PERFORMANCE MODIFICATION OF SAUDI-ASPHALT BINDERS USING SABIC POLYMERS

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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 and the plastic deformation at high temperatures. 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 the Kingdom of Saudi Arabia, most of the used asphalt-polymers are imported from abroad, which led to increase the total construction cost. The main objective of this research is to modify locally produced asphalt using polymer produced by Saudi Basic Industries Company (SABIC). The study covered the asphalt binders produced by Riyadh refinery. Ten polymers were identified as potential asphalt modifiers based on their physical properties and chemical composition. Based on the preliminary laboratory evaluation for the melting point of these polymers, five polymers were selected for local asphalt modification. In the initial stage, required mixing time was decided based on the relation between shear loss modulus and mixing time. The optimum polymer content was selected based on Superpave binder performance grade specifications. The suitability of improvement was verified through the evaluation of permanent deformation and fatigue behavior of laboratory prepared asphalt concrete mixes. The results indicate that the rheological properties of the modified binders were improved significantly with sufficient polymer content (3%). They were also influenced by the type and content of the polymer. The aging properties of the modified binders were found to be dependent on the type of polymer. The fatigue life and resistance to permanent deformation were significantly improved due to the improvement in the rheological properties of the binders. In general, the research has demonstrated the potentiality of modifying local asphalts using SABIC polymers.

Keywords: *Polymer, Rheology, Modified asphalt mixtures, Fatigue, Rutting, Permanent deformation.*

الملخص

يعتبر الأسفلت من المواد المتغيرة بالحرارة. عند درجة الحرارة المنخفضة يكون سلوكه أشبه بالمواد الصلبة المرنة بينما يكون أشبه بالموائع اللازجة عند درجة الحرارة العالية. هذه الخاصية المزدوجة جعلت من الأسفلت مادة غير متزنة حرارياً مما يزيد بعض المشاكل المصاحبة لإستخدامه في رصف الطرق مثل، التشققات عند درجة الحرارة المنخفضة، والتخدد عند درجة الحرارة العالية، مما خلق الحاجة لتحسين خواص الأسفلت للتقليل من أثر تلك المشاكل. أحد هذه الطرق المستخدمة لتحسين خواص الأسفلت في المملكة هي إضافة اللدائن التى تستورد من الخارج مما يزيذ من التكلفة الكلية فى بناء الطرق. في هذه البحث تمت دراسة إمكانية إستخدام اللدائن المصنعة محليا في تحسين خواص الأسفلت، حيث شملت الدراسة عشرة أنواع من اللدائن المصنعة بواسطة الشركة السعودية للصناعات الأساسية (سابك). أظهر إختبار تحديد درجة الإنصهار أن خمسة أنواع من هذه اللدائن يمكن إستخدامها بينما أظهرت نتائج مواصفات الأداء أن اربعة أنواع من اللدائن لديها ثبات مقبول وفقا لمواصفات الخلطات المتميزة الأداء. كما أظهرت النتائج أن مقاومة الخلطات المحسنة باللدائن ضد تشققات الكلال والتخدد قد تحسن بصورة جيده. بصورة عامة، أظهرت الدراسة إمكانية إستخدام لدائن سابك لتحسين خواص الأسفلت بالمملكة العربية السعودية.

1. INTRODUCTION

The use of Polymer-Modified Asphalt (PMA) to achieve better asphalt pavement performance has been observed for a long time. The improved functional properties include permanent deformation, fatigue, low temperature cracking, stripping, wear resistance and aging. The properties of PMA are dependent on the polymer characteristics and content and bitumen nature as well as the blending process. Despite the large number of polymeric products, there are relatively few types which are suitable for bitumen modification. When used as bitumen modifiers, selected polymers should be compatible with bitumen, be capable of being processed by conventional mixing and laying equipment, and be able to maintain their premium properties during mixing, storage and application in service. The use of a modifier should also be cost-effective.

