International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:10, No:2, 2016

Comparison of Rheological Properties for Polymer Modified Asphalt Produced in Riyadh

Ali M. Babalghaith, Hamad A. Alsoliman, Abdulrahman S. Al-Suhaibani

Abstract**—**Flexible pavement made with neat asphalt binder is not enough to resist heavy traffic loads as well as harsh environmental condition found in Riyadh region. Therefore, there is a need to modify asphalt binder with polymers to satisfy such conditions. There are several types of polymers that are used to modify asphalt binder. The objective of this paper is to compare the rheological properties of six polymer modified asphalt binders (Lucolast7010, Anglomak2144, Paveflex140, SBS KTR401, EE-2 and Crumb rubber) obtained from asphalt manufacturer plants. The rheological properties of polymer modified asphalt binders were tested using conventional tests such as penetration, softening point and viscosity; and SHRP tests such as dynamic shear rheometer and bending beam rheometer. The results have indicated that the polymer modified asphalt binders have lower penetration and higher softening point than neat asphalt indicating an improvement in stiffness of asphalt binder, and as a result, more resistant to rutting. Moreover, the dynamic shear rheometer results have shown that all modifiers used in this study improved the binder properties and satisfied the Superpave specifications except SBS KTR401 which failed to satisfy the rutting parameter ($G^*/\sin\delta$).

Keywords**—**Polymer modified asphalt, rheological properties, SBS, crumb rubber, EE-2.

I. Introduction

THE roadway networks in the Kingdom of Saudi Arabia (KSA), especially Riyadh city are built with flexible pavements due to the availability of relatively low cost asphalt binders. The currently available 60-70 penetration grade asphalt binder produced by the Riyadh refinery satisfies the performance grade specification PG64-22 [1]. Field measurement in KSA revealed that the asphalt pavement temperature ranges between 3°C to 72°C and 4°C to 65°C, for coastal and inland areas; respectively [2]. Al-Abdul Wahhab et al. [3] developed the performance of neat asphalt specifications for the gulf countries. The results showed that locally produced asphalt binder not satisfactory to be used in some regions within KSA where high temperature condition prevails, such as high traffic roads and slow as well as stationary traffic of intersections. So it needs modification to suit different Gulf temperature zones.

There are some previous local studies on polymer modified asphalt using local polymers produced by Saudi Basic Industries Company (SABIC). The results showed that, the local polymers produced by SABIC were found to be effective in improving the rheological properties of the neat (original) asphalt binders produced by Riyadh refinery and met the performance requirements [4]-[6]

Ali M. Babalghaith, MSc student, Hamad A. Alsoliman, Assistant Professor, Abdulrahman S. Al-Suhaibani, Professor, are with the King Saud University, Riyadh, KSA (phone: +966-538058203; e-mail: ababalghaith@ksu.edu.sa, hasoliman@hotmail.com, asuhaib@ksu.edu.sa).

Airey [7], performed research on polymer modified asphalt based on conventional tests (penetration, Softening point and rotational viscosity). The styrene butadiene styrene (SBS) polymer was used at various percentages 3, 4, and 5%. Two different penetration grades neat (original) asphalt binder (penetrations of 73 and 81 mm) were investigated. The results revealed that with increasing polymer content, penetration is decreased but the softening point is increased.

Kök et al. [8], compared the crumb rubber (CR) and SBS modified asphalt. Samples were evaluated by rotational viscosity, dynamic shear rheometer and conventional binder tests. The results showed that 8% of crumb rubber modification is required to achieve the same performance as that of 4% SBS modification. The use of crumb rubber is preferred over SBS modification because it can provide a significant cost savings and prevent the accumulation of this waste material in the environment.

Kumar et al. [9], compared the rheological properties of modified binders at high temperature. The research studied polymers ethylene vinyl acetate (EVA), SBS and CR. The rheological properties of the binders, named complex modulus, G^*, storage modulus, G', loss modulus, G'', and phase angle, δ, were measured using dynamic shear rheometer. Testing was performed at temperatures ranging from 46 to 82°C before and after aging. The study observed that, the rheological properties of the neat asphalt after mixing with modifiers were improved.

