Journal of Engineering and Sustainable Development
Vol. 23, No.06, November 2019
ISSN 2520-0917
https://doi.org/10.31272/jeasd.23.6.7

INVESTIGATING EFFECTS OF APPLICATION OF SILICA FUME AND SBS AS MODIFIERS TO REDUCE MOISTURE SENSITIVITY OF ASPHALT CONCRETE MIXTURE

*Dr. Zaynab Ibrahim Qasim[1], Dr. Karim Hadi Ibrahim Al Helo[2], Sara Nadhim hameed[3]

1) Assistant Professor, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq
2) Assistant Professor, Building and Construction Engineering Department, University of Technology, Baghdad ,Iraq
3) M.Sc. Student, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.

Received 29/7/2018 Accepted in revised form 9/10/2018 Published 1/11/2019

Abstract: Moisture damage is one of the most common reasons for the premature deterioration of Hot Mix Asphalt (HMA) pavements. Over the years, extensive research has been carried out by scientists and engineers on this subject; however, pavements still succumb to early failure from infiltrating moisture. A very popular method of minimizing the moisture susceptibility of asphalt pavements is by the use of anti-stripping agents. These additives are chemical substances that alter the physicochemical properties of the asphalt by making it more hydrophobic. This study focuses on the effect of anti-stripping agents on the moisture susceptibility of asphalt Concrete mixture. The anti-stripping agents used were (SBS, Silica fume, and SBS with Silica fume) with different percentages. The laboratory tests include indirect tensile strength test, Marshall and retained Marshall Stability test (RMS) and double punching shear strength test. The test results show that the asphalt mixtures modified by (Silica fume+ SBS) have highest values in Marshall Stability, RMS and it increased the moisture and stripping resistance. However, using (3% Silica fume+3% SBS) has the best effect on Marshall Stability, TSR value and stripping resistance. While (4% Silica fume+3% SBS) has the best effect on RMS value. From the experimental results, it is observed that the addition of anti-stripping agents had a significant positive influence on the results of the test properties being evaluated in each test.

Keyword: *Styrene Butadiene Styrene, SBS, Polymer Modified, Silica Fume, Moisture Sensitivity andAsphalt Concrete Mixture.*

تقييم تأثيرات اضافة السيلكا فيوم مع مادة SBS كمحسنات لتقليل حساسية الرطوبة للخلطات الاسفلتية الساخنة

الخلاصة:يعتبر فشل الرطوبة احد المسببات الشائعة للفشل المبكر للخلطة الاسفلتية الساخنة في التبليط، على مر السنوات طبقت الكثير من البحوث من قبل العلماء والباحثين على هذا الموضوع ،على كل حال مازال يعاني التبليط من الفشل المبكر نتيجة ترشح المياه اليه. الطريقة الشائعة لتقليل حساسية الرطوبة للتبليط الاسفلتي هو باستخدام موانع الرطوبة. هذه المضافات هي مواد كيمياوية تغير من الخواص الفيزيو-كيمياوية للاسفلت مما تجعله اكثر نافرة للماء. تركز هذه الدراسة على تاثير المواد المانعة للرطوبة على الخلطات الاسفلتية الساخنة حيث تم استخدام المواد (مادة SBS، السيلكا فيوم، مادة SBSمع السيليكا فيوم) بنسب مختلفة. شملت الفحوصات

**Corresponding Author*:zaynab.2010@yahoo.com

فحص الشد غيرالمباشر ،فحص مارشال ،فحص قيمة مارشال المسترجعة وفحص مقاومة الاختراق المزدوج. بينت نتائج الفحوصات ان الاسفلت المحسن ب SBS+ السيليكااعطت اعلى النتائج لثبوتية مارشال ومقاومةمارشال المسترجعه وكذلك ازدادت مقاومه الخلطة الاسفلتيهللرطوبه والانتزاع وان استخدام (3% من السيليكا+3% SBS) يعتبر النسبة المثلى عند فحص مارشال، الشد غير المباشر وفحص الاختراق المزدوج. بينماكانت (4%سيليكا+ 3% SBS) هي الافضل عند فحص مقاومة مارشال المسترجعه. لوحظ من النتائج المختبرية ان اضافة العوامل المضادة للرطوبة لها تاثير ايجابي على نتائج الفحوصات والتي قيمت لكل فحص.