Two classes of polymers are typically used in asphalt modification, elastomers and plastomers. The relative usefulness of these polymers can vary widely. The main objective of this research is to characterize and test the fundamental properties of modified bitumens supplied by Riyadh refinery (RY), containing different thermoplastic polymers produced by SABIC. This will be achieved through the evaluation of permanent deformation and fatigue behavior of laboratory prepared asphalt mixes. The factors affecting modification will also be evaluated.

2. BACKGROUND

The concept of modifying asphalt binders and mixtures is not new. Many authors have studied the effects of mineral fillers on the behavior of asphalt (Al-Abdul Wahhab and Al-Amri, 1991; Bouldin et al., 1991; Sartori et al., 1996; Baig and Al-Abdul Wahhab, 1998). The main reason for using these fillers and some other types of modifiers is to improve the performance of paving mixture to meet requirements under prevailing conditions. Another early method of asphalt

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modification consisted of mixing two or more asphalt binders of different paving grades or sources. This technique has continued through the years and often delivers a satisfactory product. One major problem with this technique is that sometimes asphalt is not chemically compatible with each other. Compatibility cannot be predicted effectively and leads to premature pavement distresses (Anderton, 1991).

For the past two decades, significant research has been conducted on PMA mixtures. Polymers can successfully improve the performance of asphalt pavements at low, moderate and high temperatures by increasing mixture resistance to fatigue cracking, thermal cracking and permanent deformation. It was found that the rheological and engineering properties of PMA mixtures largely depend on the polymer type and content. The improvement in fatigue life and resistance to permanent deformation is mainly due to the improvement in the rheological properties of the binders (Khattak and Baladi, 2001). When an asphalt binder is subjected to cyclic load or stress, the material response to tension and compression consists of three major components: elastic, viscoelastic and plastic. The tensile plastic, i.e. permanent strain, is responsible for permanent deformation and consequently results in pavement rutting. On the other hand, a perfectly elastic material will never fail in fatigue.

In most cases, it has been found that the structure of the pure modified binder is completely different from the structure of the polymer in the asphalt-aggregate mixture (Wegan and Brule, 1999). Where a continuous network of the polymer phase could be detected in the binder, no continuous network of the polymer phase could be detected in the asphalt-aggregate mixture. This is the case with 7% Ethylene Vinyl Acetate (EVA) or Styrene Butadiene Styrene (SBS) modified binder. However, for low polymer content (3%), same structure of the polymer phase in the binder and in the asphalt-aggregate mixtures was reported. EVA seems to have an affinity for the surfaces of the aggregates. If the EVA phase, swollen by a part of the maltenes, has a higher solubility parameter compared to the asphalt phase, the EVA phase will, at equilibrium, surround the aggregate, which has many polar groups.

The compatibility and storage stability of Polymer-Modified Bitumen (PMB) were shown to be largely dependent on polymer content and were influenced by the characteristics of base bitumens and polymers. Polymer modification increased the elastic responses and dynamic module of bitumens at intermediate and high temperatures (Isacsson and Lu, 1999). It also reduced the temperature susceptibility and glass transition, and limiting stiffness temperatures of the bitumens. The degree of the improvement generally increases with polymer content, but varies with bitumen source/grade and polymer type.

From October 1987 through March 1993, the Strategic Highway Research Program (SHRP) conducted a $50 million asphalt research and developed a performance-based specifications for binder that are intended to succeed the present penetration and viscosity graded asphalt specifications. The program yielded a set of tests to measure asphalt binder properties at high, intermediate and low temperatures, and for fresh and aged conditions. These tests intend to represent 8 to 10 years of pavement service. A bimodal grading system, based on rational performance indices, was established for both low temperature and high temperature pavement service. Thus, a precise grade may be selected to accommodate for the need to control low-temperature cracking, rutting or both in a particular construction project. In addition, it will