Recently, polymer modified asphalt is gaining attention in KSA. Due to distresses that occur in KSA roads, the Ministry of Transportation has adopted the specifications of Superpave binder grade. Most of asphalt plants in Riyadh region produce polymer modified asphalt using different polymers types. This research is a laboratory study to compare the rheological properties of polymer modified asphalt binders produced by different asphalt plants.

II. Materials

A. Asphalt Binder

A penetration-grade asphalt of 60-70 is used as a control asphalt binder for this study. The asphalt binder was obtained from the Riyadh Refinery. The properties of the asphalt binder are presented in Table I.

B. Polymer Modified Asphalt

The polymer modified asphalt binders were collected directly from asphalt plants in Riyadh city, where polymers were blended with asphalt binder at percentages of polymers required to achieve PG 76-xx according to the requirements of the Ministry of Transportation as shown in Table II. The temperature of 76ºC was selected since it represents the highest performance grading requirements in KSA [6].

TABLE I
PROPERTIES OF THE NEAT ASPHALT BINDER

Property	Test Reference	Value
Penetration @ 25°C (dmm)	ASTM D0005-05	68
Softening Point (°C)	ASTM D0036-95	48
Penetration Index	-------------	- 0.99
Ductility (cm)	ASTM D0113-99	+ 100
Rotational Viscosity @ 135 °C (cps)	ASTM D4402-02	487
Specific Gravity	ASTM D0070-03	1.025
Rolling Thin Film Oven Test @ 163°C, for 85 minutes, (% wt loss)	ASTM D2872-04	0.07
High Temperature Grade (°C)	ASTM D7175	64
Low Temperature Grade (°C)	ASTM D6648-01	- 22

TABLE II
PHYSICAL FORM AND PERCENTAGE

SN	Commercial Name	Code	Physical Form	%
1	Lucolast7010	LU	Pellet	3.6
2	Anglomak 2144	AM	Pellet	3.2
3	Paveflex140	PF	Powder	5
4	SBS KTR 401	SBS	Pellet	3
5	EE-2	EE	Pellet	4
6	Crumb Rubber	CR	Pellet	8

III. EXPERIMENTAL PROCEDURES

According to ASTM method [10], all tests on the samples were conducted to characterize the properties of polymer modified asphalt binders. The rheological tests include penetration at 25ºC, softening point, viscosity, dynamic shear rheometer and bending beam rheometer tests.

A. Penetration

The penetration test is an empirical test which measures the distance in tenths of millimeter (e.g., if the needle penetrates 6 mm, the asphalt penetration number is 60), a standard needle penetrates into the sample under given conditions of loading 100 grams, during 5 seconds and temperature which at 25°C. The test procedure is described in ASTM D0005-03.

B. Softening Point

Softening point is also an empirical test, which measures the temperature at which the asphalt becomes soft, and cannot support the weight of a metal ball and begins to flow. The rings and assembly are placed in a water bath filled to a depth of 105 ± 3 mm, a 9.5 mm steel ball bearing (weighing 3.50 ± 0.05 g) is centered on each specimen and raises the temperature by 5 ± 0.5°C per minute. Finally, the mean of the temperatures at which the two asphalt binder specimens fall a distance of 25 mm and touches the base plate is recorded. The test procedure is described in ASTM D0036-95.

C. Rotational Viscometer

The rotational viscometer test is performed on the un-aged Asphalt binder to ensure that it can be pumped and handled at the hot mixing facility. Brookfield viscometer (Model DV-II) is employed to measure the rotational viscosity of asphalt binders according to ASTM D4402. The viscosity is determined by measuring the torque required to maintain a constant rotational speed (20 revolutions per minute) of a cylindrical spindle while submerged in an asphalt binder sample (8-11 grams) at a constant temperature (105, 120, 135, 150, 165 and 180°C).

