Engineering and Technology Journal
Journal homepage: engtechjournal.org

Effect of Modified Asphalt Cement of the Performance of Stone Matrix Mixtures

Duaa A. Khalaf [a]*, Zaynab I. Qasim [b], Karim H. Al Helo [c]

[a] Civil Engineering Dep., University of Technology, Baghdad, Iraq. duaa.asaad199312@yahoo.com

[b] Civil Engineering Dep., University of Technology, Baghdad, Iraq.

[c] Civil Engineering Dep., University of Technology, Baghdad, Iraq.

*Corresponding author.

Submitted: 25/07/2019 Accepted: 28/09/2019 Published: 25/05/2020

K E Y W O R D S

Stone matrix asphalt SMA, SBS polymer, Modified asphalt, Moisture susceptibility, and Rutting.

A B S T R A C T

This research investigates the behavior of Stone Matrix Asphalt mixtures (SMA) modified with styrene-butadiene-styrene (SBS) polymer at four percentages (1, 2, 3 and 4%) by weight of asphalt cement. The moisture susceptibility and rutting were taken into consideration in this study. To achieve the objective of this research the superpave system is conducted to design the asphalt mixtures. The physical properties of aggregate, bitumen and other mix materials were assessed and evaluated with the laboratory tests. The mixtures were prepared using penetration Graded (40-50) bitumen and a chemical named Polypropylene Fibers was used as a stabilizing additive. Fibers have been used in SMA mixtures for two main reasons: To increase the toughness and fracture resistance of hot mix asphalt (HMA) and to act as a stabilizer to prevent drain down of the asphalt binder. The laboratory tests include indirect tensile strength test, Marshall stability and retained Marshall Stability test (RMS). For rutting test the Roller wheel compactor is used for preparing the asphaltic samples and Wheel tracking device is used to evaluate the rutting of asphaltic slabs. The results showed that the SBS polymer asphalt mixture gave better moisture sensitivity and better fracture resistance according to the study.It is noted that indirect tensile strength ratio (TSR) increases by 93.1 % and the rut depth decreases by 32.5 % when adding 3% SBS polymer to SMA.

How to cite this article: D. A. Khalaf, Z. I. Qasim and K. H. Al Helo, “Effect of modified asphalt cement of the performance of stone matrix mixtures,” Engineering and Technology Journal, Vol. 38, Part A, No. 05, pp. 789-800, 2020.

DOI: https://doi.org/10.30684/etj.v38i5A.489

1. Introduction

Asphalt pavements in general are facing serious distress problems worldwide. So much has been done to improve the quality of the mix through research and innovations [1]. Stone Matrix Asphalt (SMA) has been used successfully in Europe for over 20 years to provide better rutting resistance [2].

Since 1991, the use of SMA has increased steadily in the United States, [3]. SMA is a tough, stable, rut-resistant mixture that relies on stone-on-stone contact to provide strength and a rich mortar binder to provide durability, as shown in Figure 1. These objectives are usually achieved with a gap-graded aggregate coupled with fiber or polymer modified, and high asphalt content matrix, [4]. SMA has a high Skeleton to resist permanent deformation. The stone skeleton is filled with mastic of bitumen and filler to which fibers are added to provide adequate stability of bitumen and to prevent drainage of binder during transport and placement. Typical SMA composition consists of 70−80% coarse aggregate, 8−12% filler, 6.0−7.0% binder, and 0.3 per cent Fiber, [5]. SMA, due to its high asphalt binder content, requires fibers such as stabilizing additive so that segregation or exudation does not occur during the mixing process and placement. The utilized fibers do not produce any chemical alteration in the asphalt cement, but physical properties are altered. The fibers are classified as organic or inorganic. The organic fibers are classified as natural (cellulose) or artificial (polyester, polypropylene, polyetilene). The inorganic fibers are also subdivided as natural or artificial; a fiber-designated amianthus is an example of a natural inorganic fiber. Steel fibers, carbon, and glass are examples of artificial inorganic fibers. The proportion of coarse aggregate that interlocks to form stone on-stone cellulose fibers are the most commonly applied in the production of SMA, [6]. A study conducted in Ontario, Canada, by the Ministry of Transportation on SMA pavement slabs trafficked with a wheel-tracking machine gave less rut depths in comparison to that occurring in a dense friction coarse [7]. Coarse aggregate have the most important role in obtaining high rutting resistance of SMA and that’s why regulations emphasize on type and quality of aggregate [8]. Interlock between coarse aggregates, which constitute the skeleton of SMA, is an important factor of rutting performance of these mixtures. The interlock can be improved through better selection of fiber type and content, volume of bitumen or filler used and grading of aggregates [9]. The main objective of this work is to specify the maximum amount of SMA for HMA with unmodified and modified binder (40-50) for improving moisture susceptibility and rutting resistance of surface course. Thus, the following tasks will be carried out for SMA mixtures: using superpave system to design mixtures and determining the physical properties of asphalt modified with (1, 2, 3 and 4%) SBS by weight of asphalt binder; evaluating the ITSR for unmodified and modified mixtures; and evaluating the rutting performance and specify the best percentage for both unmodified and modified Stone matrix asphalt mixtures.

