EFFECT OF POLYMER MODIFICATION ON RHEOLOGICAL PROPERTIES OF ASPHALT

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ABSTRACT: *Flexible pavement structures are subjected to heavy traffic loading and repetition of such loading deteriorates the pavement. Fatigue cracking and permanent deformation (rutting) in pavement layers are the results of this deterioration. These problems arise due to improper characterization of asphalt binder. The conventional testing procedure does not provide deeper picture about behaviour of asphalt. It is required to characterize the asphalt after making some polymer modification and by using some advance testing protocol. This paper tries to evaluate the temperature susceptibility behaviour of virgin and polymer modified asphalt and suggests some practical implication considering local industry use. Six polymer modified asphalt samples were prepared in the laboratory and tested with two virgin grades and one factory polymer modified sample using Dynamic Shear Rheometer (DSR). The testing results revealed that polymer modification has significant impact on rheological properties of asphalt binder. Viscosity-temperature susceptibility changes with the addition of polymer which makes asphalt suitable to use in warmer and colder regions in order to control the various distresses in flexible pavements. The finding of this paper would be helpful for local road construction industry for characterization of locally available asphalts and their modified versions.*

Keywords: Polymer, Modified Asphalt, Viscosity-Temperature Susceptibility

1. INTRODUCTION

Asphalt is largely used to construct pavements for highways and airports. Both asphalt binder and asphalt aggregate mixtures show temperature and time dependent behaviour. Fatigue cracking and rutting are two major flexible pavement distresses. Temperature, loading and time dependent behaviour of asphalt binder affect the rutting and cracking characteristics of asphalt concrete mixture. Rutting is a major reason of premature deterioration of asphalt pavements in warm climatic regions of Pakistan whereas fatigue and thermal cracking is a common problem in cold regions. In Pakistan, the maximum temperature lies in the range of 45-50 °C whereas an average minimum temperature fall in the range of -20 to -15 °C [1]. It is believed that early failure of asphalt pavement (e.g. rutting) usually results from inadequate strength properties of mix, while long-term failure is the result of significant fatigue in the pavement structure [2]. These problems arise in asphalt pavements due to improper mix design and lack of asphalt binder characterization. Therefore, now-a-days polymer modification has been increasingly employed in asphalt concrete, primarily for control of short-term permanent deformation [3-54]. Polymer modification typically improves asphalt binder ductility, thereby providing asphalt binder that is more durable to pavement stress and deformation [6-8].

Temperature susceptibility of asphalt cement is an important control parameter during the mixing, placing, compaction, and performance of asphalt concrete. Viscosity temperature susceptibility and temperature relationship is used to predict the rheological properties of asphalt binder. A regression of the double logarithm of the viscosity points versus the logarithm of respective temperatures in the Rankine scale (TR) provides the basis of the ASTM (American Society for Testing and Materials) Ai-VTSi relationship as follows in Eq. 1[9].

$$\text{Log-log}\ (\eta^*) = A + VTS \log (T_R) \quad (1)$$

Where,

η^* = Complex viscosity, cP
T_R = temperature, degree Rankine
A = regression intercept
VTS = regression slope (viscosity temperature susceptibility parameter)

The objective of this paper is to evaluate the influence of polymer modification on viscosity temperature susceptibility of asphalt binder using dynamic shear test protocol. This paper is organized in the following manner. Section 2 describes the details of materials and equipment setup. Section 3 presents the results of tests and analysis. Last section summarized the key findings and their implications.

2. MATERIALS AND EXPERIMENTAL SETUP

This research included laboratory testing to study the effect of polymer modification on temperature susceptibility of asphalt binder. Three asphalt samples from Attock Oil Refinery 60/70, 60/70P (polymer), 80/100 were obtained and six PMA (polymer modified asphalt) samples were prepared in the laboratory by blending three percentages (i.e. 1.35, 1.7 & 2 %) of DuPont™ Elvaloy® RET polymer [10] with two virgin grades i.e. 60/70 & 80/100. It is a reactive elastomeric polymer that bonds with asphalt through a chemical reaction and gives elastomeric properties to improve road performance at high temperature. At a low-temperature (below approximately 4°C) the properties of polymer-modified asphalt are determined mainly by the base asphalt. This polymer is provided as free-flowing pellets that melt into hot asphalt to form permanently modified asphalt binder. The PMA remains easy-to-use, and also delivers improved long-term resilience and climate resistance. The improved asphalt binder remains homogenous, with good aggregate coating and adhesion properties (DuPont).