D. Dynamic Shear Rheometer (DSR)

A Bohlin DSR is used to determine the complex modulus, G*, and phase angle, δ. G*is defined as the ratio of maximum shear stress to maximum strain and it provides a measure of the total resistance to deformation during shear loading. It consists of loss modulus (G′′) (viscous behavior), and storage modulus (G′) (elastic behavior). The phase angle is defined as the ratio of loss to storage modulus, hence it reflects the viscous response of the asphalt binder. The test is conducted in un-aged and RTFO aged binders. Samples are placed between two 25mm parallel plates, the gap is adjusted to 1mm for the both un-aged and RTFO aged binders with high testing temperature range from 58°C to 82°C, with interval 6°C. The test procedure is described in ASTM D7175.

In Superpave specification, in order to minimize the permanent deformation (rutting), the parameter $G^*/\sin\delta$ must be greater than or equal to 1.00 kPa for the un-aged asphalt binder and 2.20 kPa for the RTFO aged asphalt binder.

E. Bending Beam Rheometer (BBR)

The BBR is used to evaluate the properties of the asphalt binder at low Temperatures. The test is performed on binders that have been aged in the RTFO and PAV. The beam specimen is molded by pouring RTFO/PAV-aged asphalt binder in a rectangular shaped aluminum mold (6.25mm thickness, 12.5mm width and 125mm length). Once temperature conditioning is done, the beam specimen is supported at two points 102 mm apart and loaded at mid point with a load of 980 mN (±50mN) for a period of 240 s. Creep stiffness (S) and the slope of creep stiffness master curve (m-value) are calculated at a loading time of 60 s. According to Superpave specification the creep stiffness should be less than 300 MPa and m-value greater than 0.3. The test procedure t is described in ASTM D6648-01.

IV. RESULT AND DISCUSSION

A. Penetration at 25ºC

Regarding the effect of the different polymers on the penetration value of the neat binder, it can be seen that in all cases the polymers have reduced the penetration value of the neat binder. The penetration value of neat binder is 68, it is within the range of its specified grade of 60-70 penetration as shown in Table III. The increase in binder hardness at normal temperature is indicated by the decrease in penetration. Fig. 1

illustrates that there is variation in penetration value of the six polymer modified asphalt binders. The asphalt modified with polymers, Pavflex2144, Lucolast7010, Anglomak2144 and EE-2 seem to be the most effective polymers for decreasing the binder penetration, while SBS KTR401 and Crumb rubber showed less effectiveness. The modified asphalt that has a low value of penetration is harder, which is good in one sense, since it might improve the rutting resistance. On the other hand, this may affect flexibility of the asphalt binder by making it stiffer, thus reducing resistance to fatigue cracking.

TABLE III
PENETRATION OF NEAT AND POLYMER MODIFIED ASPHALT BINDERS

	Code	Penetration
Neat Binder	NB	68
Paveflex140	PF	34
Lucolast 7010	LU	36
Anglomak2144	AM	34
EE-2	EE	35
Crumb Rubber	CR	40
SBS KTR401	SBS	47

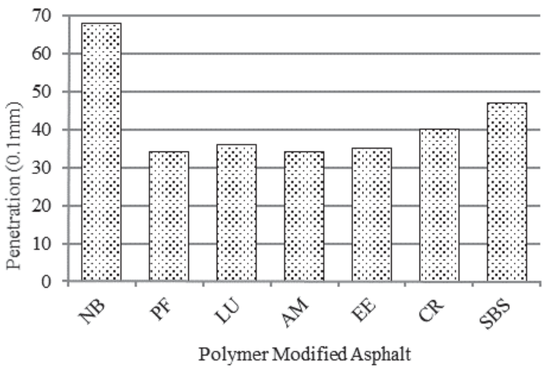

Fig. 1 Penetration of neat and polymer modified asphalt binders

B. Softening Point

Softening point results for the neat and polymer modified asphalt binders are presented in Table IV. The increase in softening point indicates an increase in asphalt hardness. Fig. 2 displays that the values of softening point for all polymer modified asphalt binders are higher than neat binder that indicate higher improvement in rheological behavior at high temperature. Moreover, it was found that there are variations in softening point results similar to penetration results, the asphalt modified with polymers, Pavflex2144, Lucolast7010, Anglomak2144 and EE-2 increased the binder softening point more than SBS KTR401 and Crumb rubber.