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address certain aspects of fatigue cracking. For a given type of asphalt cement to satisfy performance criteria for a given temperature zone, it must satisfy SHRP performance tests which have to be conducted at certain designated temperatures. Details about SHRP binder specifications and testing are given in Harrigan et al., (1994). Similar work was carried out to adapt SHRP binder performance specifications for the Gulf Countries (GC) environment (Al-Abdul Wahhab et al., 1996). In this work, the GC were divided into different temperature zones and the required asphalt performance grade (PG) for each zone was specified. They concluded that the asphalt cement as used locally is only suitable for about 40 percent of the GC area, and found that the required asphalt binder PG range between 64-10 and 76-10. Different modification procedures (ranging from air blowing to polymer modification) for the different asphalt binders produced in GC need to be performed in order that these asphalt binders will be suitable for the areas they are used in (Al-Abdul Wahhab et al., 1996).

Imported polymers are used to improve local asphalt concrete mixes. Polymers are imported at high cost, while SABIC, which is one of the largest polymer producers in the world, produces very wide range of polymers. Off-spec polymers, which are considered industrial wastes, are sold at minimal cost. These polymers, if proved effective for asphalt modification, will lead to significant construction cost reduction.

3. EXPERIMENTAL DESIGN

The work in this study consists of three phases; the first phase is comprised of collection of asphalt from Riyadh refinery (RY) and potential polymers from SABIC Company. In the second phase, the use of local polymer to modify the local asphalt is evaluated based on Superpave binder performance specifications. In the third phase, polymer-modified asphalts are used in Hot Asphalt Concrete Mixture (HACM) and tested for resistance to fatigue, permanent deformation and environmental effect. Figure 1 shows schematic a flow chart of the work.

3.1. Materials

Ten different grade polymers were used in this study. These can be grouped into six main groups, linear low density polyethylene, high density polyethylene, low density polyethylene, medium density polyethylene, polypropylene and styrenic heavy waste. Table 1 shows the list of the selected polymers according to their grade.

The coarse and fine aggregates used in the asphalt mixture were obtained from Abu-Hadriyah, Eastern Province of Saudi Arabia.

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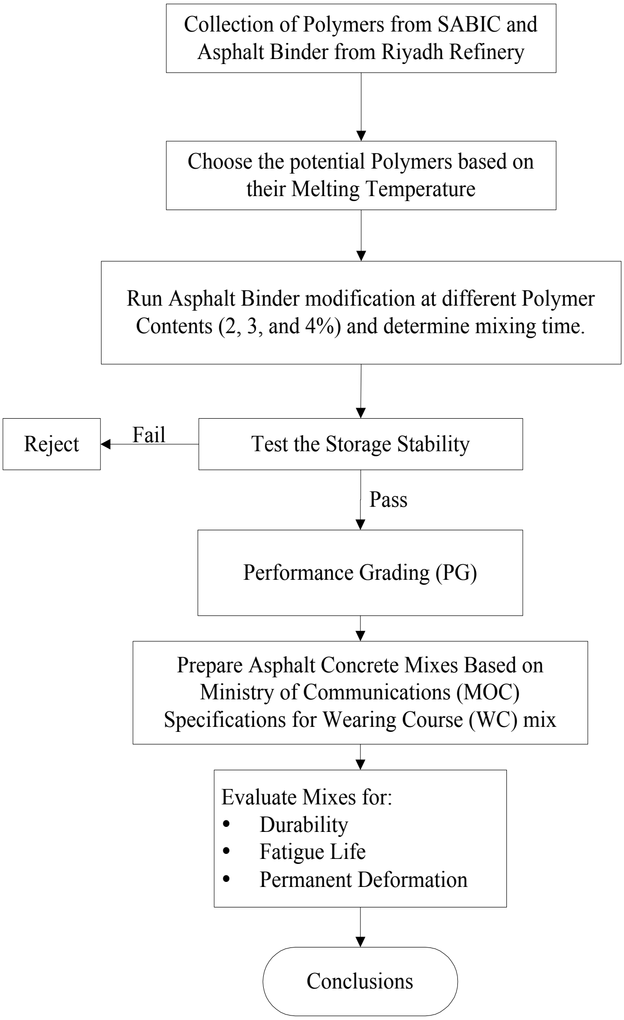

Figure 1. Schematic flow chart for work procedure

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3.2. Identification Of Potential Polymers

The first phase of the modification work focused on the identification of potential polymers. The cited literature coupled with manufacturer recommendations and melting temperatures were employed to identify the tentative polymer concentrations, blending times and blending temperature.

