INFLUENCE OF STYRENE BUTADIENE RUBBER ON THE MECHANICAL PROPERTIES OF ASPHALT CONCRETE MIXTURES

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ABSTRACT

Asphalt binder, is a thermoplastic liquid, which behaves as an elastic solid at low service temperatures or during rapid loading. At high temperature or slow loading, it behaves as a viscous liquid. This classical dichotomy creates a need to improve the performance of an asphalt binder to minimize the stress cracking that occurs at low temperatures (fatigue) and the plastic deformation at high temperatures (rutting). Use of polymer-modified asphalt binder is one of the solutions to meet the required performance standards for the pavements of today. It appears to be a logical, practical, and economical approach.

In this research an investigation was made to evaluate the influence of asphalt cement modifier on the mechanical properties of asphalt concrete mixtures. The conventional asphalt cement of penetration grade 40-50 was used within this work, modified with styrene butadiene rubber (SBR) at five different modification levels namely 0%, 1%, 3%, 5% and 7% by weight of asphalt cement. Asphalt concrete mixes were prepared at selected optimum asphalt content (4.7%) and then tested to evaluate their mechanical properties which include resilient modulus, permanent deformation and fatigue characteristics in addition to Marshall Properties. The mechanical properties have been evaluated using uniaxial repeated loading and repeated flexural beam tests.

From the experimental results, it can be concluded that the mixes modified with SBR polymer have shown an improved fatigue and permanent deformation characteristics as well as superior elastic properties as a characterized via resilient modulus.

The use of 3 percent SBR has added to local knowledge the ability to produce more durable asphalt concrete mixtures with better serviceability.

KEYWORDS: Asphalt concrete, Styrene butadiene rubber (SBR), Fatigue, Permanent deformation, Resilient modulus.

تاتير استخدام اللدائن نوع SBR على الخصائص الميكانيكيه لخلطات الخرسانه الإسفلتيه

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الخلاصه:

يعتبر الإسفلت من المواد المتغيرة بالحرارة .عند درجة الحرارة المنخفضة يكون سلوكه اشبه بالمواد الصلبة المرنة بينما يكون اشبه بالموائع اللزجة عند درجة الحرارة العالية .هذه الخاصية المزدوجة جعلت من الإسفلت مادة غير متزنة حراريًا مما يزيد بعض المشاكل المصاحبة لاستخدامه في رصف الطرق مثل، التشققات عند درجة الحرارة المنخفضة، والتخدد عند درجة الحرارة العالية، مما خلق الحاجة لتحسين خواص الإسفلت للتقليل من اثر تلك المشاكل .احد هذه الطرق المستخدمة لتحسين خواص الإسفلت هي إضافة اللدائن والذي يعتبر SBR واحد من انواعها.

لقد تم في هذه الدراسة تقييم الخصائص الميكانيكية لخلطات الخرسانة الإسفلتية والتي تحوي على نسب مختلفة من SBR وهذه النسب هي (٠ ، ١ ، ٣ ، ٥ و ٧ % من وزن الإسفلت)،فقد تم إجراء فحوصات مارشال ،الحمل المحوري المتكرر وكذلك فحص الانحناء المتكرر للنماذج المختبرية والتي اعدت باستخدام نسبة إسفلت مقدارها (٤.٧٠) لتقييم الخصائص المتعلقة بخصائص مارشال ومعامل المرونة الاستردادي، التشوهات الدائمة وكذلك خاصية الكلل. لقد بينت النتائج بان استخدام SBR يحسن إلى حد كبير خصائص الاداء المتعلقة بمعامل المرونة الاستردادي ومقاومة التشوهات الدائمة والكلل. إن استخدام نسبة ٣% من SBR كمادة مضافة ممكن إن تضيف إلى الخبرة المحلية في هذا المجال بانه من الممكن إنتاج خرسانة إسفلتية لإغراض التبليط تمتاز بديمومة افضل ومستوى خدمة اعلى.

1-INTRODUCTION

It is important to understand the mechanism of complex behaviors of asphalt concrete mixtures in the field of improving the pavement mechanical performance. Aggregate gradation and asphalt cement are two key factors that influence the engineering properties of asphalt concrete mixtures; essentially the asphalt binder is the component that determines the mix viscous behavior and consists of asphalt cement and modifier. Many research works suggest that a specified polymer is a promising modifier to improve the asphalt binder properties and hence to develop the mixture viscoelastic properties.

The use of polymer modified bitumen (PMB) to achieve better pavement performance has been studied for a long time. The properties of PMB are dependent on the polymer characteristics and content as well as the bitumen nature. Polymer that used to modify bitumen for road applications is divided to two main basic type, plastomers and elastomers. Plastomers such as Polyvinyl chloride (PVC), Ethyl-vinyl-acetate (EVA) and Ethylene propylene (EPDM) are typically used to modify bitumen by forming a tough, rigid, three-dimensional network to resist deformation. Elastomers such as styrene butadiene rubber (SBR) and styrene butadiene styrene (SBS) have a characteristically high elastic response and, therefore, resist permanent deformation by stretching and recovering their initial shape, also it exhibit increased tensile strength with elongation and have the ability to recover to the initial condition after an applied load is removed.

SBR latex has been widely used as a binder modifier. An Engineering Brief from 1987 available at the US Federal Aviation Administration website (**Bates, 1987**)(6) describes some of the benefits of SBR modified asphalt in improving the properties of asphalt concrete pavement. Low-temperature ductility is improved, viscosity is increased, elastic recovery is improved, adhesive and cohesive properties of the pavement are improved. In view of this, the necessity for the use of SBR to improve the performance of local asphalt concrete performance has been arising. With this purpose in mind, the primary objective of this study is to evaluate the mechanical properties of asphalt concrete mixtures containing SBR polymer based on the following tests, Marshall properties (Mix design parameters), uniaxial repeated load test (Resilient modulus and permanent deformation) and repeated flexural beam test (Fatigue characteristics).