1. Introduction

Moisture damage in asphalt mixtures refers to loss in strength and durability due to the presence of water. Iraqi road network is showing severe deterioration such as raveling and stripping because the bond between aggregates and asphalt film is broken due to water intrusion [1]. It is often directly disrupts the integrity of the mix, thereby reducing pavement performance life by accelerating all the modes of distress of interest in pavement design, including fatigue cracking, permanent deformation (rutting) and thermal cracking in asphalt concrete, and rutting in the unbound soil layers due to the reduced load carrying capacity of distressed asphalt concrete layers. In some cases when pavement is not loaded, moisture may simply weaken the asphalt mix by softening or partially emulsifying the asphalt film without removing it from aggregate surfaces. The resulting loss of stiffness or strength is recovered when water is removed from the mix [2]. However, when a pavement is loaded during this weakened condition damage is accelerated and may become irreversible.

2. Background and Significance of Work

Due to the increasing of traffic volumes, truck tire pressures, axle loads, and atmospheric temperature, many modified asphalt materials and mixtures have been used to solve a large number of premature failures of asphalt pavement. Previous research and application have shown that the modification of asphalt binders by polymer materials significantly improved the properties of asphalt material in several ways, such as a reduction in temperature susceptibility, improved rheological characteristics, and enhanced material durability [3]. The common polymers used to modify the performance of bituminous binders are styrene butadiene styrene (SBS), styrene-butadiene rubber (SBR), ethylene evinyl acetate (EVA), and polyethylene (PE) [4,5]. Among polymers, the elastomer SBS block copolymer is the most widely used.

(Won and Ho., 2003) studied the effect of anti-striping additives on polymer-modified asphalt mixture. It is foundthat using of polymer such as SBS improves mixture properties to fatigue cracks, rutting resistance, moisture damage, compared with mixtures contain EVA polymer.

Sturat 2001 studied the effect of polymer addition on the adhesion force between the aggregate and asphalt binder. It is found that mixtures modified by polymer (SBS and SBR), exhibited greater resistance to moisture damage than the unmodified mixtures, due to increased adhesion force to the aggregate, and creating a network with the bitumen.

[8]: Studied the effect of using SBS with hydrated lime on the moisture damage sensitivity resistance of asphalt mixtures. It is found that SBS have good effect on moisture damage resistance and increase its resistance.

In recent years, nanotechnology has become a promising and creative technique in the material industry, andnano-materials have been widely applied to various fields across the world [9]. However, the use of nano-material such as nano-silica in asphalt pavement started relatively late but there are an evidences that nano-silica forms agglomeration of nano-particles to form micro size clusters which can reduce nano-silica effectiveness while making asphalt binder more susceptible to shear. Therefore, this paper studies effectiveness of using silica fume to reduce moisture sensitivity while alleviating agglomeration issue. [10].

[11] studied the effect of additives such as fly ash, fumed silica on asphalt cement properties, it was concluded that when silica fume was implemented as additives to asphalt cement, it was noticed that penetration decreased, softening point increased and the control on the sensitivity to temperature (PI) could be achieved. On the other hand, fly ash improved the elastic properties of 40-50 asphalt cement.

[12] Investigate the performance characteristics of SBS polymer-modified asphalt mixture (PMA) with the addition of nano-silica particle. It is found that the Nano-silica reduces the susceptibility to moisture damage and increases the strength of asphalt mixes.

The main objectives of this study are to evaluate the effect of usage of SBS at(3% by weight of asphalt)as the optimum percentage according to previous study and silica fume at different percentages of (1%,2%,3%, and 4% by weight of asphalt and modifier asphalt) on moisture susceptibility of asphalt concrete mixture. In addition to compare the differences in pavement performance of modified asphalt concrete mixture and the control mixture.