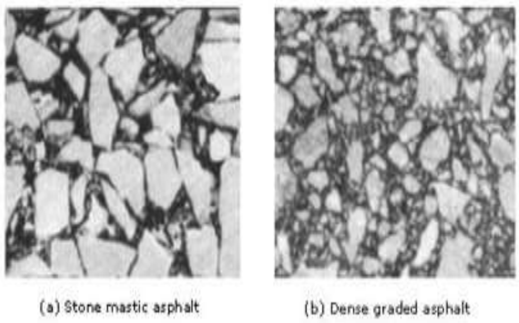

Figure 1: The difference between SMA and dense-graded mixtures [10]

2. Materials and Mix Design

I. Materials

The crushed aggregates that used in this work were brought from Al-Nibaie quarry. For surface course, the nominal maximum aggregate size was 12.5 mm. Table1 presents the physical properties for crushed aggregates. Asphalt cement with (40-50) penetration grade was used in this research which supplied from Al- Daurah Refinery in Baghdad city. The physical properties of asphalt cement are shown in Table 2. One type of fillers was used in this work. This type is the limestone dust obtained from the lime factory of Karbala governorate. The physical properties of limestone passing sieve No. 200 (0.075mm) dust are shown in Table 3.
SBS polymer had been utilized to change the bitumen for the arrangement of adjusted cover. The properties of SBS utilized in this examination are shown in Table 4. The polymer SBS and asphalt (locally produced) were mixed at a temperature of 180℃ during (4-5 hours) on a high shear mixer at 1250 rpm [11]**.** One of the concerns with SMA asphalt mixtures is the potential for asphalt drain-down. The nature of SMA mixes can lead to the asphalt binder draining down and out of the mix.

This could be the result of gravity, transportation of the mix, as well as construction practices. To prevent drain-down from occurring in porous mixes, fibers are recommended. The fibers aid in stabilizing the asphalt binder during production and placement [12] .For stabilization; one of the serious issues normally experienced in SMA blends can be the draining down of the cover amid blending, transportation and compaction. To conquer this issue, fibers are normally added to SMA blends, as shown in Figure 2.

Polypropylene Fibers could be utilized as settling operators in SMA blends, at the rate of 0.3% and 0.5% by weight of blend [13] polypropylene fiber is added by (0.4%) by weight blend; the technical specifications of PE are presented in Table 5.

Aggregate Asphalt Mixture SBS Polymer Polypropylene Fibers

Figure 2: The Materials Used in the Study

II. Superpave Mix Design

Superpave method was adopted to design asphalt mixture. Three aggregate gradations were selected according to AASHTO Designation: (M 325-08, 2012) [14] for surface course. The aggregate blend gradations are displayed in Figure 3. The content of the asphalt binder model is determined at 4% air voids and the content of the asphalt was 6.8% by the mixture weight; to confirm that these features comply with AASHTO M325 .The aggregate requirement (control points and restricted zone) not mentioned in the specification.

Table 1: The physical properties and standard limitation for coarse and fine aggregates

Property	Value		ASTM/AASHTO Designation
Coarse Aggregate > 4.75 mm			
Wear % (Loss Angeles abrasion)	21.3 %		**AASHTO_T96, 30 % max(2012)**
Soundness (Loss by Na_2SO_4),%	3.2%		**AASHTO_T104 12% max**
Angularity,%	97%		**ASTM D 5821, min 95%**
flat and elongated particles, %	Flat, Elongation	0.9%, 2.5%	**ASTM D4791, max 10%**
Fine Aggregate Properties (Crushed Sand < 4.75 mm)			
Bulk Specific Gravity	2.643		**C128-04**
Apparent Specific Gravity	2.616		**C128-04**
Water Absorption %	0.19		**C128-04**
Equivalent Sand (Clay Content,%)	Natural, Crashed	84.5%, 89.6%	**ASTM D2419, min 45%**
Deleterious Material, %	1.12		**AASHTO T112(3Max.)**

