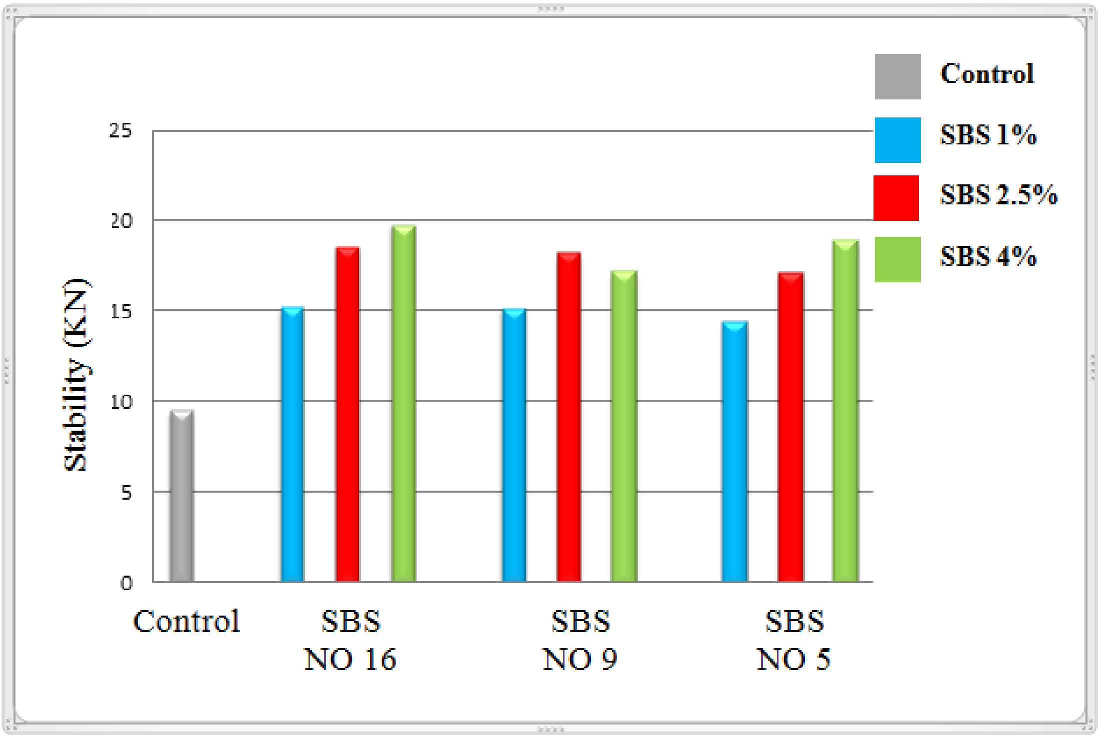


Figure 2: Effect of Particles Sizes of Styrene Butadiene Styrene Polymer (SBS) on Stability of Asphalt Concrete Modified Mixture.