3. Laboratory Testing

The testing program consists of physical tests include penetration, specific gravity, ductility, and softening point for asphalt binder and particle shape, specific gravity, water absorption and Los angles abrasion test for aggregate, and the mechanical tests included the Marshall test, double punching shear, and indirect tensile test. The experimental test program consisted of the following main work elements: (a) Preparation of test asphaltmixtures specimens, (b) laboratory tests before adding anti-stripping agents, and (c) laboratory tests after adding anti-strippingand polymer agents.

3.1. Material

The materials used in this study are locally available. They are including asphalt binder, crushed aggregate, mineral filler, and anti-stripping andpolymer agents.
agents.In this work, asphalt cement grade (40-50) was used and it was obtained from Al-Durrah Refinery, south-west of Baghdad. The physical properties of this binder are presented in Table 1. The source of the used aggregate (Coarse and fine) in this

research is from AL- Nibaie quarry. This aggregate is widely used in Baghdad city for asphalt mixes. Table 2 illustrates the physical properties of coarse and fine aggregate.Filler is a non- plastic material passing sieve No.200 (0.075mm) usually used to fill the voids and improve mixture properties. Mineral filler used in this study is limestone dust obtained from the lime factory of Karbala' governorate, the physical properties of the used filler are presented in Table 3. Results were compared with the SCRB (R/9, 2003) specification requirements as presented later.

Table 1 physical properties of asphalt cement binder.

Property	ASTM designation	Test result	SCRB specification
Penetration ,25°c, 100gm,5sec	D-5	47	40-50
Ductility , 25°c, 5cm/min	D-113	114	>100
Softening point	D-36	53.5	---
Flash point	D-92	291	Min 232℃
Specific gravity	D-70	1.031	1.05-1.01

Table 2: Physical Properties of Coarse and Fine Aggregates

Property	Coarse Aggregate			Fine aggregate
	Sieve size			
	12.5	9.5	4.45	
Bulk Specific gravity(C127,C128)	2.651	2.585	2.570	2.635
Apparent Specific gravity(C127,C128)	2.674	2.591	2.582	2.655
Absorption%(C127,C128)	0.32	0.09	0.18	0.25
Toughness, by (Los Angeles Abrasion) %C131		21.3		-

Table 3 physical properties of mineral filler

Property	Value
Specific gravity	2.73
%Passing Sieve No.200 (0.075 mm)	97

3.2. Samples Preparation

In this research, the Superpave mix design system was adopted with varying volumetric composition. The Superpave Gyratory Compactor was used to prepare 14 asphalt concrete cylindrical specimens of (150 mm in diameter and larger than 100 mm to 173 mm in height) for carrying out volumetric design according to Superpave system (AASHTO Designation: T 312-2010). The optimum asphalt content was 4.7% for the selected gradation and asphalt binder shown in Table 4 and Figure1.

Table 4: Gradation of selected Blend

Sieve size		Superpave Specification , 2007		Iraqi Specification (SCRB R9, 2003) surface layer type IIIA		% selected passing of aggregate
Standard Sieves	English Sieves	max	min	max	min	
19mm	3/4"	100	--	100	--	100
12.5mm	1/2"	100	90	100	90	97
9.5mm	3/8"	---	90	90	76	86
4.75mm	#4	---	---	74	44	60
2.36 mm	#8	39.1	39.1	58	28	36
1.18mm	#16	31.6	25.6	---	---	25
0.6mm	#30	23.1	19.1	---	---	19
0.3mm	#50	15.5	15.5	21	5	14
0.15mm	#100	---	---	---	---	10
0.075mm	#200	10	2	10	4	6