The polymer modified asphalt binders have less penetration and higher softening point than those of neat asphalt indicating an improvement in stiffness of polymer modified asphalt binders. These modified binders are thus more appropriate for paving applications, since they will be more resistant to rutting and fatigue cracking [11].

TABLE IV
SOFTENING POINT OF NEAT AND POLYMER MODIFIED ASPHALT BINDERS

	Code	Softening Point
Neat Binder	NB	48
Paveflex140	PF	59.2
Lucolast 7010	LU	59
Anglomak2144	AM	60.8
EE-2	EE	67
Crumb Rubber	CR	57
SBS KTR401	SBS	55

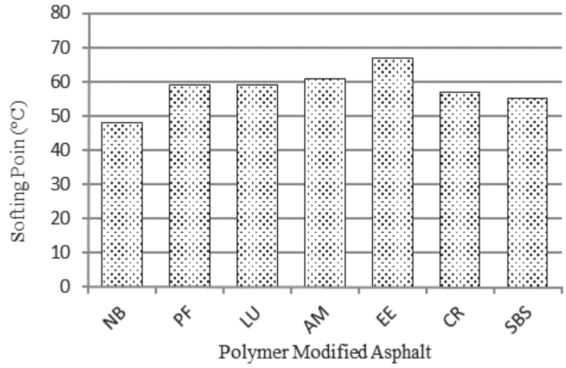

Fig. 2 Softening point of neat and polymer modified asphalt binders

C. High Temperature Viscosity

The variation of viscosity with temperature is presented in Fig. 3. The general trends of the results are such that as the temperature increases the difference between the polymer modified asphalt viscosities decrease. All polymer modified asphalt binders have higher viscosity values than neat binder. The asphalt modified viscosity curves display that the asphalt modified with polymers, Paveflex140, Anglomak2144 and Lucolast7010 have higher viscosity values. Higher viscosity leads to high resistance to heavy loads at high temperature.

The Superpave specification (AASHTO M320) requires that the maximum viscosity of asphalt binder is less than 3000 centipoises (cp) at 135 ºC for storage and pumping in construction period, Table V shows the viscosity for neat and polymer modified asphalt binders at 135ºC and 165ºC, it obvious that all binders fulfilled Superpave specification requirement.

TABLE V
VISCOSITY OF NEAT AND POLYMER MODIFIED ASPHALT BINDERS

	Code	Viscosity	
		135 ºC	165 ºC
Neat Binder	NB	487	150
Paveflex140	BF	1200	287
Lucolast 7010	LU	1225	337
Anglomak2144	AM	1175	337
EE-2	EE	662	237
Crumb Rubber	CR	687	200
SBS KTR401	SBS	800	250