Table 2: The Physical Properties of Asphalt Cement

Test	Test Conditions	ASTM Designation	Units	Test results	SCRB/ R9 Specif.,2003
Penetration	100 gm, 25°C, 5 sec., (0.1mm)	D5	1/10 mm	49	**40-50**
Ductility	25°C, 5 cm/min	D113	cm	120	**>100**
Softening Point	(4±1) °C/min.	D36	ºC	48.5	----
Specific gravity	25°C	D70	----	1.031	----
Flash and fire points	----	D92	ºC flash fire	290 300	**>232 °C** ----
Rotational Viscosity	135ºC, 165ºC	D4402	Pas.sec	0.508,0.16	
Residue from thin film oven Test, D-1754					
%Retained penetration of	25 °C, 100 gm, 5	D5	1/10	66	**>55**

original	sec		mm		
Mass Loss	163 °C, 50gm, 5 hr	D-1754	%	0.34	**< 0.75**
Ductility of Residue	25 °C , 5 cm/min	D113	cm	57	**> 25**

Table 3: Physical Properties of Mineral Filler (Source: the lime factory of Karbala governorate)

Property	**Test Result**
Bulk specific gravity	**2.913**
Passing Sieve No.200 (0.075 mm)	**97 %**

Table 4: Physical and mechanical properties of SBS (Source: The State Company for Mining Industry)

Properties	**Value**
Density(Kg/m3)	**1247**
Melting point	**197**
Apparent	**Wight**

Table 5: Technical properties of PF stabilizer (The specification was brought from a polypropylene box)

Property	**Test Result**
Fiber's length	12mm
certain weight	0.911 (g/cm³)
Alkali contents	Nil
Sulphate contents	Nil
Chloride contents	Nil
ingredients	Polypropylene fiber C_3 H_6,
Fiber thickness	18 micron 2denier
certain surface area	244.2 m^2-/kg

Table 6: The Aggregate Gradation Structural Design

Sieve Size		**AASHTO Designation: M325-08(2012)**		**%Passing Blend (1)**	**%Passing Blend (2)**	**%Passing Blend (3)**
Standard Sieves	English Sieves	Min.	Max.			
19mm	3/4"	....	100	100	100	**100**
12.5mm	1/2"	90	100	95	92	**98**
9.5mm	3/8"	50	80	65	60	**78**
4.75mm	#4	20	35	27.2	23	**31**
2.36 mm	#8	16	24	20	18	**22**
0.3mm	#50	....	.....	13	11	**15**
0.075mm	#200	8	11	9.4	9.4	**9.4**

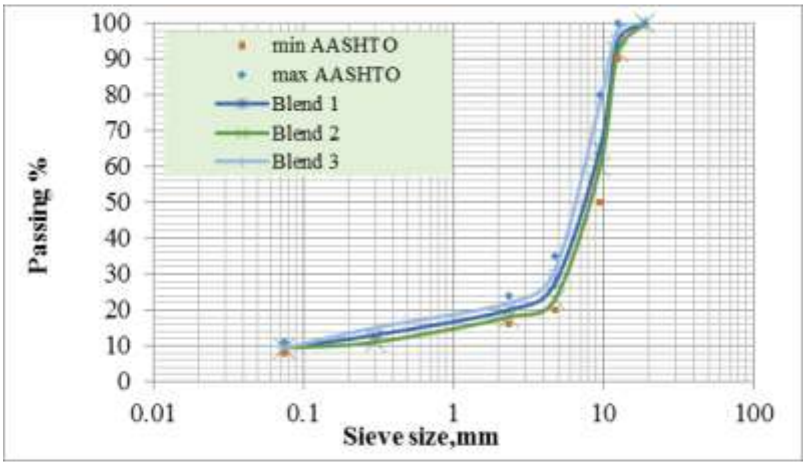

Figure 3: Trail selected Aggregate Gradation Blends

3. Testing Program

I. Effect of additives on asphalt cement's physical characteristics

Penetration value test on asphalt is a measure of hardness or consistency of bituminous material. It was carried out in accordance with the standard ASTM D5 specification. Figure 4 demonstrates the penetration impact of the type of additive and percentages. As demonstrated, the penetration decreases from 49 for control asphalt to 42 when SBS is added by weight of asphalt binder at (1, 2 ,3 and 4) percent. If the addition of SBS is increased to %20, the viscosity increases and goes beyond the limits of the standard in addition to the high cost.