Based on the melting temperatures, five types of polymer from a total of ten were found to be suitable for blending with asphalt. The polymers, which have a melting temperature of more than 180°C, were rejected. Table 2 shows the list of the acceptable polymers, which have melting temperatures of less than 180°C.

Table 1. List of the selected polymers

SN	Commercial Name	Grade Name
1	Linear Low Density Polyethylene (LLDPE)	118N
2	" "	M200024
3	" "	M500026
4	High Density Polyethylene (HDPE)	F00952
5	" "	M80064
6	" "	M200056
7	Low Density Polyethylene (LDPE)	HP4023W
8	Medium Density Polyethylene (MDPE)	R50035
9	Polypropylene (PP)	500U
10	Styrenic Heavy Waste (SHW)	---

Table 2. Selected types of polymer based on melting temperatures

SN	Commercial Name	Grade Name	Code Name
1	Linear Low Density Polyethylene (LLDPE)	M500026	P5
2	Medium Density Polyethylene (MDPE)	R50035	P6
3	Linear Low Density Polyethylene (LLDPE)	M200024	P7
4	High Density Polyethylene (HDPE)	M200056	P8
5	High Density Polyethylene (HDPE)	M80064	P9

Polymers were blended with asphalt from RY; a special blender was assembled, comprising a high shear blade, a heated oil bath, and a Direct Current (DC) motor capable of producing up to 2500 revolutions per minute (rpm). Each polymer type was blended with 800 gm of asphalt binder to produce the polymer-modified asphalt binder. The quantity and concentration of each polymer were fixed to be 3, 4, and 5%.

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4. RESULTS AND DISCUSSION

4.1. Blending Time

Optimum blending time was determined by means of $G^*/\sin\delta$ at 76°C (G^* = Shear modulus; δ = Phase angle). The $G^*/\sin\delta$ was evaluated during the blending process at an interval of 30 minutes. The maximum blending time was assumed to be two hours. Figure 2 shows the typical behavior of P5-4% throughout the blending process.

4.2. Storage Stability

The storage stability of the PMA for various polymers was evaluated with reservation of the actual storage conditions in the field. The storage temperature was 160°C and stirred at a speed of 200 rpm. The storage time was fixed to be three days. Samples were taken from the top and bottom portion of the storage container at an interval of 24 hours. $G^*/\sin\delta$ at 76°C were measured to identify the storage stability and the maximum possible storage time. Table 3 shows the final results for the different types of polymers from which the following observations were found:

1. The stable blends that passed storage condition are P5, P6, P8, and P9. The stable state was determined based on the difference between the value of $G^*/\sin\delta$ at the top and bottom of the storage container. It was assumed that the sample is stable if the difference is less than or equal to 20%.

Table 3. Measured stored stability

Polymer Type	Time (hr)	$G^*/\sin\delta$ kPa		Loss %
		Top	Bottom	
P5-3%	0	1.635	1.635	0.000
	24	1.896	2.016	5.952
	48	2.543	2.896	12.189
	72	3.177	3.786	16.086
	RV after 72 hours	2436	2596	6.163
P6-3%	0	1.241	1.241	0.000
	24	1.203	1.256	4.220
	48	1.288	1.378	6.531
	72	1.639	1.811	9.498
	RV after 72 hours	2768	2808	1.425
P8-3%	0	1.219	1.219	0.000
	24	1.550	1.568	1.148
	48	2.455	2.517	2.463
	72	3.678	3.987	7.750
	RV after 72 hours	2635	2799	5.859
P9-3%	0	1.191	1.191	0.000
	24	1.973	2.011	1.890
	48	2.513	2.713	7.372
	72	3.149	3.500	10.029
	RV after 72 hours	3210	3350	4.179