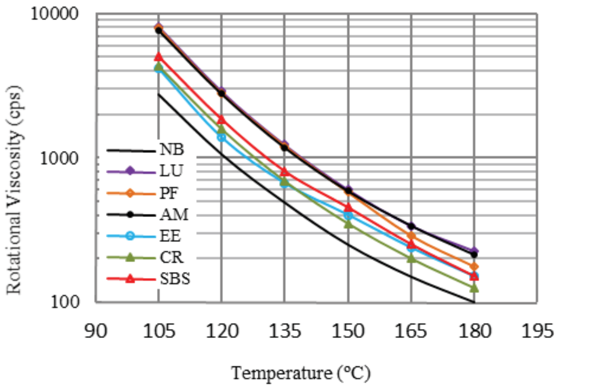

Fig. 3 Viscosity vs. temperature of neat and polymer modified asphalt binders

D. Dynamic Shear Rheometer (DSR)

The Superpave methodology can indicate the major stresses observed in asphalt paving such as permanent deformation and fatigue cracking through the rheological parameters G*/sinδ and G*.sinδ; respectively. The G*/sinδ values are calculated for the temperatures 52, 58, 64, 70, 76 and 82 °C for neat and polymer modified asphalt binders as shown in Fig. 4; for the un-aged binders and Fig. 5; for the RTFO aged binders. The results show that adding polymers to asphalt increase significantly the G*/sinδ value and this extends the temperature range from 64°C to 76°C in comparison to the neat asphalt binder. The G*/sinδ values were calculated at temperature of 76ºC for un-aged and RTFO aged conditions to compare the polymer modified asphalt binders. G*/sinδ values are presented in Fig. 6 for both conditions. For un-aged condition, the results show that there are variations in G*/sinδ values. The increase in G*/sinδ values means that the binders become more stiff (higher rutting resistance). The asphalt modified by polymers, Lucolast7010, Anglomak2144, Paveflex140, EE-2 and Crumb Rubber have high G*/sinδ values, while SBS KTR401 has a critical value (1.002 kPa) compared with the Superpave specification (1.0 kPa). On the other hand, for the RTFO aged binders, Lucolast7010, Anglomak2144, Paveflex140, EE-2 have higher G*/sinδ values, while Crumb Rubber has critical value (2.207 kPa) compared with the Superpave specification (2.2 kPa), while SBS KTR401 failed to satisfy the parameter G*/sinδ for RTFO aged.

E. Bending Beam Rheometer (BBR)

The creep stiffness and the slope of the logarithm of the stiffness vs. the logarithm of the time curve have been used as performance-based specification criteria for asphalt binders in SHRP [12]. The measurements of low-temperature creep responses were conducted at a temperature of 10ºC higher than the minimum pavement design temperature.

The low temperature creep stiffness and creep rate (m-value) are determined using a BBR at different temperatures. The results are shown in Table VI and the graphical representation for creep stiffness and creep rate are shown in Figs. 7 and 8; respectively.