2- LITERATURE REVIEW

(**Xicheng, 1995**)(12) investigated the permanent deformation behavior of unmodified asphalt concrete mixtures as compared to the behavior of asphalt concrete mixtures modified with polyethylene. The polyethylene modified mixtures exhibit higher resistance to rutting than the unmodified ones. In addition the layer coefficients of the polyethylene-modified mixtures were 75-85% higher than the layer coefficients of the unmodified ones. The dynamic stiffness modulus, fatigue resistance, and creep resistance of the mixtures were evaluated. The results showed that all the polymer-modified mixtures performed better than the unmodified ones. The polyethylene binder-rich mixtures are superior to binder-rich unmodified mixtures in their rutting resistance, immunity to densification, and resistance to fracture.

(**Awanti, 2008**)(5) presented the laboratory investigations carried out to determine the various engineering properties such as physical properties of asphalt cement and (polymer modified asphalt binder) PMAB with (styrene-butadiene-styrene triblock copolymer) SBS, he concluded that:

a- The temperature susceptibility of PMAB-SBS is lower than asphalt cement.

b- Marshal stability and flow of PMAC mix are higher than compared to AC mix at optimum binder content.

c- The static indirect tensile strength values for PMAC mixes were higher compared to AC mixes at different temperatures.

d- Moisture susceptibility of PMAC mixes is low when compared to AC mixes.

(**Al-Hadidy, 2010**)(3) studied the properties of modified asphalt binders and stone mastic asphalt concrete (SMAC) containing such as asphalt binders and made a comparison with asphalt cement. They used a mechanistic-empirical design approach for estimating the improvement in service life of the pavement or reduction in thickness of SMAC and base layer for the same service life due to modification the SMAC. They showed that the performance of SBS-modified SMAC is slightly better when compared to starch-modified SMAC. Also the pavement consisting of SBS and starch-modified SMAC as a surface layer is beneficial in reducing the construction materials.

(**Reynaldo, 2005**)(9) used both styrene butadiene styrene (SBS) and Ground Tire Rubber (GTR) as a modifier, they found that the SBS-polymer reduced the rate of micro-damage development and consequently increased the number of load repetitions required for crack initiation. This is consistent with the lower m-value determination for the modified mixtures. The normalized resilient deformation prior to crack initiation was about the same for modified or unmodified mixtures because the failure limits (fracture energy, dissipated creep strain energy to failure) were relatively unaffected by the SBS modifier. The relative effect of SBS modifier was increased at higher binder contents temperatures.

3- MATERIAL CHARACTERIZATION

Asphalt cement, aggregate, and filler used in this work have been characterized using routine type of tests and the results were compared with State Corporation for Roads and Bridges specifications (SCRB, R/9 2003)(10). One type of electrometric polymer which was Styrene Butadiene Rubber (SBR) has been used as an additive for asphalt cement. A photograph for this additive is shown in **figure (1)**.

3-1 Asphalt Cement

The asphalt cement used in this work is 40-50 penetration grades. It was obtained from the Dora refinery, south-west of Baghdad. The asphalt properties are shown in **Table (1)**.

3-2 Aggregate

The aggregate used in this work was crushed quartz obtained from Amanat Baghdad asphalt concrete mix plant located in Taji, north of Baghdad, its source is Al-Nibaie quarry. This type of aggregate is widely used in Baghdad city for asphaltic mixes. The coarse and fine aggregates used in this work were sieved and recombined in the proper proportions to meet the wearing course gradation as required by SCRB specification (**SCRB, R/9 2003**)(10). The aggregate gradation properties are presented in **table (2)** and gradation curve is shown in **Figure (2)**.

Routine tests were 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 (3)**. Tests results show that the chosen aggregate met the SCRB specifications.

3-3 Filler

The filler is non plastic materials that pass sieve No.200 (0.075mm). Mineral filler used in this work is limestone dust obtained from Ammanat Baghdad asphalt concrete mix plant; its source is the lime factory in Kerbala governorate. The chemical composition and physical properties of the used filler is presented in Table (4).

4- EXPERIMENTAL WORK

The experimental work was started by the selection of 4.7 percent optimum asphalt content for control mix and used in all other SBR modified mixes to maintain consistency throughout the research. To investigate the effect of SBR on the asphalt cement, Asphalt binder (asphalt cement and SBR mixes) were prepared and tested using the conventional binder tests, penetration and softening point. The test results were used in the calculation of penetration index to evaluate the effect of SBR on the temperature susceptibility of asphalt cement. Also, asphalt concrete mixes were made using 0, 1, 3, 5 and 7 percent SBR by weight of asphalt cement and tested to evaluate the Marshall properties as well as the mechanical properties which include resilient modulus, permanent deformation and fatigue characteristics. The mechanical properties have been evaluated using uniaxial repeated loading and repeated flexural beam tests.

4-1 Conventional Binder Test

To investigate the effect of SBR upon the asphalt cement, the penetration as well as softening point tests was conducted according the ASTM D5 and ASTM D 36, respectively. In addition, the temperature susceptibility of the modified bitumen samples has been determined in terms of penetration index (PI) using the results obtained from penetration and softening point tests. Temperature susceptibility is defined as the change in the consistency parameter as a function of temperature. A classical approach related to PI calculation has been given in the Shell Bitumen Handbook (**Whiteoak, 1990**)(11) as shown with the following equation :

$$PI = \frac{1952 - 500\ \log\ (pen_{25})\ - 20\ sp}{50\ \log\ (pen_{25}) - sp - 120} \tag{1}$$

Where:

Pen $_{25}$ = penetration at 25°C
Sp= softening point, °C

4-2 Marshall Properties

For each percentage of SBR content, Marshall specimens were prepared according to the Marshall method as outlined in AI’s manual series No.2(**AI,1981**)(2) using 75 blows (**SCRB, R/9 2003**) (10) of the automatic Marshall compactor on each side of specimen. The specimens were evaluated for Marshall Stability, flow value, density, percent air voids (AV) and percent voids in mineral aggregate (VMA).