RV = Rotational Viscosity

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2. In general, all asphalt polymer blends after storage exhibit an increase in *G** (top or bottom) in comparison to the freshly tested blend (unstored), which may be attributed partially to an increase in the molecular association between the polymer and the asphalt binder and partially to the aging of asphalt due to prolonged storing.
3. The Rotational Viscosity (RV) increases with the storage time. This increase in viscosity may limit the storage time in order not to get very stiff asphalt since rotational viscosity should not be more than 3000 cp. It was found that the RV of P5, P6, and P8 blends are still within the limit after 72-hour storing while it was exceeding 3000 cp in the case of P9, which indicate that the blend with P9 cannot be stored for more than 48 hours.

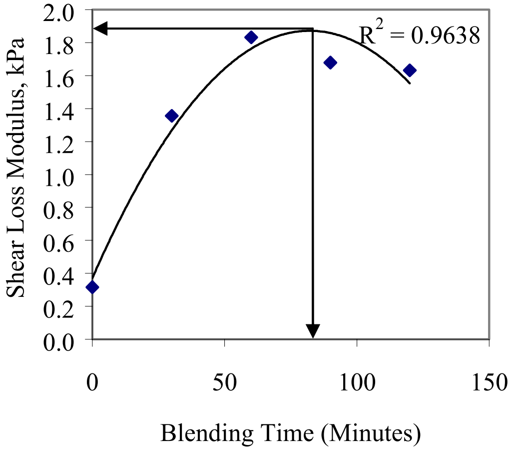

Figure 2. Determination of optimum blending time of P5-4%

4.3. Performance Grade

Based on the SHRP binder performance specifications, the final PG was determined for the selected types of polymers with RY asphalt. The polymer content is fixed to three levels (2%, 3%, and 4%). Table 4 shows the PG. It is clear that polymer modification generally has improved asphalt PG from 70-10 to 76-10 at least.

4.4. Asphalt Concrete Mix Evaluation

Asphalt concrete mix has been designed following Marshall mix design in accordance with the MOC specifications. The optimum asphalt content obtained through the Marshall mix design for wearing course is used for preparing control mix and polymer-modified asphalt concrete specimens. The standard Marshall specimens of 100 mm × 62.5 mm were prepared separately for each polymer and control mix.

The following tests were carried out in order to fully evaluate the polymer-modified mixes and to compare with control mix:

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1. Lottman test for durability (AASHTO T-283-89)
2. Resilient modulus test (ASTM D 4123)
3. Fatigue test
4. Permanent deformation (rutting test).

The results obtained for each test are discussed below.

Water sensitivity test (Lottman test AASHTO T-283-89)

This test was carried out in order to find the water susceptibility (stripping resistance) of modified and control mixes utilizing Indirect Tensile Strength (ITS). The results obtained indicate that the average percent loss in strength due to water damage is effectively reduced in P8 modified asphalt concrete mix. The percent loss in P5, P6, and P9 are less than the percent loss in the control mix but still they are higher than the recommended limit based on Superpave specification (20%). Table 5 and Figure 3 show the percent loss in the indirect tensile strength after Lottman conditioning of the samples. The results indicate significant improvement of stripping resistance of local mixes when P8 is used to modify the asphalt.

Resilient modulus test, M_R (ASTM D 4123)

Resilient modulus is the most important variable to mechanistic design approaches for pavement structures. It is the measure of pavement response in terms of dynamic stresses and corresponding strains. Polymer-modified mixes have improved the diametral resilient modulus of modified mixes as compared to the control mix. The average resilient modulus of the control mix at 25°C was found to be 547.3 ksi; this value increased to 799.8 ksi for P8. The average resilient modulus at 50°C increased from 85.0 ksi for the control mix to 369.3 ksi for P8. The other obtained results are shown in Table 6 along with Figure 4.