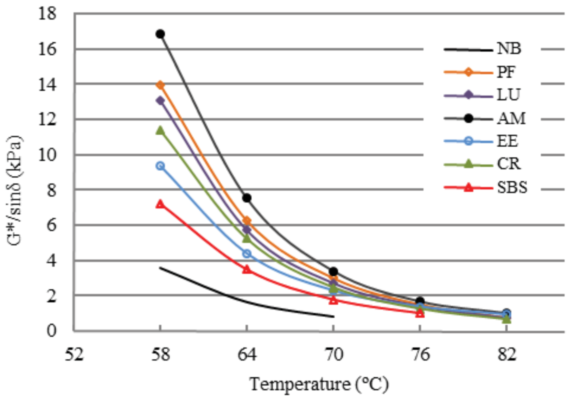

Fig. 4 G*/sinδ vs. temperature for un-aged binders

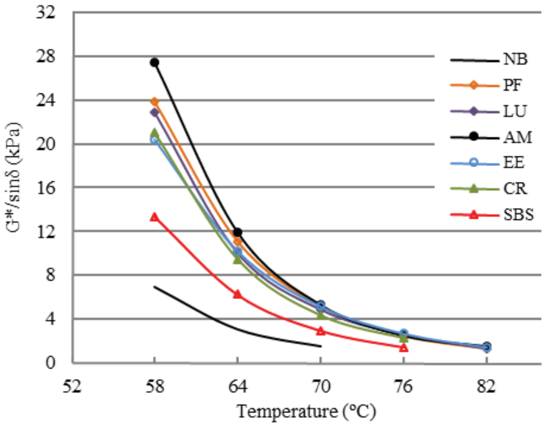

Fig. 5 G*/sinδ vs. temperature for RTFO aged binders

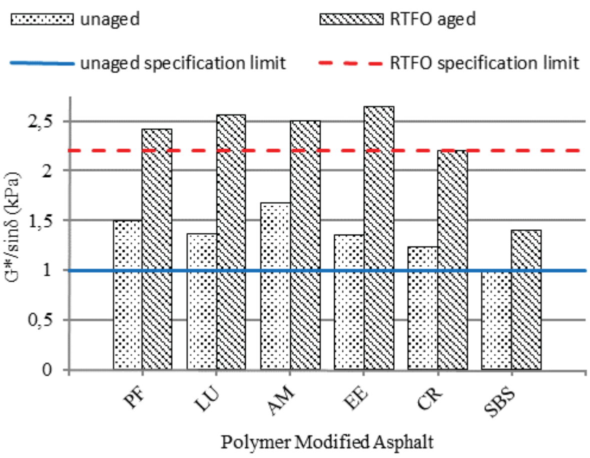

Fig. 6 G*/sinδ at 76 ºC for un-aged and RTFO aged polymer modified asphalt binders

TABLE VI
CREEP STIFFNESS AND M-VALUE AT LOADING TIME OF 60 S AND DIFFERENT TEMPERATURES

Code	Creep stiffness (MPa)			m-value			Grade
	-10 ºC	-16 ºC	-22 ºC	-10 ºC	-16 ºC	-22 ºC	
NB	39.29	79.04	166.90	0.380	0.319	0.307	-22
PF	60.12	112.81	-	0.320	0.290	-	-10
LU	47.92	105.97	202.36	0.366	0.315	0.285	-16
AM	57.45	103.95	-	0.312	0.279	-	-10
EE	54.62	103.83	-	0.309	0.288	-	-10
CR	39.52	79.19	176.50	0.361	0.318	0.286	-16
SBS	45.71	98.98	158.71	0.367	0.311	0.287	-16

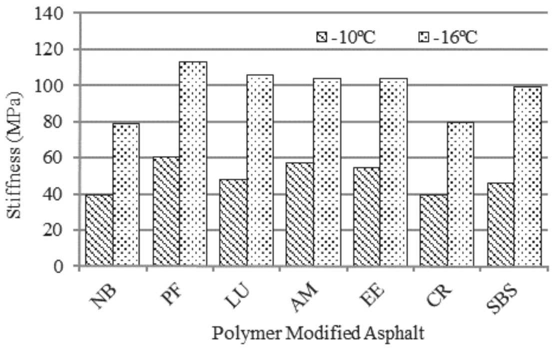

Fig. 7 Creep stiffness at temperatures -10 and -16ºC for polymer modified asphalt binders

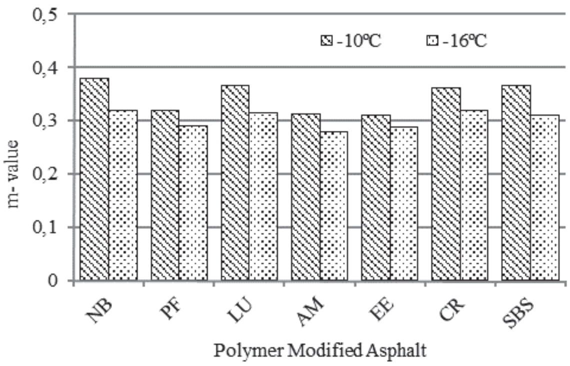

Fig. 8 Creep rate (m-value) at temperatures -10 and -16ºC for polymer modified asphalt binders