4-3 Uniaxial Repeated Loading Test

The uniaxial repeated loading tests were conducted for cylindrical specimens, 101.6 mm (4 inch) in diameter and 203.2 mm (8 inch) in height, using the pneumatic repeated load system (shown below

in **fig.(3)**). In these tests, repetitive compressive loading with a stress level of 20 psi was applied in the form of rectangular wave with a constant loading frequency of 1 Hz (0.1 sec. load duration and 0.9 sec. rest period) and the axial permanent deformation was measured under the different loading repetitions. All the uniaxial repeated loading tests were conducted at 40°C (104°F). The specimen preparation method for this test can be found elsewhere (**Albayati, 2006**)(9).
The permanent strain (εp) is calculated by applying the following equation:

$$\varepsilon_p = \frac{p_d \times 10^6}{h} \tag{2}$$

Where:

εp= axial permanent microstrain
pd= axial permanent deformation
h= specimen height

Also, throughout this test the resilient deflection is measured at the load repetition of 50 to 100, and the resilient strain (εr) and resilient modulus (M_R) are calculated as follows:

$$\varepsilon_r = \frac{r_d \times 10^6}{h} \tag{3}$$

$$M_R = \frac{\sigma}{\varepsilon_r} \tag{4}$$

Where:

εr= axial resilient microstrain
rd= axial resilient deflection
h= specimen height
M_R= Resilient modulus
σ = repeated axial stress
εr= axial resilient strain

The permanent deformation test results for this study are represented by the linear log-log relationship between the number of load repetitions and the permanent microstrain with the form shown in Eq.5 below which is originally suggested by (Monismith,1975)(8) and (Barksdale,1972)(7).

$$\varepsilon_p = aN^b \tag{5}$$

Where :

ε_p= permanent strain
N=number of stress applications
a= intercept coefficient
b= slope coefficient

4-4 Flexural Beam Fatigue Test

Within this study, third-point flexural fatigue bending test was adopted to evaluate the fatigue performance of asphalt concrete mixtures using the pneumatic repeated load system, this test was performed in stress controlled mode with flexural stress level varying from 5 to 30 psi applied at frequency of 2 Hz with 0.1 sec loading and 0.4 sec unloading times and in rectangular waveform shape. All tests were conducted as specified in SHRP standards at 20°C (68°F) on beam specimens 76 mm (3 in) x 76 mm (3 in) x 381 mm (15 in) prepared according to the method described in (**Alkhashab,2009**)(4). In the fatigue test, the initial tensile strain of each test has been determined at the 50th repetition by using (Eq.6) shown below and the initial strain was plotted versus the number of repetition to failure on log scales, collapse of the beam was defined as failure, the plot can be approximated by a straight line and has the form shown below in (Eq. 7).

$$\varepsilon_t = \frac{\sigma}{Es} = \frac{12h\Delta}{3L^2 - 4a^2} \quad (6)$$

$$N_f = k_1(\varepsilon_t)^{-k2} \quad (7)$$

Where:

ε_t = Initial tensile strain
σ =Extreme flexural stress
Es =Stiffness modulus based on center deflection.
h =Height of the beam
Δ =Dynamic deflection at the center of the beam.
L = Length of span between supports.
a =Distance from support to the load point (L/3)
N_f = Number of repetitions to failure
k_1 = fatigue constant, value of N_f when ε_t = 1
k_2 = inverse slope of the straight line in the logarithmic relationship

5- RESULTS AND DISCUSSION

5-1 Effect of SBR on Asphalt Binder

The experimental results for the effect of SBR content on the asphalt binder properties are listed in **table (5)**, from this table the following points can be noticed:

- A slight decrease in penetration value was obtained with increasing SBR content as shown in **fig (4)**. The reduction in penetration ranged from (48) to (35) for an increment in the SBR content from (0%) to (7%). The modification also reduces temperature susceptibility of the bitumens, as indicated by increased penetration index (PI) as exhibited in **fig(6)**
- The results of softening point are shown in **fig (5)**. It can be seen that the highest softening point for the modified binder occurred at SBR content of (7%) which was (57.3 ºC) compared to the conventional asphalt cement (0%) SBR which was (48 ºC).
- The improvements of the above examined properties of the modified binder can be attributed to the distribution of fine SBR in the base asphalt which led to stiffening of the blend. This reflects the decrease in the penetration value and increase in softening point. The best improvements were obtained at (7%) SBR content.

5-2 Effect of SBR on Asphalt Concrete Mixture Properties

Results were listed in **table (6)** and presented in **fig.(7)** , from this table the following points can be concluded:

- Marshall Stability value of the modified asphalt mixes is higher than that of the conventional asphalt mix. Asphalt mix modified with (7%) SBR has higher stability value by (18%) than the conventional mix (0%) SBR.
- The modified asphalt binders produced mixes with higher flow values by (36%) at (7%) SBR in comparison with that of the conventional mix. Also the mix density increased slightly with increasing the SBR content.
- As demonstrated in plot "d", the trend observed for the effect of SBR content on air voids values is exactly opposite to that observed between SBR content and density , for SBR content ranged from 0 to 7 percent, the air voids decreases with a rate of -0.092 percent for each 1 percent change in SBR content. the effect of SBR content on voids in mineral aggregate (VMA) is exhibited in plot "e" , as its clear from the plot the VMA decreases as the SBR content increases which means the increment in SBR content resulted in less spaces to be accommodated by asphalt binder.