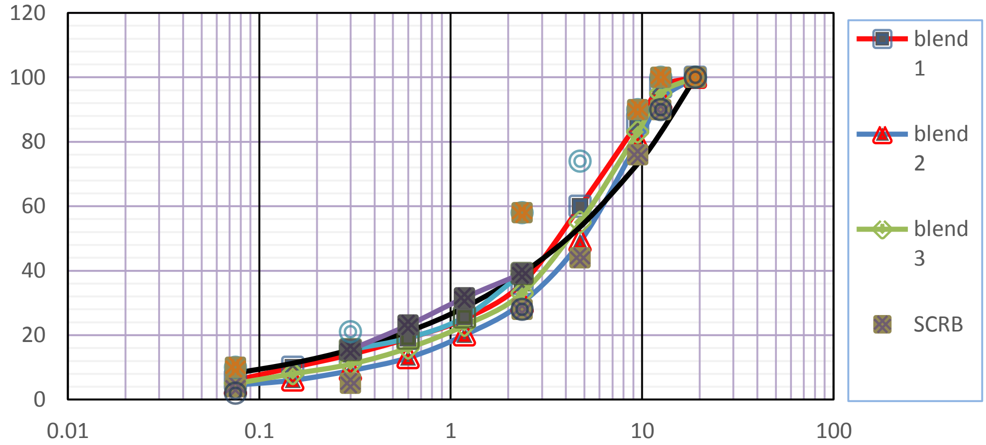

Figure1: Gradation Blends with Iraqi and Superpave Requirements

3.3. Indirect Tensile Test

The moisture susceptibility of the asphalt concrete mixtures was evaluated using AASHTO T-283. The result of this test is the indirect tensile strength (ITS) and tensile strength ratio (TSR). In this test, a set of specimens were prepared for each mix according to Superpave procedure and compacted to 7±1 % air voids. The set consists of six specimens and divided into two subsets, one set (unconditioned) was tested at 25°C and the other set (conditioned) was subjected to one cycle of freezing and thawing then tested at 25°C. A static load is increasingly applied at rate of 2.0"/min to the sample until failure. The indirect tensile strength which is calculated according to Eq 1 of the conditioned specimens (ITScond.) is divided by the control specimens (ITSuncond.), which gives the tensile strength ratio (TSR) as the following Eq2.

$$ITS = 2000P/\pi t\, D \qquad (1)$$

Where:
ITS = indirect tensile strength, kPa
P = maximum load, N
t = specimen height immediately before tensile test, mm, and
D = specimen diameter, mm.
Then the Tensile Strength Ratio is determined as follows:

$$TSR = (ITScond./\ ITSuncond.) * 100 \qquad (2)$$

Where:
TSR= tensile strength ratio, percent
ITScond. = average tensile strength of the moisture conditioned samples, kPa.
ITSuncond. = average tensile strength of unconditioned samples, kPa.
The minimum requirement for tensile strength ratio is 80%. The value of tensile strength ratio for asphalt grade (40-50) is 87.1 %

3.4 Retained Marshall Stability Test

Retained Marshall Stability (RMS) test is used to determine retained Marshall Stability for Marshall Compaction specimens after curing for 24 hours in a water bath at60°C.It is one of tests required by SCRB to be performed on asphalt mixes used in surface course in addition to Marshall Tests, in accordance with method ASTM D 1075. The specimens were divided into two groups; the first group (un conditioned) were immersed in water at 60 C° for 30 min, and then loaded to failure by using curved steel loading plated along with a diameter at a constant rate of compression of 51mm/min. The second group (conditioned) was placed in water bath at 60 C° for 24hr then tested, as shown in Figure 2. The retained Marshall stability (RMS) was calculated according to the following equation.

$$RMS = \frac{MS_{cond}}{MS_{uncond}} \times 100\% \qquad (3)$$

Where:
RMS = retained Marshall stability.,
MScond = Marshall stability for conditioned samples.
MSuncond = Marshall stability for unconditioned samples.

Figure 2.Retained Marshall stability test

3.5 Retained Double Punching Shear Test

This test procedure was developed at the University of Arizona by Jimenez 1974, and it was used to measure the stripping of the binder from the aggregates. This test was reported by many studies, [13 , 14 and 15]. Marshall Specimen was used for this test; it was conditioned by placing in water bath at 60ºC for 30 min.