Table 4. PG of different polymers

Polymer Type	Polymer Content (%)	PG
RY	0	PG 70-10
P5	2	PG 70-22
	3	PG 76-16
	4	PG 82-10
P6	2	PG 76-22
	3	PG 76-16
	4	PG 76-10
P8	2	PG 76-22
	3	PG 76-22
	4	PG 82-16
P9	2	PG 76-16
	3	PG 76-10
	4	NA

Table 5. I.T.S test results

Polymer Type	Condition	Sample No.			Average	Loss%
		1	2	3		
Control	Initial I.T.S	11.10	10.42	9.23	10.25	48.8
	Final I.T.S	5.51	4.98	5.26	5.25	
P5	Initial I.T.S	15.51	16.20	15.28	15.66	28.6
	Final I.T.S	9.75	10.35	13.45	11.18	
P6	Initial I.T.S	16.00	15.60	14.20	15.27	32.7
	Final I.T.S	11.20	10.45	9.16	10.27	
P8	Initial I.T.S	13.52	12.65	12.68	12.95	16.3
	Final I.T.S	10.31	11.42	10.80	10.84	
P9	Initial I.T.S	13.56	14.17	13.21	13.65	39.9
	Final I.T.S	8.52	7.77	8.32	8.20	

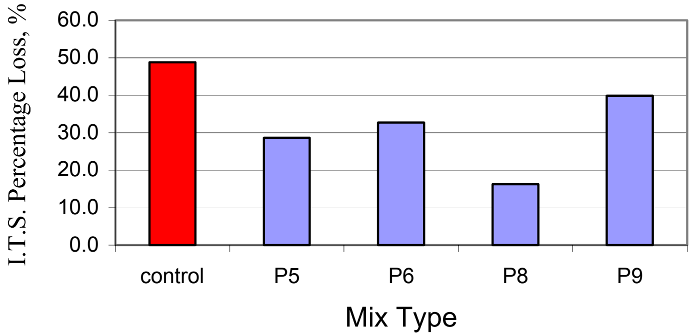

Figure 3. Lottman test results

Table 6. Resilient modulus (ksi)

Polymer Type	Temperature	
	50°C	25°C
Control	85.0	547.3
P5	171.9	576.4
P6	293.6	654.2
P8	369.3	799.8
P9	305.6	671.7

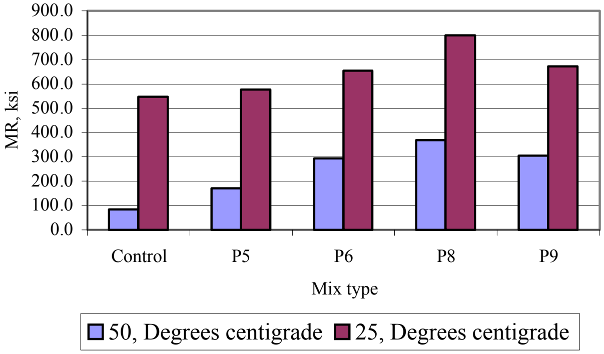

Figure 4. Comparison of M_R (ksi) at 50°C and 25°C

Fatigue performance

Diametral fatigue test results for wearing course mixes of the four polymer types (P5, P6, P8 and P9 in addition to the control mix) at testing temperatures of 25°C and 50°C are shown in Figures 5 and 6 for each polymer, 9 samples were tested for fatigue (3 at each strain level); regression lines were then drawn through the mean of samples at each strain level. The results show a normal linear relationship between the logarithm of applied initial tensile strain and the logarithm of fatigue life (number of applied load repetitions until failure). The fatigue data were analyzed by running a regression analysis to determine the fatigue relationship parameters in the following form:

$$\varepsilon_t = I * (N_f)^S \tag{1}$$

where:

ε_t = initial tensile strain,
N_f = number of load repetitions to failure,
I = anti-log of the intercept of the logarithmic relationship, and
S = slope of the logarithmic relationship.