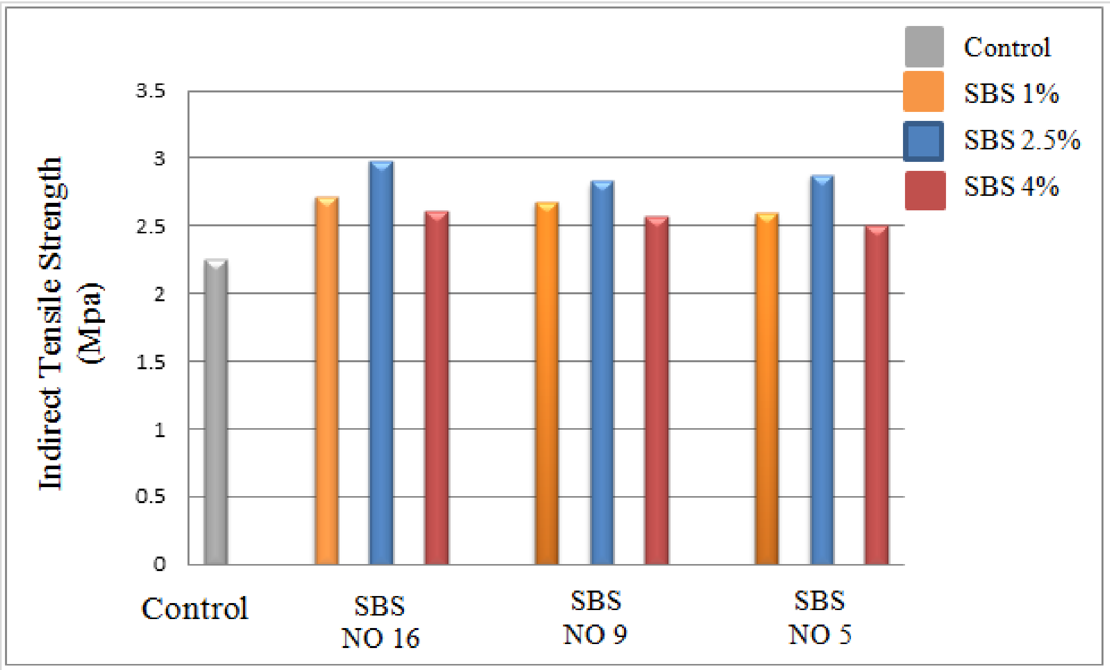


Figure 3: Effect of Particles Sizes of Styrene Butadiene Styrene Polymer (SBS) on the Indirect Tensile Strength (ITS) of Asphalt Concrete Modified Mixture.

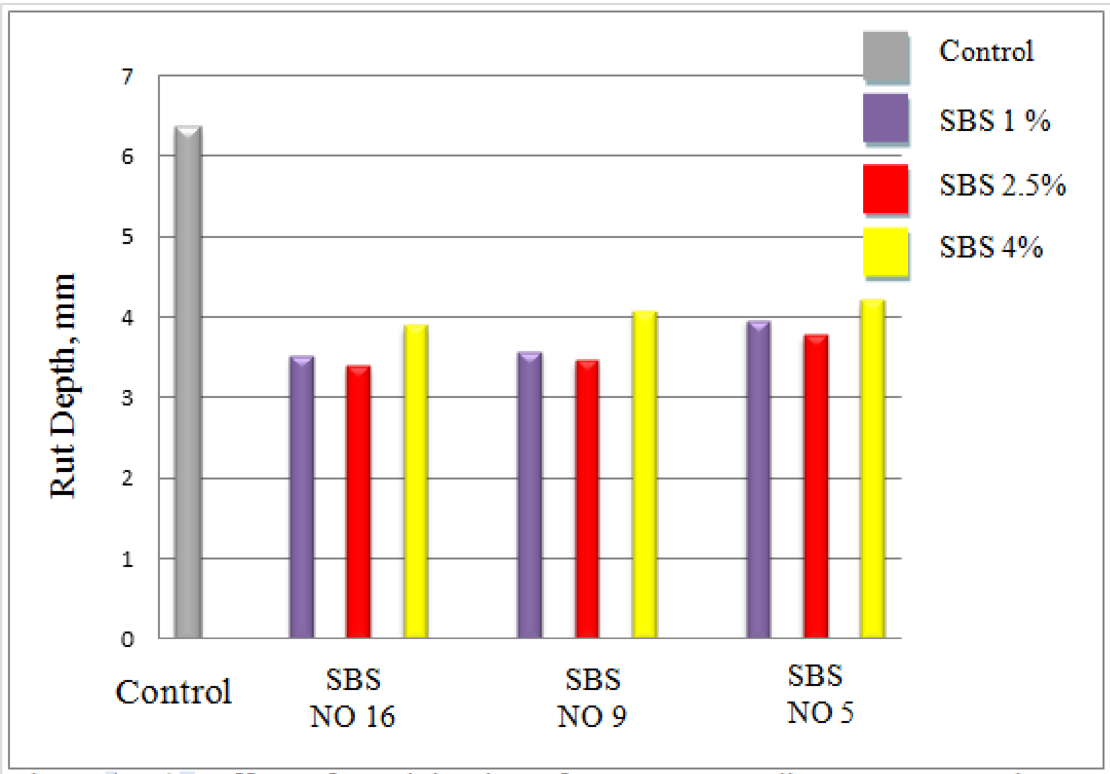


Figure 4: Effect of Particle Size of Styrene Butadiene Styrene Polymer (SBS) on Permanent Deformation(Rutting Depth @ 50˚C Test) of Asphalt Concrete Modified Mixture.