

# Characterization of Visco-Elastic Properties of Locally Available Asphalts in Pakistan

M. A. Javid<sup>1</sup> and A. Rahim<sup>1</sup>

<sup>1</sup>Department of Transportation Engineering and Management, University of Engineering & Technology, Lahore  
Corresponding Author: ma.javid@hotmail.com

## Abstract

*Asphalt is a visco-elastic material having properties of elastic solid at low temperature and viscous liquid at high temperature. Properties of asphalt binder depend upon temperature, rate of loading and aging conditions. Although asphalt binder is only 4-5 % of asphalt concrete mix by weight but it plays a vital role in defining the pavement performance. That is, pavement response is heavily dependent upon the viscous and elastic properties of asphalt. In this research six asphalt samples were obtained from Attock and Karachi oil refinery and Dynamic Shear Rheometer was used in the laboratory to evaluate their viscous and elastic properties. Witczak predictive model was used to predict the binder viscosity and phase angle by using complex shear modulus and viscosity temperature susceptibility. The study revealed that Karachi virgin asphalt grades are more elastic as compared to Attock virgin asphalt grades both at low and high temperature. Similarly Attock PMB is more stiff and elastic as compared to Karachi 40/50, 60/70, and Attock 60/70. The research also revealed that Attock PMB has lesser temperature susceptibility as compared to virgin grades which makes it more suitable to resist rutting and cracking in extreme climatic conditions of Pakistan.*

**Key Words:** Visco-elastic; Elastic modulus; Viscous modulus; 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 behavior. Asphalt concrete mixture and its structural design are two key components of flexible pavement design. The objective of mix design is to determine the optimum content of materials. Although asphalt binder is only 4 to 5 % in mix by weight but it plays a very vital role in defining the performance of the pavement. That is, pavement response is heavily dependent upon the visco-elastic properties of asphalt [5-6]. Rutting is a major reason of premature deterioration of asphalts pavements in warm climatic regions of Pakistan whereas fatigue and thermal cracking is a common problem in cold regions.

Asphalt binders exhibits visco-elastic properties, which means it behaves like a viscous liquid at high temperature and elastic solid at low temperature. The behavior of asphalt binder is dependent upon time, temperature and aging conditions. The visco-elastic properties of asphalt binder affect the performance of the pavements [7]. At present in Pakistan the asphalt

binder's specifications are typically based on measurements of viscosity, penetration and ductility. These measurements are not sufficient to completely describe viscous and elastic properties that are needed to define the performance of pavement.

Visco-elastic properties of asphalt binder can be described by using complex shear modulus ( $G^*$ ) and phase angle ( $\delta$ ).  $G^*$  is a measure of total resistance of a material to deformation under repeated action of shearing stress. It has two components: one is elastic component as shown on horizontal axis and second is viscous component as indicated on vertical axis in Figure 1. Phase angle ( $\delta$ ) is the angle made by complex modulus with the horizontal axis and it is the indication of amount of temporary and permanent deformation. In this example as follows in Figure 1, two visco-elastic asphalts are considered; asphalt 1 is more viscous because of its larger  $\delta$ . Similarly the elastic component of asphalt 2 is more as compared to 1. For asphalt binder the value of  $G^*$  and  $\delta$  is highly dependent on rate of loading and temperature [6].

Temperature susceptibility of asphalt cement is an important control parameter during the mixing,

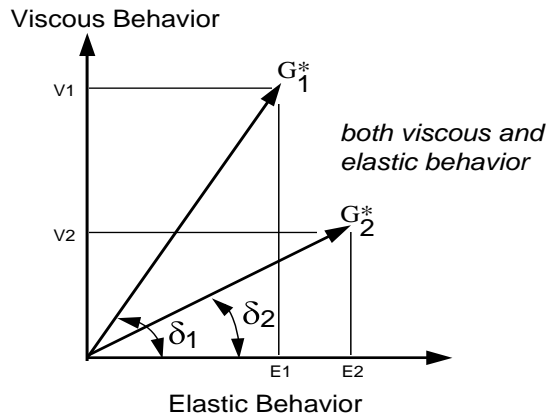
placing, compaction, and performance of asphalt concrete [5]. Viscosity temperature susceptibility and temperature relationship is used to predict the rheological properties of asphalt binder. A regression of the double logarithm of the viscosity points versus the logarithm of respective temperatures in the Rankine scale ( $T_R$ ) provides the basis of the ASTM  $A_i$ -VTS $_i$  relationship as follows in Eq. 1 [3].