5-3 Effect of SBR on Resilient Modulus M_R

Table (7) and **Fig (8)** show the values of M_R for the mixtures with different SBR contents. The results indicate that the polymer modifier has a remarkable effect on the M_R values since the M_R increased by 19 percent with increasing SBR content from 0 percent to 7 percent. After careful consideration, it was realized that the above findings are in agreement with the basic of strength of materials and asphalt theology phenomena, when axial pulsating load is applied on the specimen, tensile stresses are developed in the horizontal direction at the mid depth plane of the specimen, since the SBR has an improved elastic recovery therefore the modified asphalt concrete mixtures show higher resilient modulus value as the SBR content become higher.

5-4 Effect of SBR on Permanent Deformation

Based on the data shown in **Table (8)** and **figure (9)**, it appears that the examined SBR contents have influence on the plastic response of the material as characterized by the intercept and slope values. The lowest value for the plastic strain accumulation with load repetitions (slope) is associated with the SBR content of 3 percent (0.305). Also the SBR content of 3 percent showed the lowest intercept value of 90 microstrains. Further increases in SBR content beyond 3 percent will lead to increases in slope as well as intercept values since the mixes offer more flexibility.

5-5 Effect of SBR on Flexural Fatigue

For the 40-50 penetration grade asphalt cement used in this study, SBR significantly affect the number of cycles to failure N_F and provide an increased level of protection against cracking due to repetitive loading. This is due to the elastic effect of SBR on the asphalt binder as mentioned above. Fatigue cracking coefficient (k_1) and exponent (k2) are presented in **table (9)** for the conventional mix and mixes with 1, 3, 5 and 7 percent SBR content.

Values of k_1 and k_2 can be used as indicators of the effects of SBR on the fatigue characteristics of a paving mixture. The flatter the slope of the fatigue curve, the larger the value of k_2 which indicates a potential for longer fatigue life. On the other hand, a lower k_1 value represents a shorter fatigue life. As can be seen from **Fig (10)** as the SBR content increase the k_2 value increases and the k_1 value decreases. These results highlight the improvement in fatigue resistance for mixes with high content of SBR. The fatigue life could reach the level of more than 83000 cycles for asphalt mix modified with 7% SBR and 40000 cycles for conventional asphalt mix, with an increase of 78% in N_F.

6- CONCLUSIONS AND RECOMMENDATIONS

Within the limitations of materials and testing program used in this work, the following principal conclusions are made based on the findings of the investigations:

1- SBR modification causes an increase in binder consistency (decrease in penetration and increase in softening point). The modification also reduces temperature susceptibility of the bitumen's, as indicated by increased penetration index.

2- In comparison to conventional mixes with 0 percent SBR Content, Asphalt concrete mixes modified with 7 percent SBR has shown an increased Marshall stability and flow at a rate of 18 and 36 percent, respectively.

3- Both air voids and voids in mineral aggregate are decreased slightly with an addition of SBR. The air voids and the voids in mineral aggregate decreases with a rate of -0.092 and -0.084 percent for each 1 percent change in SBR content, respectively.

4- The addition of SBR with a rate ranged from 1 to 7 percent has shown an improved elastic property characterized with resilient modulus, the resilient modulus for mixes contain 7 percent SBR was 1.19 times that for mixes with 0 percent SBR.

5- When 3% SBR is added as a polymer modifier, the asphalt concrete mixture displayed lower potential for permanent deformation compared to conventional mixes with 0 percent SBR. Both the

Slope and intercept values decrease 18 percent. An extra addition of SBR weakening the resistance for this type of distress.

6- Fatigue behavior of SBR modified mixes was found to be significantly improved compared to conventional mixes as determined by flexural test, the k_2 value (inverse slope of fatigue line) and N_F (fatigue life) for mixes with 7 percent SBR was more than that of 0 percent SBR by 60 and 78 percent, respectively.

7- The use of 3 percent SBR has added to local knowledge the ability to produce more durable asphalt concrete mixtures with better serviceability.

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Table (1) Properties of Asphalt Cement

Property	ASTM designation	Penetration grade 40-50	
		Test results	SCRB specification
1-Penetration at 25C,100 gm,5 sec. (0.1mm)	D-5	48	40-50
2- Rotational viscosity at 135°C (cP.s)	D4402	523	……
2- Softening Point. (°C)	D-36	48	……
3-Ductility at 25 C, 5cm/min,(cm)	D-113	>100	>100
4-Flash Point, (°C)	D-92	291	Min.232
5-Specific Gravity	D-70	1.041	……
6- Residue from thin film oven test - Retained penetration,% of original - Ductility at 25 C, 5cm/min,(cm)	D-1754 D-5 D-113	 59.0 80	 >55 >25

Table(2) : Asphalt Concrete Gradation

sieve		% passing	Weight
19	0.75	100	57.5
12.5	0.5	95	138
9.5	9.5	83	333.5
4.75	No.4	54	207
2.36	No.8	36	264.5
0.3	No.50	13	69
0.075	No.200	7	80.5

Table (3): Physical Properties of Aggregates

Property	ASTM designation	Test results	SCRB specification
Coarse aggregate			
1. Bulk specific gravity	C-127	2.614	……
2. Apparent specific gravity		2.686	……
3. Water absorption,%		0.440	……
4. Percent wear by Los Angeles abrasion ,%	C-131	18	30 Max
5. Soundness loss by sodium sulfate solution,%	C-88	3.3	10 Max
6. Fractured pieces, %		97	9٠ Min
Fine aggregate			
1. Bulk specific gravity	C-127	2.664	……
2. Apparent specific gravity		2.696	……
3. Water absorption,%		0.724	……
4. Sand equivalent,%	D-2419	57	45 Min.