The Softening Point is described as the temperature at which asphalt sample no longer supports the weight of a 3.5-g steel ball. It was carried out in compliance with the standard ASTM D36 specification. Figure 5 indicates that the softening point of control asphalt was 48.5, then increased to 66 when added by weight of asphalt at (1, 2, 3 and 4) percent. The softening point indicates a slight increase as SBS was added to the asphalt at distinct percentages. The optimum percentage can be added to improve the asphalt at (4%) SBS according to the study

The ductility test measures ductility of the asphalt binder by stretching to its breaking point a normal sized briquette of asphalt binder. After splitting, the extended range in centimeters is recorded as ductility. It was carried out in compliance with the standard ASTM D113 specification .Figure 6 shows that ductility of control asphalt was 120, and then decreased to 85 when SBS was added at (1, 2, 3and 4) % by weight of asphalt. The ductility indicates a slight decrease as SBS has been added to asphalt at distinct percentages. The model is considered successful if the distance exceeded by the model before it cuts 100 cm on the measuring ruler of the device according to the specification.

As the specific gravity of the asphalt binder changes with temperature, specific gravity tests are useful for temperature-based volume correction. It was carried out in compliance with the standard ASTM D70 specification. Figure 7 shows Gs with and without additives of asphalt. Gs of asphalt control was 1,031 and by weight of asphalt binder was 1.02 when SBS was added at (1, 2, 3, and 4) percent, however, reduced with increased SBS content.

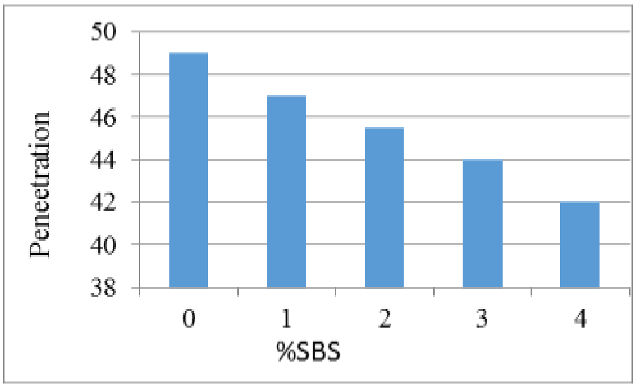

Figure 4: percentages of penetration versus SBS polymer content

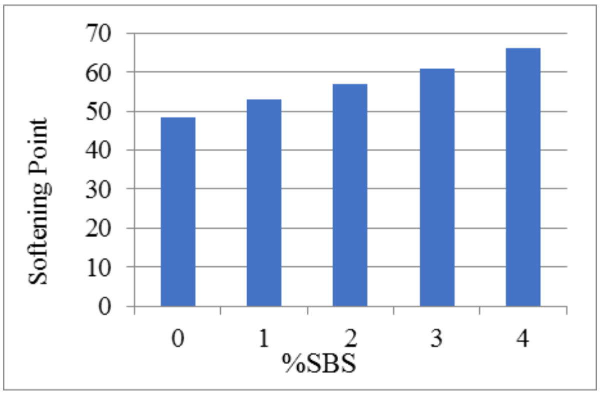

Figure 5: percentages of softening point versus SBS polymer content

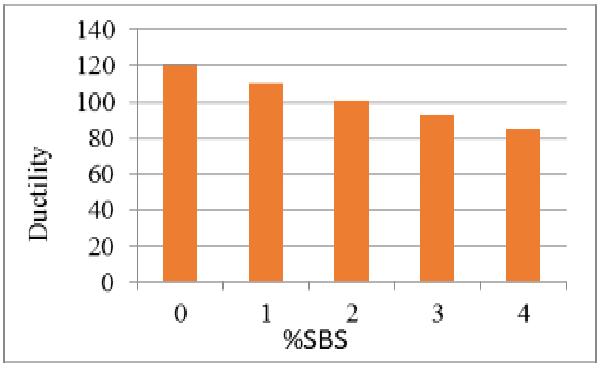

Figure 6: percentages of ductility versus SBS polymer content

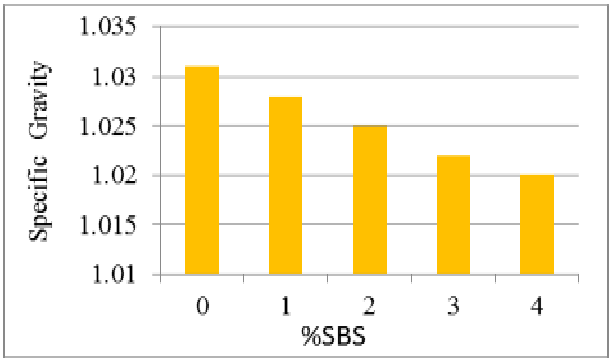

Figure7: Specific Gravity (Gs) percentages versus SBS polymer content.