The test was performed by centrally loading the cylindrical specimen, using two cylindrical steel punches placed on the top and bottom surface of the sample. The specimen was centered between the two punches 2.54cm in diameter, perfectly aligned one over the other, and then loaded at a rate of 2.54cm /minute until failure. The reading of dial gage at the maximum load resistance was recorded. Figure 3shows double punch test apparatus. The punching strength is computed by the equation:

$$\sigma t = \frac{p}{\pi(1.2bh - a^{2})} \qquad (4)$$

Where:
σt = punching stress, Pa
P= maximum load, N
a= radius of punch, mm
b=radius of specimen, mm
h=height of specimen, mm

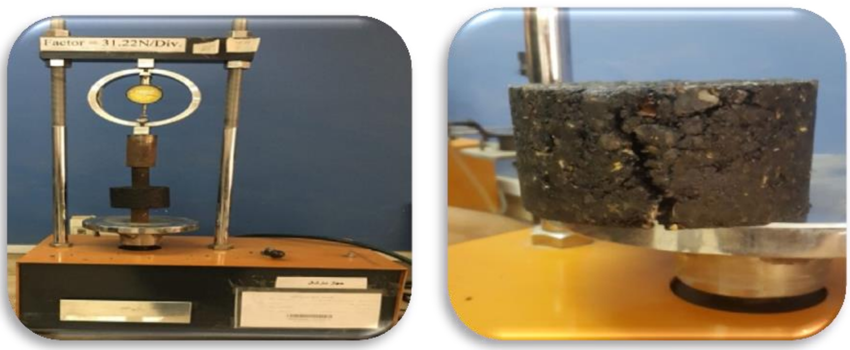

Figure 3.Double Punch Test Apparatus

4. Results and Analysis

4.1 The Indirect Tensile Strength and TSR Values

The indirect tensile strength for both types of samples (unconditioned and condition) and TSR values are listed in Table 5. As shown in Figure 4, the ITS for control mixture was (975.8 and 849)Kpa for (unconditioned and condition) respectively.

And when SBS was added at 3% of weight of asphalt it increased to (1073 and 975.2) and from this figure note that the ITS for mixture contain silica fume was lower than control mixture and mixture contain SBS, while the mixtures containing (SBS and silica fume) at different percent have higher values of tensile strength at failure under static load which indicates greater cohesive strength of modified mixture and improve cohesion and adhesion of binder and donot allow the stripping of asphalt from aggregate particles

For TSR values shown in Table 5, TSR value for control mixture was 87.1% and this value meets the specification limit (TSR=80% as minimum value) and when using SBS it increased to 90.9% while when silica fume was added at different percent firstly it reduced to 85.6% at 1%silica fume then it increased to 90% at 3% silica fume. When using silica fume and SBS together the TSR values are gradually increasing to become a peak which is 97% when 3% silica fume+ 3% SBS were used.

Table 5: Indirect tensile strength and tensile strength ratio results

Mixture type	ITS_{uncon} kpa	ITS_{con}kpa	%TSR
AC	975	849	87
SBS	1073.15	975.5	90.9
SI 1%	750	642.5	85.6
SI 2%	839.8	738	87.9
SI 3%	780	702	90
SI 4%	696	591.7	84.9
SBS+SI 1%	1153.97	1089.8	94.4
SBS+SI 2%	1282.8	1231.5	96
SBS+SI 3%	1376.9	1335.6	97
SBS+SI 4%	1166.69	1035	88.7