Table (4): Properties of Fillers

Filler type	**Chemical Composition ,%**							**Physical Properties**		
	Cao	Sio_2	Al_2-0_3	Mgo	Fe_2o_3	So_3	L.O.I	Specific gravity	Surface area* (m^2/kg)	% Passing sieve No. 200 (0.075)
Limestone Dust	٦٨.٣	2.23	-	٠.٣٢	-	١.٢٠	٢٧.٣	2.41	٢٤٤	٩٦

***** Blain air permeability method (ASTM C204)

Table (5) Asphalt binder tests result

SBR Content (%), by weight of asphalt cement)	Penetration	Softening point , ºC	Penetration Index (PI)
0	48	48	-1.8035
1	46	49.6	-1.4876
3	43	51.5	-1.1719
5	38	55	-0.6469
7	35	57.3	-0.3393

Table(6): Marshall Test Results

SBR %	stability	flow	density	gm max	av	vma
0	8.58	3.12	2.329	2.435	4.35	15.03
1	8.79	3.25	2.331	2.435	4.27	14.95
3	9.47	3.45	2.337	2.435	4.02	14.73
5	9.66	3.76	2.342	2.435	3.82	14.55
7	10.09	4.23	2.345	2.435	3.7	14.44

Table (7) Resilient modulus test results

SBR %	M_R (psi)
0	122300
1	125400
3	132100
5	140300
7	145400

Table (8) permanent deformation Parameters

SBR %	intercept	Slope
0	110	0.372
1	115	0.345
3	90	0.305
5	135	0.31
7	145	0.36

Table (9) Fatigue test results

SBR %	0	1	3	5	7
I	3200	2800	2150	2300	1650
S	0.372	0.344	0.302	0.281	0.234
K1	1.965E-07	5.592E-08	5.482E-09	1.323E-09	2.179E-11
K2	2.688	2.907	3.311	3.559	4.274

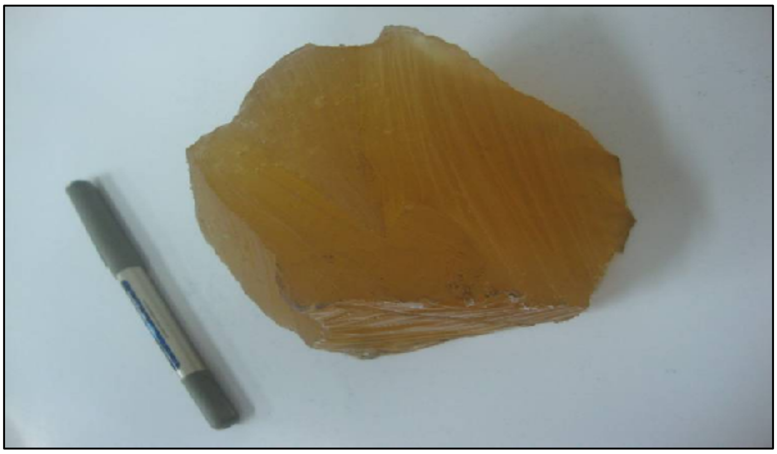
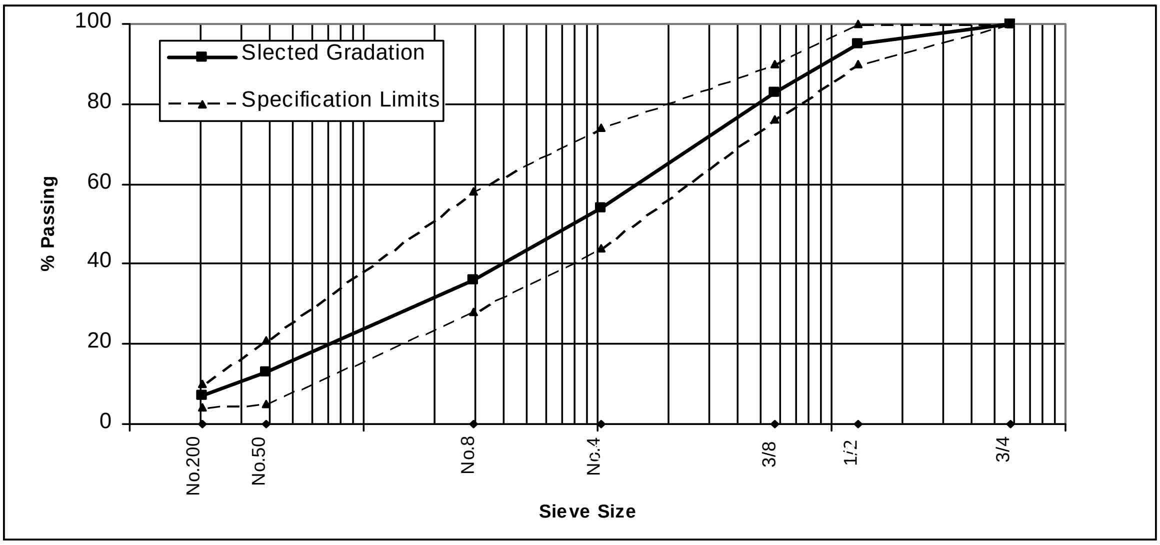