II. Marshall Test and Volumetric Features

Theoretical maxi definite gravity (G_{mm}) of uncompacted loose SMA mixtures was determined as per ASTM D 2041. After preparing them, the sizes along with weightiness of the samples had been calculated so as to determine the size definite gravity (G_{mb}), air void (V_v), Void in Mineral Aggregate (VMA), in addition to Voids Occupied with Bitumen (VFA) etc. of compacted specimens. SGC specimens were tested for conventional Marshall Stability and flow as per ASTM D 6927. For determining the stability and flow values, the specimen was immersed in a water bath at a temperature of 60° ± 1°C for a period of (30-40) minutes, and then the sample was placed in the Marshall stability testing machine. The load is at a constant rate of deformation of 50.8 mm (2 in) per minute until failure. The maximum loading (that causes failure of the sample) was reordered as Marshall Stability and the total amount of deformation had been taken as Marshall Flow. The obtained stability value was corrected for volume.

Previous research examined water immersion periods (1, 3 and 7) to assess moisture damage for longer periods than standard duration each [15,16].Voids in Coarse Aggregate (VCA) to aggregate in

Dry Rod Conditions (VCA_{DRC}) as well as for blend (VCA_{MIX}) had also been measured by employing the following equations; (Brown and Cooley, 1999) [17]:

$$VCA_{DRC} = \left(\frac{G_{ca}*\gamma_w-\gamma_s}{G_{ca}*\gamma_w}\right)*100 \quad (1)$$

$$VCA_{MIX} = 100-\left(\frac{G_{mb}}{G_{ca}}P_{CA}\right) \quad (2)$$

Where:

G_{ca}: size definite gravity of the rough aggregates portion; γ_w: water's unit weightiness (998 kg/m3); γ_s: portion of rough aggregates unit weightiness in dry-rod condition (kg/m^3) (Defined as per ASTM C 29); G_{mb}: Bulk specific gravity of compacted mixture; P_{CA}: Percent coarse aggregate in the total mixture.

The findings of the Marshall Stability and flow test are shown respectively in Figures 8 and 9. Figure 8 shows clearly by adding the SBS polymer to Gap graded blend enhances the Marshall Stability. It can be seen that the steadiness incremented approximately (9.4, 23.4, 27.3 and 21.1 %) from original mixture, when adding (1, 2, 3 and 4%) SBS content respectively. Regarding flow which represents the quantity of vertical deforming for the sample when failing, the outcomes appeared that the flowing increases when SBS contents increase in Figure 10 and 11 respectively. It can be noticed that the outcomes conform to the specifying scope that is 2-4 mm consistent with (SCRB/R9, 2003) [18].

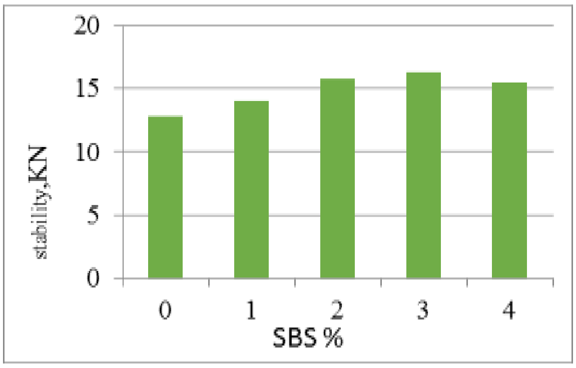

Figure 8: Marshall Stability versus SBS polymer content at 0 days immersion periods

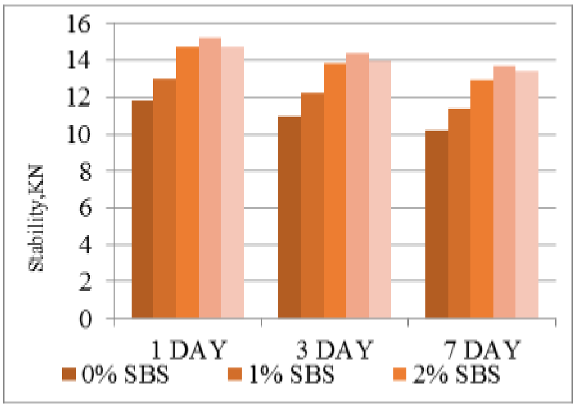

Figure 9: Marshall Stability versus SBS polymer content at different immersion periods