Table VI demonstrates the effect of polymers on the creep stiffness and the creep rate at various test temperatures (-10, -16 and -22ºC). It was found that the stiffness increases with adding polymers to asphalt, which indicates that the addition of polymers reduce resistance of the modified binders to low temperature cracking. It was found that the m-value is reduced with the addition of polymers. The m-value of polymer modified asphalt at Superpave low temperature grade must be greater than 0.3, for example, the Paveflex140 sample was tested by BBR at a temperature of -6°C, the stiffness is 112.81 MPa, and the m-value is 0.290, which is less than the target value of 0.300. Therefore, the Superpave low temperature grade of this sample has to be one-grade higher than -16°C (i.e., -10°C; m-value is 0.320). The Superpave low temperature grade for neat binder is -22, while The asphalt modified with polymers, Pavflex2144, Lucolast7010, Anglomak2144, EE-2, Crumb rubber and SBS KTR401 are -10, -16, -10, -10, -16 and -16; respectively.

V. CONCLUSION

- Pavflex2144, Lucolast7010, Anglomak2144 and EE-2 seem to be the most effective polymers for decreasing penetration and increasing softening point of the modified binders. These modified binders are appropriate for paving applications, since they will be more resistant to rutting.
- All polymer modified asphalt binders fulfilled Superpave specification requirement that the maximum viscosity of asphalt binder should be less than 3000 centipoises at a temperature of 135 ºC.
- With the exception of SBS KTR401, all modifier used in this study improved binder properties and satisfied rutting parameter (G*/sinδ). They can be used at temperatures up to 76 °C. SBS KTR401, however, which failed to satisfy G*/sinδ after RTFO, can be used only up to 70°C.
- All polymers have negative effects on the creep rate (m-value) of the modified binders compared with neat asphalt. The Superpave low temperature grade for neat binder is -22, while that for asphalt modified with Pavflex2144, Lucolast7010, Anglomak2144, EE-2, Crumb rubber and SBS KTR401 are -10, -16, -10, -10, -16 and -16; respectively.

REFERENCES

[1] I. A. Al-Dubabe, Polymer modification of Arab asphalt to suit Gulf countries performance requirments *phD Dissertation*. (1996).
[2] H. Al-Abdul Wahhab, and F. Balghunaim, Asphalt pavement temperature related to arid Saudi environment. *Journal of materials in civil engineering*. 6, 1-14 (1994).
[3] H. I. Al-Abdul Wahhab, I. M. Asi, I. A. Al-Dubabe, and M. F. Ali, Development of performance-based bitumen specifications for the Gulf countries. *Construction and Building Materials*. 11, 15-22 (1997).
[4] H. A. ALsolieman. *Engineering characteristics of local polymer modified asphalt mixtures* (dissertation). King Saud University (2010).
[5] H. I. Al-Abdul Wahhab, I. M. Asi, I. Abaker, and M. G. Baig, Performance Modification of Saudi-Asphalt Binders Using SABIC Polymers. (2002).
[6] I. A. Al-Dubabe, H. I. Al-Abdul Wahhab, I. M. Asi, and M. F. Ali, Polymer modification of Arab asphalt. *Journal of materials in civil engineering*. 10, 161-167 (1998).
[7] G. D. Airey, Rheological properties of styrene butadiene styrene polymer modified road bitumens. *Fuel*. 82, 1709-1719 (2003).
[8] B. V. Kök, and H. Çolak, Laboratory comparison of the crumb-rubber and SBS modified bitumen and hot mix asphalt. *Construction and Building Materials*. 25, 3204-3212 (2011).
[9] P. Kumar, H. Mehndiratta, and K. L. Singh, Comparative study of rheological behavior of modified binders for high-temperature areas. *Journal of Materials in Civil Engineering*. (2010).
[10] American Society for Testing and Materials (ASTM), (2004).
[11] M. R. S. Fernandes, M. M. C. Forte, and L. F. M. Leite, Rheological evaluation of polymer-modified asphalt binders. *Materials research*. 11, 381-386 (2008).
[12] D. A. Anderson, and T. W. Kennedy, Development of SHRP binder specification (with discussion). *Journal of the Association of Asphalt Paving Technologists*. 62, (1993).