Figure (1) Photograph of SBR Polymer



Figure(2): Aggregate Gradation

Fig. (3) Photograph for the PRLS

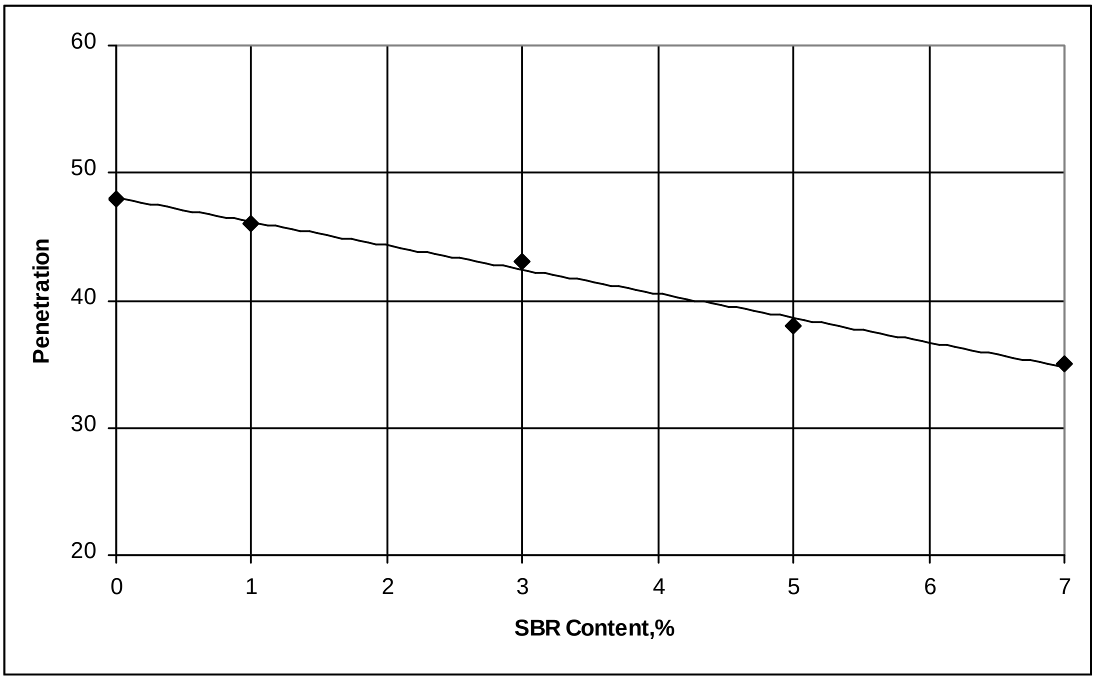


Figure (4) effect of SBR content on Penetration of Asphalt binder

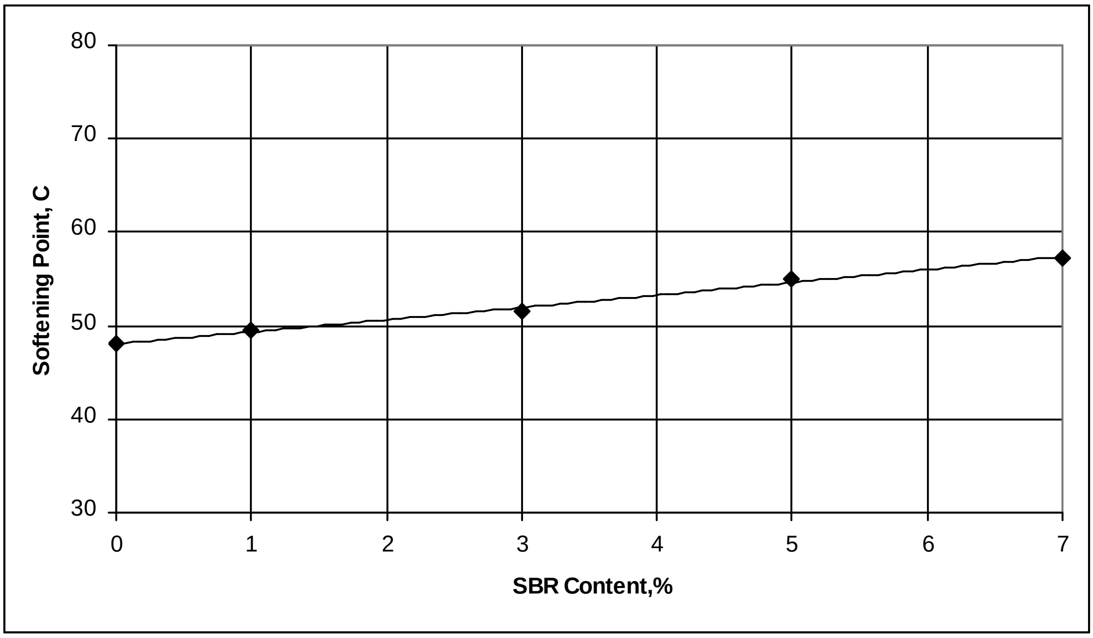


Figure (5) effect of SBR content on Softening Point of Asphalt binder