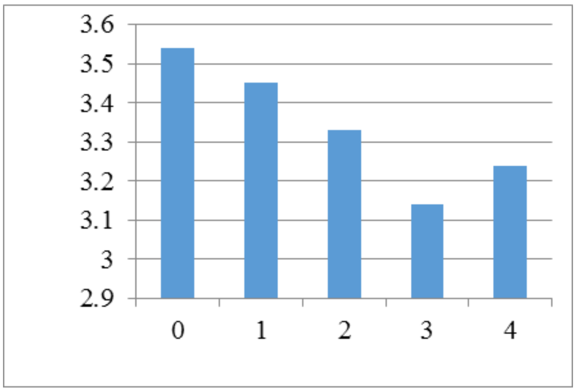

Figure 10: Marshall Flow versus SBS polymer content 0 days immersion Periods

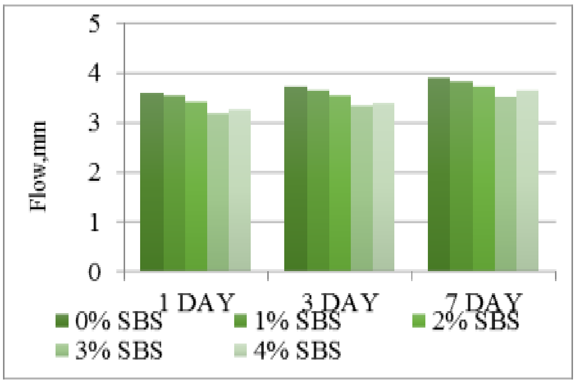

Figure 11: Marshall Flow versus SBS polymer content at different days immersion periods

III. Indirect Tensile Strength Ratio Test

The bond between aggregate mixture and asphalt binder film may lose due to presence of water or cause stripping, and it depends on several factors, asphalt characteristics, environment, traffic and aggregate characteristics. This accomplished by applying AASHTO T283"Resistance of Compacted Bituminous Mixture to Moisture- Induced Damage" [19] and ASTM D 4867 [20], compaction was done for samples to 6% air voids according to AASHTO Designation: M 325-08 (2012) standard specification for Stone Matrix Asphalt (SMA), single subsection of three examples was regarded as controlling example, the other one of three examples represents the conditioning subsection. The conditioning subsection is exposed to vacuum immersion pursued by a discretionary freezing cycle, then adding an extra immersion period for the samples at 60 ºC for separate periods (1, 3 and 7 days) .Previous researchers examined water immersion periods of (1, 3 and 7) to assess moisture damage for longer periods than standard duration [15,16]. Following the conditioning method, the two subgroups were screened for the indirect stiffness of the indirect traction device at the same velocity (50.8mm / min) and registered the largest load. The affectability of humidity is resolved as a percentage of the conditioning subsection's tensile characteristics separated by the controlling subsection's rigidity. The following is indirect tensile strength

$$ITS = \frac{2000P}{\pi t D} \qquad (3)$$

Where: ITS = indirect tensile resistance, kPa, P = peak load, N, t = height of the test, mm, and D = sample diameter, mm. Then the percentage of tensile strength is as follows**:**

$$TSR = \left(\frac{S_2}{S_1}\right) \times 100 \qquad (4)$$

Where:

TSR: tensile strength ratio, percent ,S 2 = conditioned subset average tensile strength, kPa, and, S 1= dry subset average tensile strength, kPa.

From Figures 12, by increasing the SBS polymer content, the "indirect tensile strength" of the unconditioned and conditioned sample increases. The" indirect tensile strength" ratio is shown in Figure 13. The loss in ITS for mixtures containing SBS may be obviously noted to be smaller than mixtures without SBS.

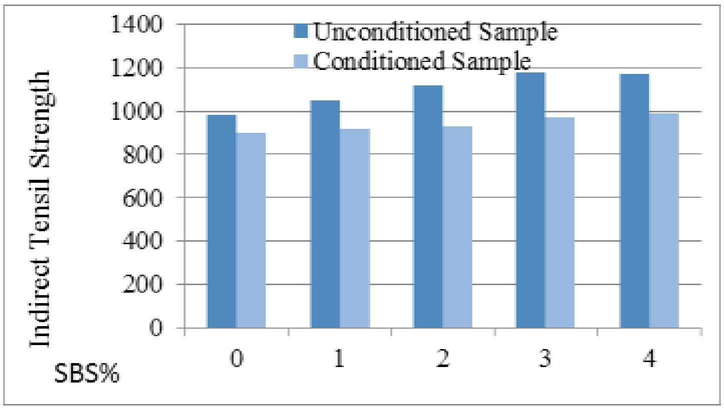

Figure 12: The indirect tensile strength Increased with increased SBS for the unconditioned of the sample and the conditioned sample