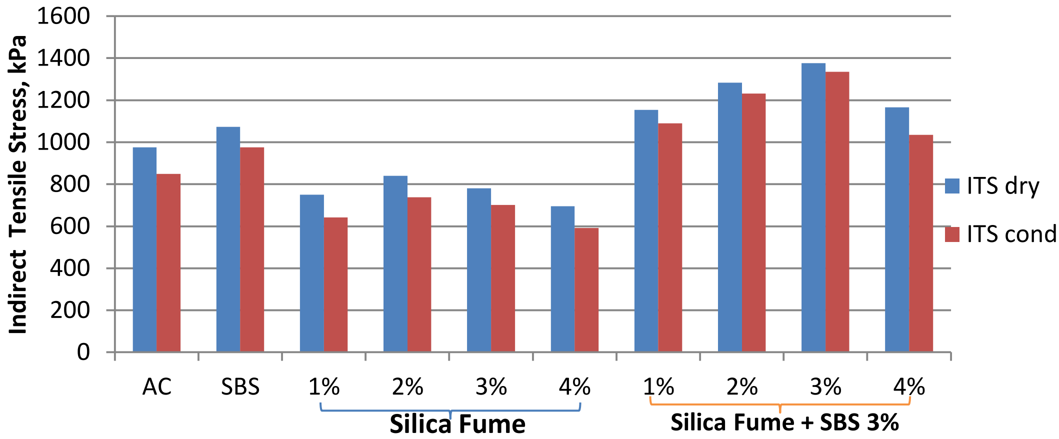

Figure 4. ITS values for unconditioned and condition for each samples

4.2 Marshal Stability and Retained Marshal Stability

The effect of additives on the marshal stability values are shown in Figure 5. Marshal stability for control mixture was 10 KN and when using SBS it increased to 11.2 KN while when using silica fume the maximum increase was at 3% silica fume which is 11.8kN.

It is clear that, there is arise in Marshallstabilityvalues at (1,2and3% silica fume+3% SBS) which is (12.3,13and15) KN respectively, then it decreased at (4% silica fume+3% SBS)but it still higher than control mixture.

Index of retained Marshall stability (RMS) can be used to measure the effect of water damage on the Marshall stability for the asphalt concrete mixtures exposed to moisture conditions. The results for this test are shown in Figure 6. The Marshall stability values for the mixtures which they exposed to moisture damage decreased at all types of mixtures except when silica fume was added, where it increased. As shown the RMS value equal to 92% for control mixture and increase for mixture contain SBS, silica fume and silica fume+ SBS. the optimum increase at 4% silica fume, where RMS equal to 101%, which indicate that the silica fume tend to reduce the effect of water action and increase adhesive strength between asphalt binder and the aggregate particles.

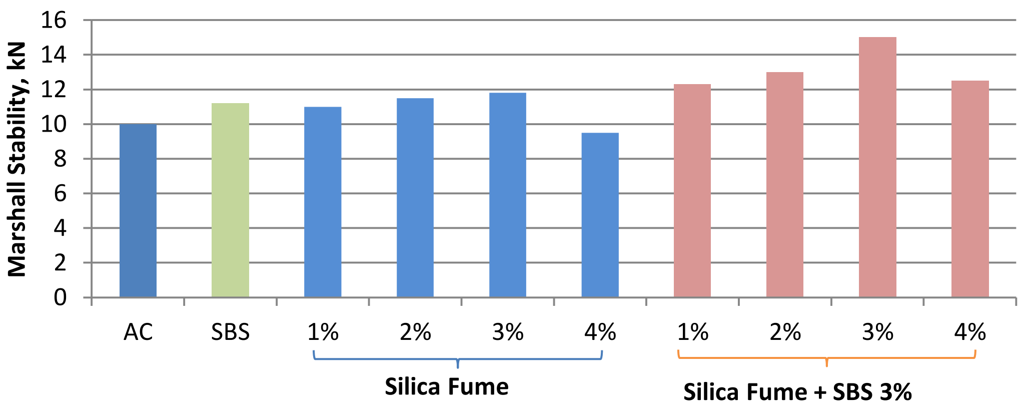

Figure 5. Marshal stability values for each type of mixtures.