Total nine samples as presented in Table 1 were tested at a frequency of 10 rad/sec and at thirteen test temperatures covering a range of intermediate temperature (7, 13, 19, 25, 31, 37 ^{0}C) and high temperature range (46, 52, 58, 64, 70, 76, 82 ^{0}C) using Dynamic Shear Rheometer [11]. In DSR test operation, the asphalt sample is sandwiched between two parallel plates, one of which is fixed and the other one is moveable, as shown in Figure 1.

Table 1: Test Samples

Sr. #	Description of Samples
1	Attock 60/70
2	Attock 60/70PMA (prepared @1.35% of polymer in Attock oil refinery)
3	Attock 60/70+1.35% Elvaloy® RET (Laboratory)
4	Attock 60/70+1.7% Elvaloy® RET (Laboratory)
5	Attock 60/70+2.0% Elvaloy® RET (Laboratory)
6	Attock 80/100
7	Attock 80/100+1.35% Elvaloy® RET (Laboratory)
8	Attock 80/100+1.7% Elvaloy® RET (Laboratory)
9	Attock 80/100+2.0% Elvaloy® RET (Laboratory)

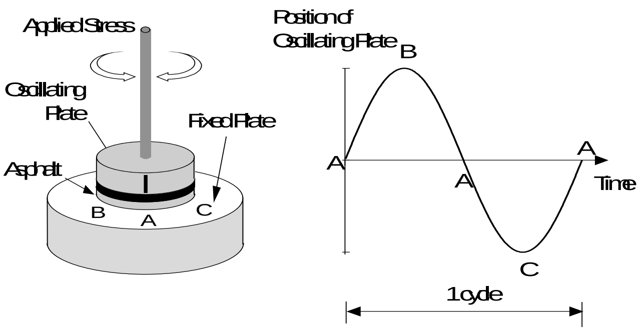


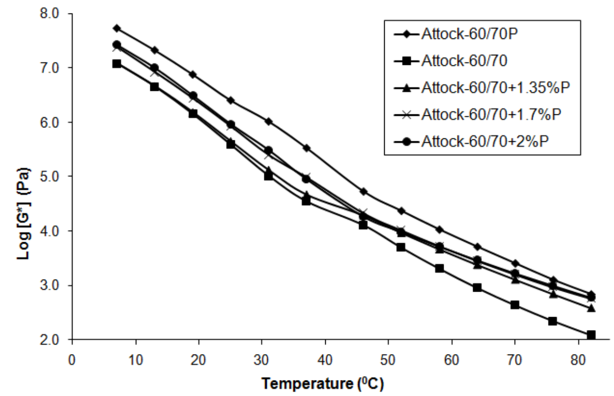
Figure 2: Operational mechanism of DSR test

2.1. Preparation of Polymer Modified Asphalt in the Laboratory

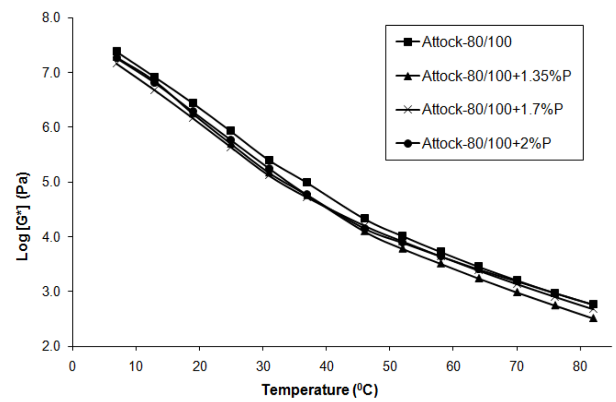
Required quantity of virgin asphalt (i.e. 800 grams) was taken for blending purpose in the mixer. This quantity of asphalt was taken considering that it should be enough to perform different tests. To make asphalt sample workable, it was heated in oven at a temperature of 165 ^{0}C. The sample was placed on hot plate at 165 ^{0}C. Then required amount (1.35 %, 1.7 % and 2 % of asphalt sample by weight) of Elvaloy® RET polymer was added into the virgin asphalt with the continuous mixing at speed of 120 rpm. The mixing was done with the help of mechanical stirrer. It was assured that there should not be any formation of clogs while adding the polymer into the asphalt binder. After the addition of whole polymer, the asphalt was kept on agitating for further half an hour to insure the proper mixing. Super Phosphoric Acid (SPA) was also added (i.e. 1.4 gram) as a catalyst in the blended sample. After the addition of SPA the viscosity was measured at 165 ^{0}C. Again after 30 minutes viscosity was measured and mixing process remained continue until the viscosity become constant. After completion of mixing the prepared sample was kept in oven for two hours for curing purpose.