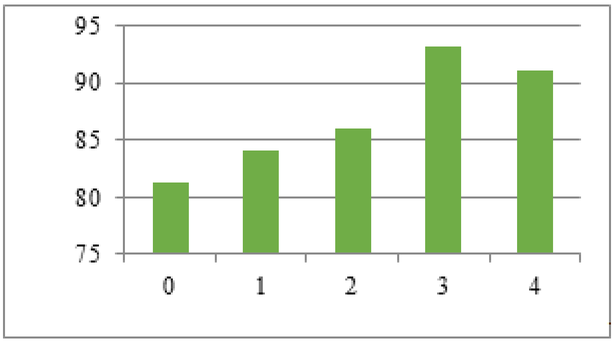

Figure 13: The percentage of indirect tensile strength

IV. Retained Marshall Stability (RMS)

Retained Marshall Stability is expressed as a percentage and is defined in terms of the Marshall stability of the composition after an immersion process in specified conditions (as explained later) as a percentage of the initial (absolute) Marshall composition Stability. The values for the RMS (ASTM D 1075) were as follows:

$$RMS = (Si/So) * 100 \quad (5)$$

Where: RMS = Retained Marshall Stability (percentage), Si = maximum time series conditioned stability and S_o = maximum unconditional stability set (0 days).The results for this test are shown in Figure 14. As shown the RMS value, the loss in RMS for mixtures containing SBS may be obviously noted to be smaller than mixtures without SBS. Due to the effect of water or vapor moisture on the asphalt mixture led to reduce retained Marshall Stability.

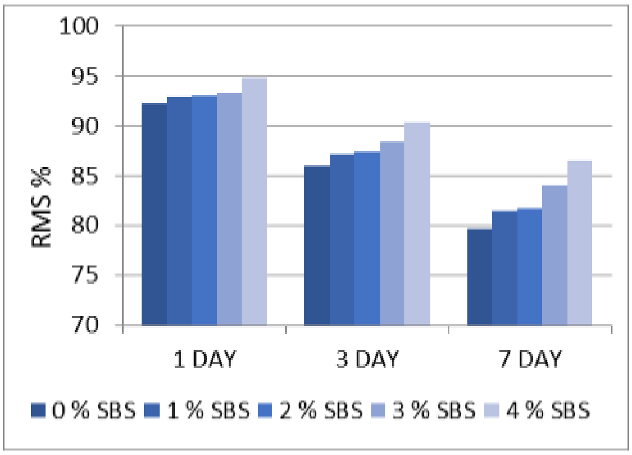

Figure 14: RMS versus SBS polymer content at different day's immersion periods

V. Durability Index (DI)

In this research, when Marshall is tested, the formula used to calculate the durability index is accepted. From the equation below (Putri and Suparma, 2010), the durability index is calculated

$$\mathrm{DI} = [\frac{1}{2tn}] \sum_{t=0}^{n-1} (S_i - S_{i+1} * 2\,tn - (t_{i+1} - t) \quad (6)$$

Where: $Si + 1 =$ percent retained power at time $ti + 1$, Si= percent retained strength at time ti, and $ti + 1$ immersion moment (calculated from the beginning of the test) in days.

The durability index is described as average region of failure of power between the curves of durability. Figure 15 demonstrates the importance of the DI, it can be obviously noted that the DI decline with an increase in SBS content.

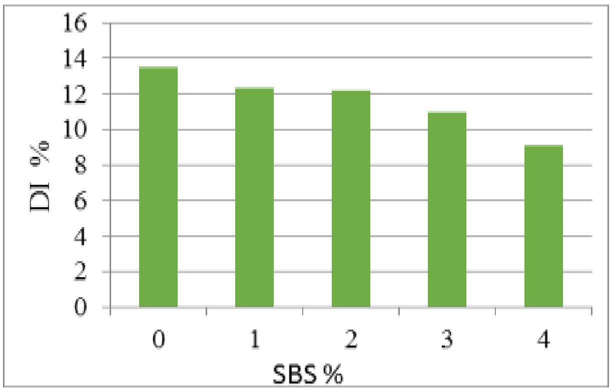

Figure 15: Durability index (DI) versus SBS polymer content.