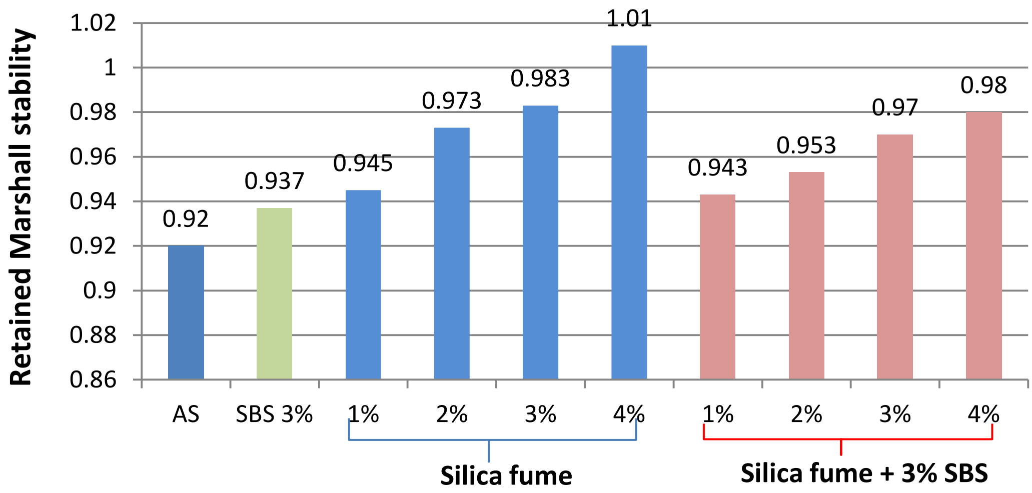

Figure 6: Retained marshall stability for each type of mixtures

4.3 Double Punching Shear Strength

Double punch test indicates the stripping behavior between binder and aggregate. As illustrated in the Figure 7 punching shear strength for control mixture was 156 and when SBS was used it rose to 221,however , when silica fume was added to asphalt binder the punching strength decreased at 1% but it increased at 2% and 3% then decreased again at 4% silica fume.

The punching shear strength increased significantly when using silica fume and SBS together, where it become 280 Kpa at 3% silica fume+3% SBS.

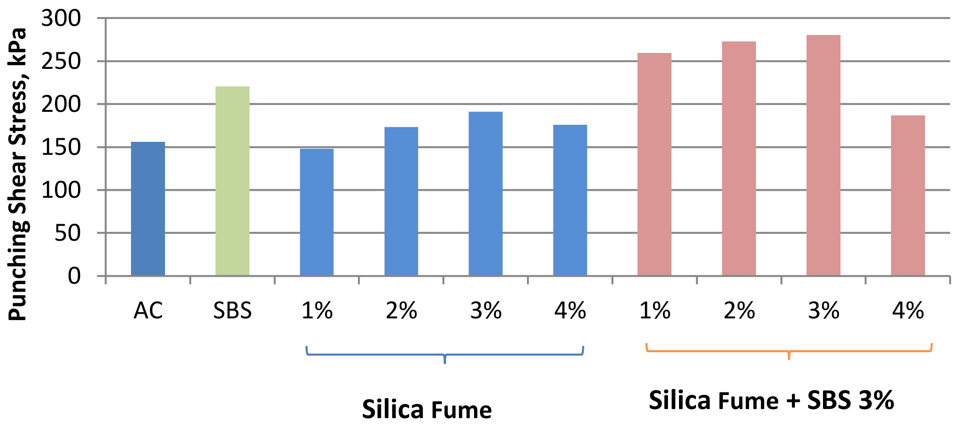

Figure 7: punching shear strength for each type of mixture

5. Conclusions

Based on the limited laboratory work done in this research, it can be concluded that:

1- The SBS polymer at 3% by weight of asphalt binder improves tensile strength and the TSR value increased by 3% from control mixture.

2- Silica fume decreased tensile strength but it increased TSR value to 3% higher than control mixture at the content 3% silica fume.
3- When using SBS and Silica fume together the ITS and TSR values increased significantly and the optimum content was at (3% Silica fume+3% SBS) where the TSR value increased from 87.1% at control mixture to 97%.
4- Marshall stability slightly increased when SBS and Silica fume was added and it increased by about 50% above control mixture when(Silica fume+ SBS) was used.
5- The higher value for RMS was 101% at (4% Silica fume) which is approximately 9.8% greater than control mixture.
6- Punching shear strength increased with (Silica fume+ SBS) content increase while it reduced when Silica fume was added only to asphalt binder.