Regression parameters for Equation (1) are shown in Table 7. The results obtained show significant improvement in fatigue life of the control specimen when modified with polymer, particularly at low strain and high temperature levels. P8 has shown higher fatigue life followed by P9, P6, and P5, respectively at high and low temperature.

Permanent deformation

The permanent deformation was simultaneously recorded while running the fatigue test, as discussed before for all tested specimens, at the testing temperatures of 25°C and 50°C. Results are presented in Figures 7 and 8. These results indicate that a straight-line relationship exists between the logarithm of number of load repetitions and the logarithm of permanent strain. The permanent deformation properties were determined using the following form:

$$\varepsilon_p = I * (N)^S \tag{2}$$

where:

ε_p = accumulated permanent strain,
N = number of load repetitions,
I = anti-log of the intercept of the logarithmic relationship, and
S = slope of straight line.

Parameters I and S in the above equation were obtained by using permanent deformation experimental data in a regression analysis. Results indicate that polymer modification has reduced permanent deformation of asphalt mixes as compared to the control mix. The improved rutting resistance is clear at low and high temperature. P5 has shown similar behavior to the control mix at 25°C while its behavior becomes more elastic at 50°C. P8 has shown best rutting performance followed by P9, P6, and P5, respectively.

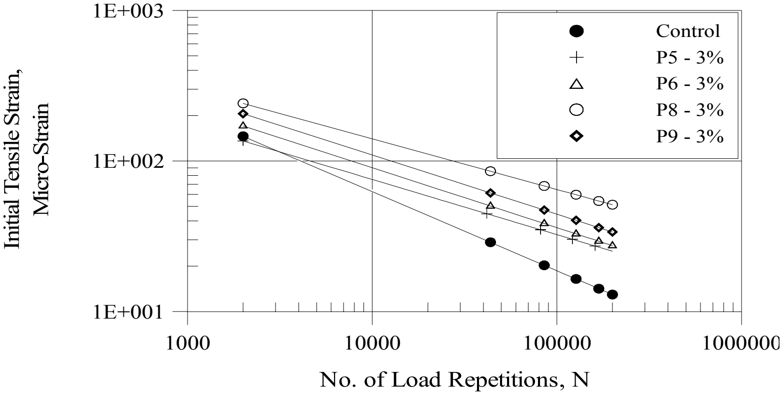

Figure 5. Fatigue curves for modified wearing course mixes at 25°C

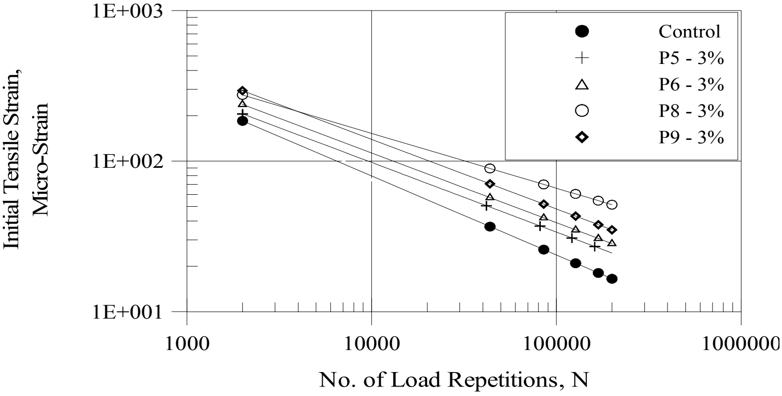

Figure 6. Fatigue curves for modified wearing course mixes at 50°C

Table 7. Regression factors for fatigue test

Mix Type	Regression Factors @ 25°C		Regression Factors @ 50°C	
	I	*S*	*I*	*S*
Control	9946.5	-0.5243	7924.9	-0.6255
P5	6890.9	-0.4641	3623.5	-0.4110
P6	7961.3	-0.4621	3514.0	-0.3977
P8	4384.3	-0.3645	1801.8	-0.2946
P9	9812.7	-0.4619	4079.9	-0.3928