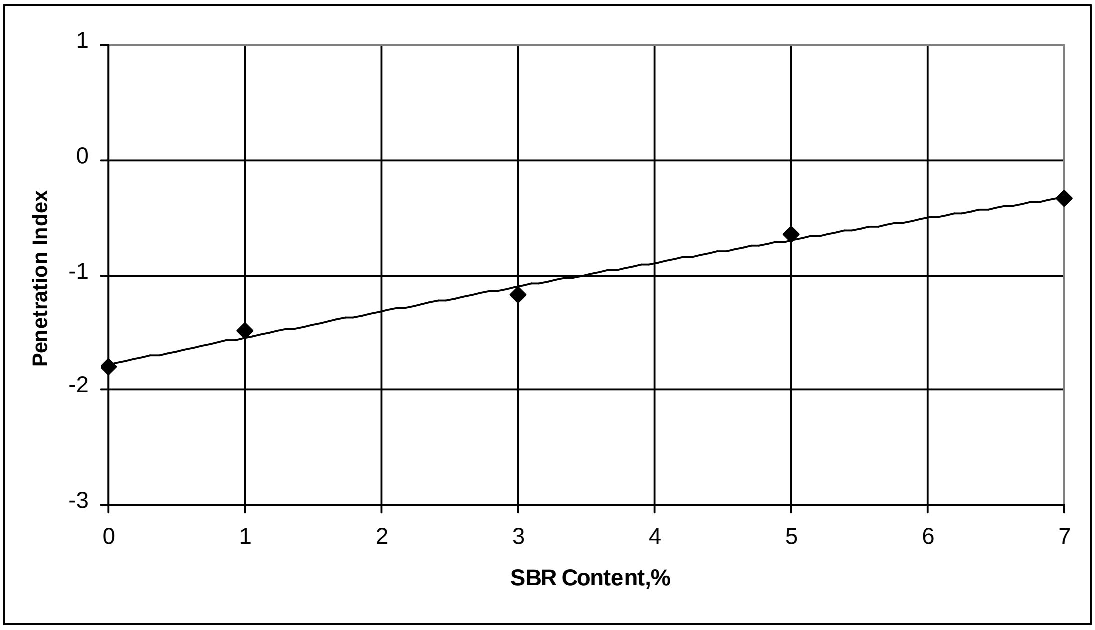
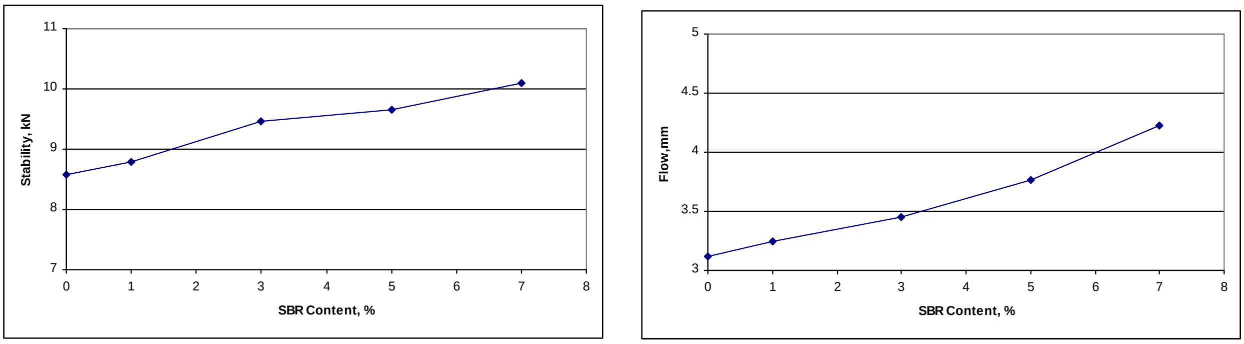
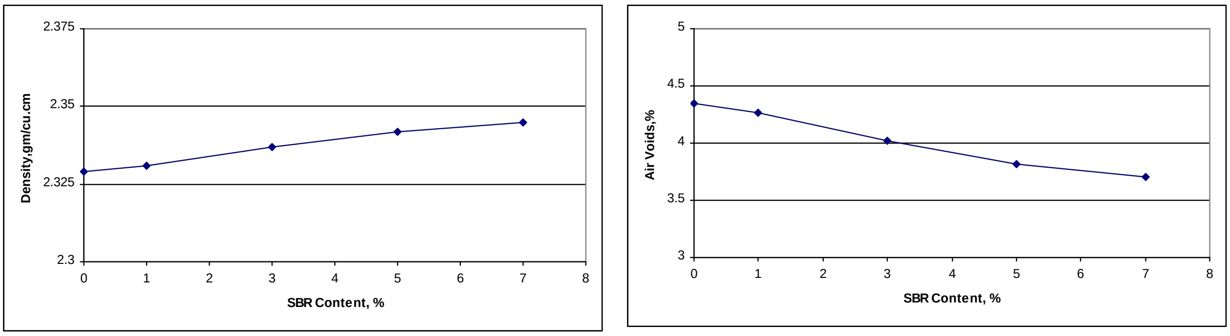


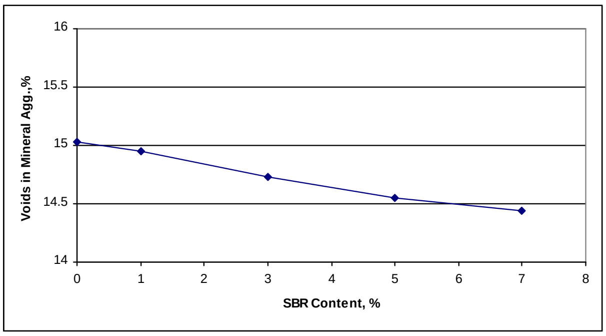
Figure (6) Effect of SBR Content on Penetration Index of Asphalt Binder



a- stability b- flow



c- density d- air void



e- voids in mineral agg.