6. Recommendations

Further research into investigating the performance properties of asphalt mixtures like rutting test and fatigue test.

Several field sections would be constructed using the same asphalt mixturesand anti-stripping aging and testing results would be evaluated to explore correlation with pavement laboratory tests and field performance.

7. References

1. Qasim , Z. I. , and Abed, A. H.(2015), "*Impact of Gradation and Modifier on Moisture Susceptibility of Iraqi Hot-Mix Asphalt*", The 2nd Conference International of Buildings, Construction and Environmental Engineering), AUB Lebanon
2. Santucci, L. (2002). "*Moisture Sensitivity of Asphalt Pavements*". Technical Transfer Program, Institute of Transportation Studies, University of California, Berkeley, California.
3. M.R. MohdHasan et al, (2016)." *A simple treatment of electronic-waste plastics to produce asphalt binder additives with improved properties*", Constr. Build. Mater.
4. Airey, G. D. (2003). "*Rheological properties of styrene butadiene styrene polymer modified road bitumens*". *Fuel, 82*(14), pp 1709-1719.
5. Chen, J. S., Liao, M. C., &Shiah, M. S. (2002). "*Asphalt modified by styrene-butadiene-styrene triblock copolymer*",Morphology and model. *Journal of materials in civil engineering*, *14*(3), pp 224-229.
6. Won, M. C., & Ho, M. K. (1994). "*Effect of antistrip additives on theproperties of polymer-modified asphalt binders andmixtures*". Transportation research record, (1436).
7. Stuart,K.D.,(2001),"*Moisture damage in asphalt mixtures*"., Research Development and Technology. Turner- Fair bank highway Research center.

8. Kok, B. V., &Yilmaz, M. (2009). "*The effects of using lime and styrene–butadiene–styrene on moisture sensitivity resistance of hot mix asphalt*". *Construction and building materials*, vol. *23 No.* 5, Pp1999-2006.
9. Yao, H., You, Z., Li, L., Lee, C., Wingard, D., Yap, Y., &Goh, S. (2012). "*Properties and chemical bonding of asphalt and asphalt mixtures modified with nanosilica. Journal of Materials in Civil Engineering*, Vol.*25 No.*(11), Pp.1619-1630
10. Abutalib, N., Fini, E. H., Aflaki, S., & Abu-Lebdeh, T. M. (2015). "*Investigating effects of application of silica fume to reduce asphalt oxidative aging*". American Journal of Engineering and Applied Sciences, Vol. 8, No. (1), Pp. 176.
11. Sarsam, S. I., &Lafta, I. M. (2014). "*Assessment of Modified-Asphalt Cement Properties*". Journal of Engineering, Vol. 20 No. (6), Pp. 1-14
12. Solaimanian, M., Harvey, J., Tahmoressi, M., &Tandon, V. (2003). "*Test methods to predict moisture sensitivity of hot-mix asphalt pavements*". In Moisture Sensitivity of Asphalt Pavements-A National SeminarCalifornia Department of Transportation; Federal Highway Administration; National Asphalt Pavement Association; California Asphalt Pavement Alliance; and Transportation Research Board..
13. Turos, M.I., (2010). "*Determining the Flexural Strength of Asphalt Mixtures using the Bending Beam Rheometer*", M.Sc. Thesis, University of Minnesota.
14. Sarsam, S. I. (2006). "*Improving asphalt concrete quality for ramps and approaches*". *Indian Highways*, Vol.*34, No.*(3).
15. Huang, Y., Bird, R. N., &Heidrich, O. (2007). "*A review of the use of recycled solid waste materials in asphalt pavements"*. *Resources, Conservation and Recycling*, Vol. *52 No.* (1), Pp. 58-73.