VI. Wheel Tracking Test

The most popular test method for measuring permanent deformation is tire tracking test. In this research, at the National Center for Construction Laboratories (NCCL), compacted asphalt plates were prepared at air voids equivalent to (4%) using roller compactor equipment in compliance with EN 12697-22:2003 [21]. The slabs used in this study are (400mm × 300mm× 40mm). After 10000 cycles, the rut depth was measured and the test temperature was 50 ° C. The Pavement Wheel Tracker is an instrument that simulates highway conditions to test asphalt mixing rutting. The experiment provides information on the rate of permanent deformation from a moving, concentrated load. A Linear Variable Displacement Transducer (LVDT) is used to assess the deformation of the specimen. The heavy wheel uses about 700 N (157 pounds) of a load at points of contact and constantly goes over most of the specimen for up to 10,000 cycles [22]. The wheel-tracking device is designed to allow the test specimen to be transferred forward and backward in a specified horizontal direction under the charged wheel in its trajectory. The tire track's center line is (5.0 mm) from the specimen's theoretical center. The center of the friction coefficient of the tire is defined in an easy rhythmic movement concerning the middle of the upper surface of the test specimen with a complete travel range of (230±10) mm and a constant load frequency of (26.5±1.0) Voltage periods per minute in approximately 10,000 load cycles or an optimum deformity of 20 mm allowed for the test device. The study design for perpetual deformation test is a complete factory to one asphalt content, five polymers content (SBS) and one warm mixed asphalt pavement compaction temperature. The necessary mineral filler or Limestone is appended depending on the gradation criteria. The aggregate has been mixed in a mixing bowl (9700 g for plate specimen) and heated to the mixing humidity before mixing with the heated asphalt of each binder [23]. The compacted specimens were cooled at ambient temperature for 24 hours, 300 mm wide, (400 mm) deep and (40 mm) high. The specimens are placed in shape for testing and then placed on the carriage table of the wheel track device (WTD). The samples in the mold were labeled with information of the mixture type .This enables adequate travel to measure the formation of the track on the specimen. In the machine, the necessary test data was entered. Once the number of necessary passes is reached or the highest permissible rut depth is attained, the test unit finishes the experiment automatically. If the maximum allowable deformation is achieved until 20,000, the wheel will be removed from the unsuccessful sample .The arm

automatically returns to its top place by the end of the experiment, while the machine screen shows the test results that can be stored in the archives and/or moved to the outside.
Adding the SBS to the mix enhanced the strength of the tire tracking to regard to the asphalt source blend. Rut depth for control mixture was (7.57 mm). Rut depth is gradually decreased by (6%), (14%) and (32.5%) for original mixture at (1,2 and 3 %) SBS respectively at 50ºC testing temperature After 10000 cycles. On the other hand , the rut depth outcomes for 4% SBS were reduced (22%) for the initial blend. This relates to adding HMA mixture SBS that enhanced the rutting resistance for the blend. The HMA mixtures become more rigid and are therefore more resistant to permanent deformation as Described in Figure 16.

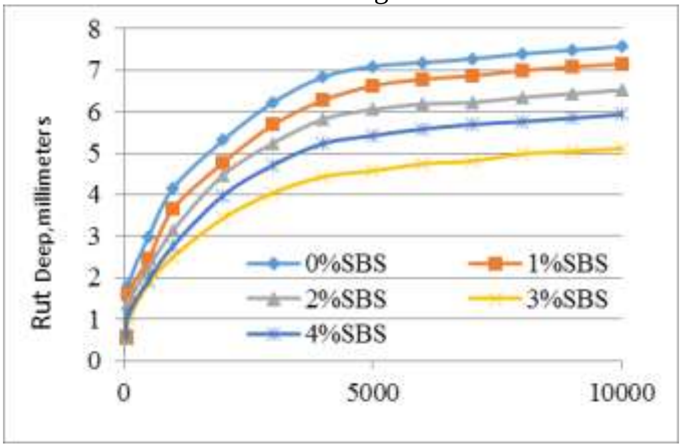

Figure 16: The rut depth versus SBS content.

4. Conclusions

In this study, the mechanical properties and dampness induced damage performing of gap sorted mixture with SBS polymer–modified asphalt mixtures have been assessed to define the resisting of SMA paving blends. The subsequent findings depend on concentrated investigational effort:

1. Addition SBS polymer to paving blend is important, as SBS has improved its moisture -induced damage resisting because of better elasticity provided via the particles of SBS.
2. The addendum of the SBS polymer to SMA mixture has clearly improved the Marshall stability by about 27.3% from original mixtures with 3% SBS polymer content.
3. From the experimental results of the three percentages (1%,2%, 3% and 4%) of SBS polymer for gap graded modified mixture, it can be concluded that 3% of SBS content gave the best results Compared with the rest of the proportions due to its improvement of mechanical properties of the mixture compared with the control mixture. due to its improvement of mechanical properties of the mixture compared with the control mixture.
4. Thus, the addition of SBS polymer to the asphalt binder in gap graded asphalt mixture has significantly make better the cohesion as well as adhesion properties of the binder, and hence the performance of the mix to moisture _induce damage.
5. The addition of the SBS polymer to the (SMA) mixture has clearly improved the permanent deformation where the best performance was clear in %3 SBS content.
6. From the experimental results of the percentages (1, 2, 3 and 4 %) SBS, it can be concluded that %3 of SBS content for modified mixture gave the best results for rutting performance resistance which is (5.11mm). While for modified mixture, 1% of SBS content gave the worst performance which is (7.15 mm).). It can be concluded that binder modified with SBS polymer makes the mixture stiffer than unmodified asphalt binder.

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