Figure (7) Effect of SBR content on Marshall properties

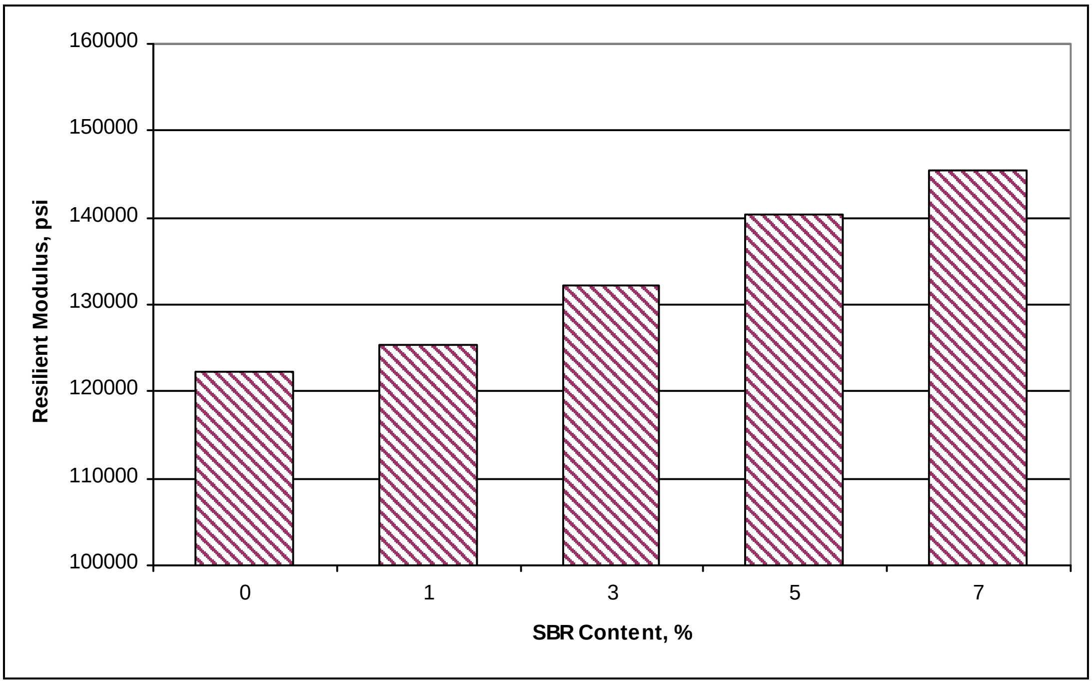


Figure (8) Effect of SBR content on resilient modulus

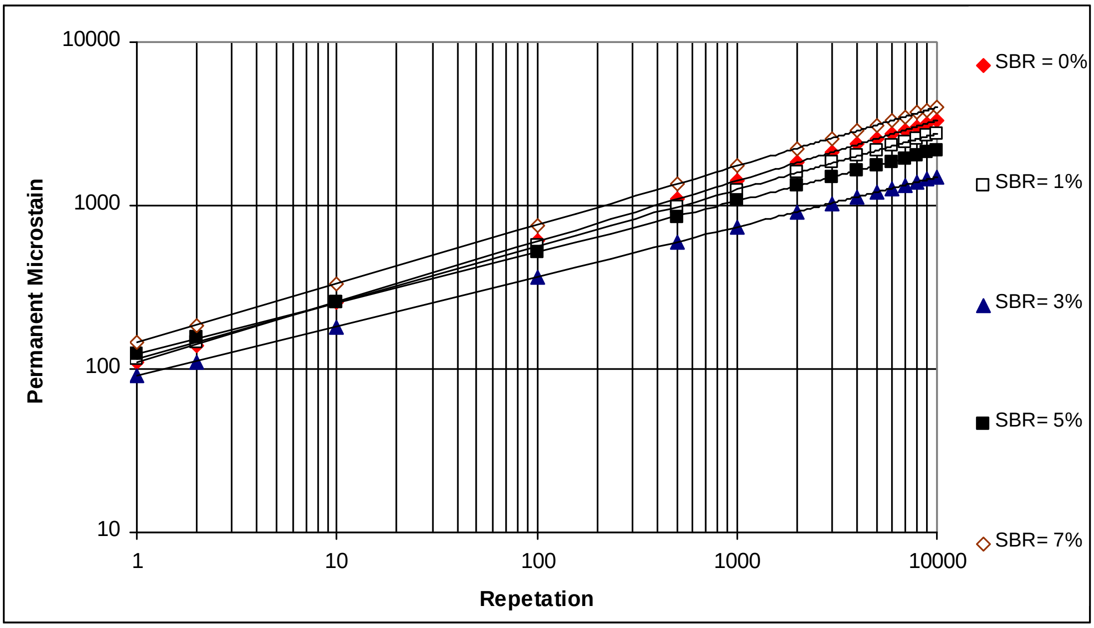


Figure (9) Effect of SBR content on Permanent Deformation

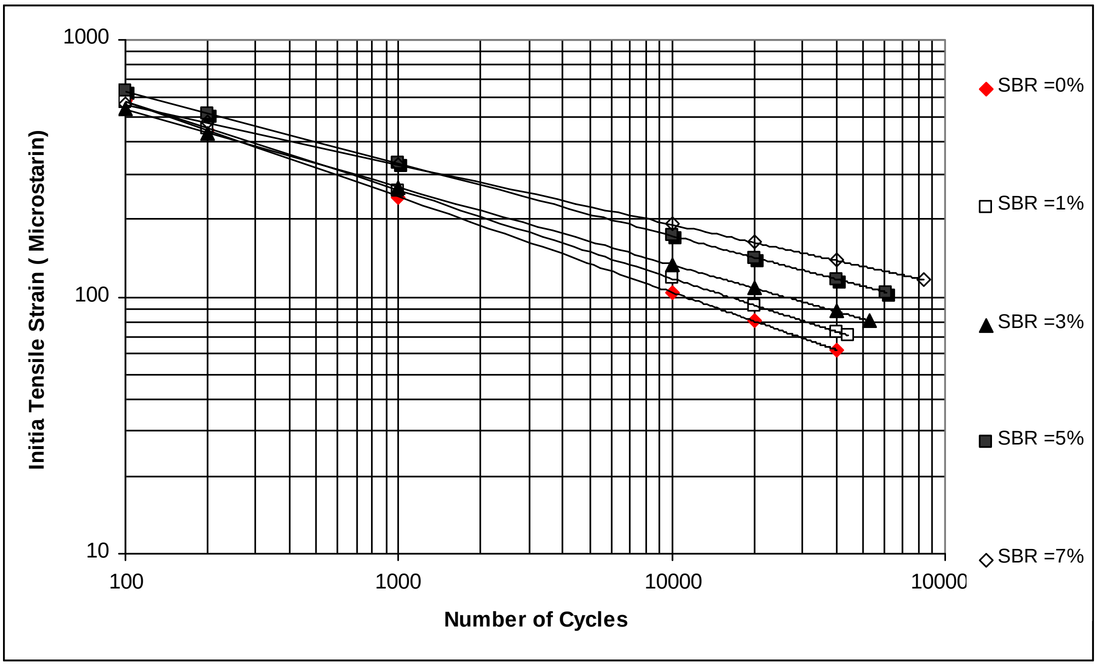


Figure (10) Effect of SBR content on fatigue performance