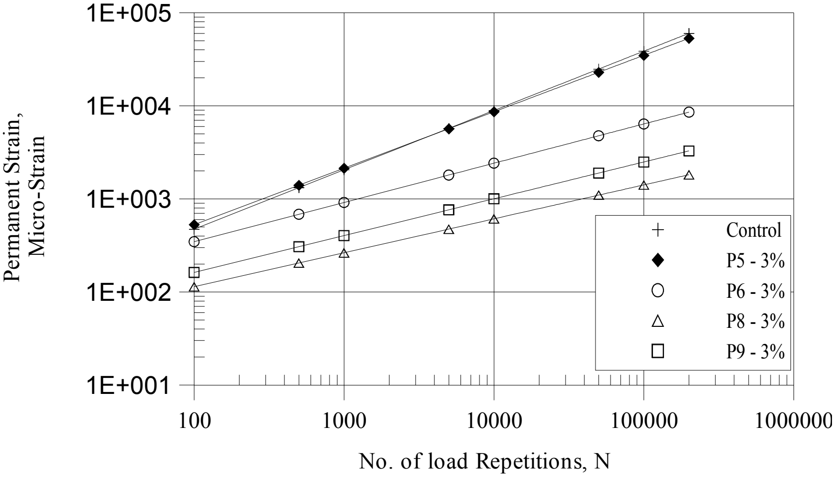

Figure 7. Rutting curve at 100-initial micro-strain @ 25°C

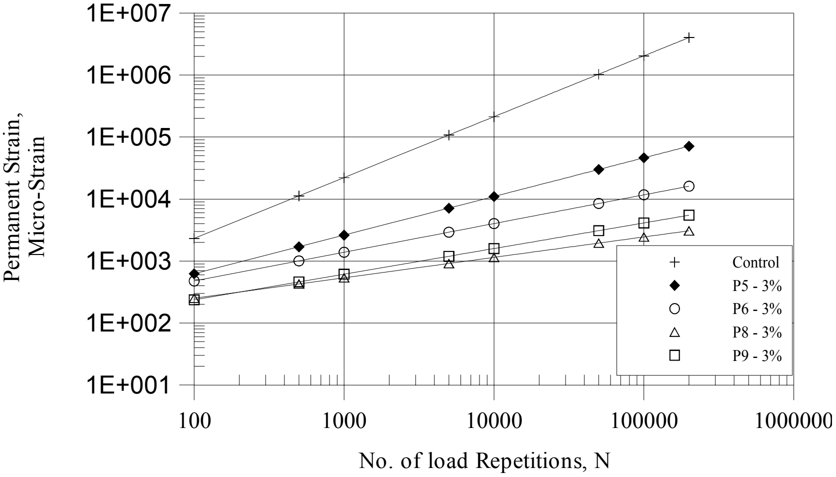

Figure 8. Rutting curve at 100-initial micro-strain @ 50°C

5. CONCLUSIONS

In general, it can be said that the polymer produced by SABIC is very effective in improving the rheological properties of the neat asphalt binders produced by RY to meet and satisfy the performance requirements of the GC. Based on the experimental results, the most promising polymer types and concentration are as follows:

- Polymer types P5, P6, P8 and P9 are satisfying the performance requirements based on PG with percentage of 3%, 2%, 2% and 2%, respectively.
- Polymer types P5, P6, P8, and P9 are satisfying the storage stability requirements based on the measured shear loss modulus after 72 hours while P7 shows great disintegration, which lead to rejection of P7.
- Lottman test results indicate that the average percentage loss in strength due to water damage is reduced effectively in polymer type P8 while it is reduced in polymer types P5, P6 and P9 but still has high value (more than 20%).
- Polymer types P6, P8 and P9 have shown significant increase in resilient modulus at both high and low temperatures while the resilient modulus of P5 is almost the same as the control mix.
- The results show significant improvement in both fatigue behavior and rutting resistance of all the polymer types mixes compared with the control mix.

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