3. ANALYSIS OF TESTING RESULTS

The complex shear modulus (G*) and phase angle (δ) were obtained by using DSR for all the asphalt samples and log of complex shear modulus was plotted against temperature as given in fig. 3 whereas phase angle plot against temperature as follows in fig. 4.



(a) Plot of Attock 60/70 and its PMB samples

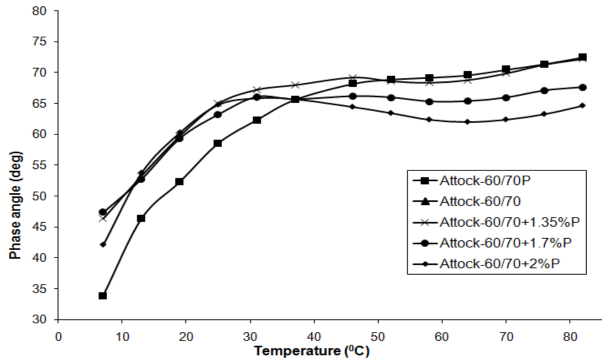


(b) Plot of Attock 80/100 and its PMB samples

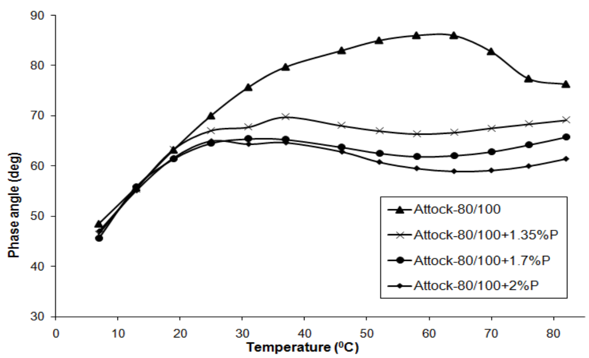
Figure 3: Comparative plots for complex shear modulus (G*)

The testing results indicate that complex shear modulus or resistance to deformation of asphalt binder increases with the addition of polymer. Complex shear modulus of Attock 60/70P is higher as compared to laboratory PMB samples which indicate this asphalt sample has more resistance to deformation. There is also significant reduction in phase angle with the addition of polymer which enhances the elastic properties of asphalt binder. This increase makes the asphalt binder more suitable to control rutting and fatigue cracking in pavements. In case of 80/100 PMB samples, the polymer is more active at high temperature as compared to intermediate temperature.

The complex viscosity (η*) was calculated by dividing the complex shear modulus (G*) with test frequency (10 rad/s) and log-log (η*) was plotted against log of temperature in Rankine deg. Results of VTS analysis indicate that temperature susceptibility of asphalt binder decreases significantly with the polymer modification which makes asphalt binder more suitable to use in extreme climatic regimes. The slope of Attock 60/7P is almost parallel to Attock 60/70 virgin grade which suggested that polymer addition only enhance the hardness instead of changing its elastic properties whereas in case of laboratory PMB samples there is an enormous decrease in viscosity temperature susceptibility. The plots of VTS analysis is given in fig. 5 and its parameter values are presented in table 2.

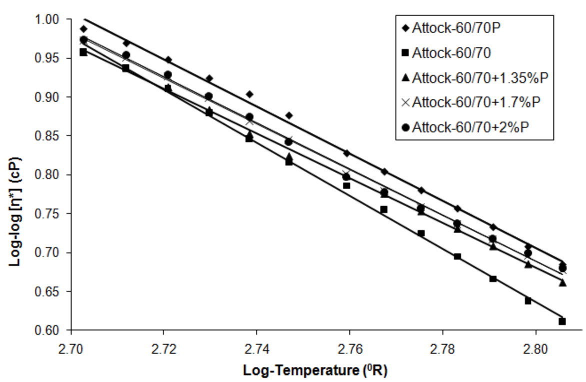


(a) Plot of Attock 60/70 and its PMB samples

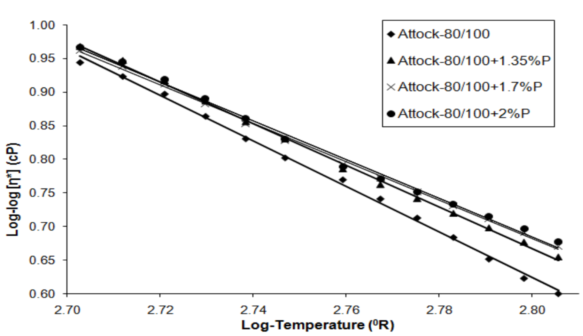


(b) Plot of Attock 80/100 and its PMB samples

Figure 4: Comparative plots for phase angle (δ)



(a) Plot of Attock 60/70 and its PMB samples



(b) Plot of Attock 80/100 and its PMB samples

Figure 5: Comparative plots for Viscosity Temperature Susceptibility (VTS)

Table 2: VTS analysis parameters

Sr. #	Asphalt Type	VTS	A	R^2
1.	Attock 60/70	-3.411	10.187	0.997
2.	Attock 60/70P	-3.036	9.206	0.996
3.	Attock 60/70+1.35%P	-2.879	8.735	0.998
4.	Attock 60/70+1.7%P	-2.942	8.925	0.998
5.	Attock 60/70+2%P	-2.960	8.976	0.996
6.	Attock 80/100	-3.387	10.110	0.998
7.	Attock 80/100+1.35%P	-3.100	9.348	0.998
8.	Attock 80/100+1.7%P	-2.845	8.649	0.998
9.	Attock 80/100+2%P	-2.875	8.735	0.995

Note: P: polymer, VTS: Viscosity temperature susceptibility, a: Intercept

4. CONCLUSIONS

This research was conducted to investigate the effect of polymer modification on temperature susceptibility of asphalt binder. The testing and analysis results reveal that there is a significant effect of polymer modification on reduction of viscosity temperature susceptibility (VTS) as temperature susceptibility of laboratory PMBs is less compared with virgin asphalts. This makes the polymer modified asphalt binder more suitable to use in extreme climatic conditions, i.e. to control rutting in high temperature regions and to control fatigue cracking in colder regions. It is found that the behaviour of modified asphalt is almost same at 1.7% and 2% of polymer contents; therefore, it can be argued that 1.7% is the optimal content of the polymer for modification. The elastic component of laboratory PMB samples is more as compared to virgin asphalt and Attock 60/70P which makes them more suitable to resistant rutting and fatigue cracking. The findings of the paper would be helpful for the local road construction industry in improving the performance of the pavement.

REFERENCES

[1] Mirza, M.W., Abbas, Z., and Rizvi, M.A. "Temperature Zoning of Pakistan for Asphalt Mix Design", *Pakistan Journal of Engineering and Applied Sciences*, 8: 49-60 (2011).

[2] Abojaradeh, M. "Development of Fatigue Failure Criterion for Hot - Mix Asphalt Based on Dissipated Energy and Stiffness Rate", *Jordan Journal of Civil Engineering*, 7(1):54-69 (2013).

[3] Javid, M.A., and Rahim, A. "Characterization of Visco-Elastic Properties of Locally Available Asphalts in Pakistan", *Pakistan Journal of Engineering and Applied Sciences*, 9:17-23 (2011).

[4] Lu, X., and Isacsson, U., (1999), Chemical and Rheological Characteristics of Styrene-Butadiene-Styrene Polymer-Modified Bitumen's. *Transportation Research Record*, 1661:83-92 (1999).

[5] Bouldin, M.G., and Collins, J.H. "Influence of Binder Rheology on Rutting Resistance of Polymer Modified and Unmodified Hot Mix Asphalt". In ASTM STP 1108: Polymer Modified Asphalt Binders, K.R. Wardlaw and S. Shuler (Eds.), American Society for Testing and Materials, San Antonio, TX, 55-60, (1990).

[6] Javid, M.A. "Analyzing Behavior of Polymer Modified Asphalt Using Master Curve Approach", *Jordan Journal of Civil Engineering*, 8(2):216-226 (2014).

[7] Glover, C.J., Davison, R.R., Domke, C.H., Ruan, Y., Juristyarini, P., Knorr, D.B. and S.H. Jung.: Development of a New Method for Assessing Asphalt Binder Durability with Field Validation. Report FHWA/TX-03/1872-2, 2005, Texas Transportation Institute, College Station, TX.

[8] Bahia, H., Hanson, D., Zeng, M., Zhai, H., Khatri, M.A., and Anderson, R.M. "Characterization of Modified Asphalt Binders in Superpave Mix Design". NCHRP Report 459. National Academy Press, Washington DC, (2001).

[9] Anderson, D.A., Christensen, D.W., Bahia, H. U., Dongre, R., Sharma, M. G., Antle, C. E. and Button, C. E .J. "Binder Characterization and evaluation", Vol. III, Physical Characterization, and Strategic Highway Research Program report, SHRP A-369, 1994, Washington, D.C.

[10] http://www.dupont.com/products-and-services/: Available online

[11] AASHTO TP51. "Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using Dynamic Shear Rheometer". FHWA-SA-94-068, (1994).