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

Where,

- $\eta$  = viscosity, cP
- $T_R$  = temperature, degree Rankine
- A = regression intercept
- VTS = regression slope (viscosity temperature susceptibility parameter)

Once the A and VTS values are known, then its viscosity over a range of temperatures can be predicted by using Eq. 1.



**Figure 1:** Visco-elastic behavior of asphalt

## 2. Prediction Models for Asphalt Binders

Sometimes it becomes difficult to conduct full range binder characterization tests. Therefore, some empirical relationships and predictive models are available for the indirect measurement of  $G^*$  or  $\eta$  [4].

In current Superpave binder characterization methodologies, the use of the binder complex shear modulus ( $G^*$ ) is considered very important. In contrast to the ASTM viscosity temperature relationship, the  $G^*$  describes the change in binder stiffness under dynamic loading with changing loading time or frequency. One of the latest  $\eta$ - $G^*$  predictive models was developed by Witczak and his

colleague at the University of Maryland [4]. The models are given in Eq. 2-3.

$$\eta = \left( \frac{G^*}{\omega} \right) \left( \frac{1}{\sin \delta} \right)^{a_0 + a_1 \omega + a_2 \omega^2} \quad (2)$$

$$\delta = 90 + (b_1 + b_2 \text{VTS}) \log(G^*) + (b_3 + b_4 \text{VTS}) \{ \log(G^*) \}^2 \quad (3)$$

Where,

- $\eta$  = binder Viscosity, cP
- $G^*$  = binder shear modulus, Pa
- $\delta$  = binder phase angle, degree
- $\omega$  = angular frequency, rad/sec

$a_0, a_1, a_2$  = fitting parameters respectively 3.63922, 0.13137 and -0.0009

$b_1, b_2, b_3$  and  $b_4$  = fitting parameters -24.878, -7.2734, 1.8118 and 0.77054

For  $\omega$  = 10 rad/s, which is the specified test frequency in the Superpave Performance Grading system and Eq. 2 becomes:

$$\eta = \left( \frac{G^*}{10} \right) \left( \frac{1}{\sin \delta} \right)^{4.8628} \quad (4)$$

## 3. Methodology

This comprehensive research included laboratory testing for the evaluation of visco-elastic properties of locally available asphalts in Pakistan. Six Asphalt samples were obtained from Attock and Karachi Oil refinery. All the asphalt samples were tested in the laboratory by using Dynamic Shear Rheometer apparatus. The main objective of this research is to synthesize the laboratory test results of binders, VTS analysis, and comparison of viscous and elastic properties between Attock and Karachi Asphalt samples in order to predict their behavior for rutting and cracking potential.

## 4. Materials

Six types of asphalt binders were selected for experimental investigating. These asphalts samples covered a wide range of practical usage for pavements that serve in hot and cold climates of Pakistan. These asphalts include three grades of Attock Oil Refinery that are 60/70, 60/70P, 80/100 and three grades of

Karachi Oil Refinery that are 40/50, 60/70, 80/100 grades of Karachi.

## 5. Equipment

Dynamic Shear Rheometer (DSR) was used to evaluate the visco-elastic properties of six asphalt samples. 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 2. The DSR measures the complex shear modulus ( $G^*$ ), and phase angle ( $\delta$ ) of the binder. DSR tests are conducted from intermediate to high temperature and parameters of DSR test are calculated by using Eq. 5-8 [1-2].

$$\tau_{\max} = \frac{2T}{\pi r^3} \quad (5)$$

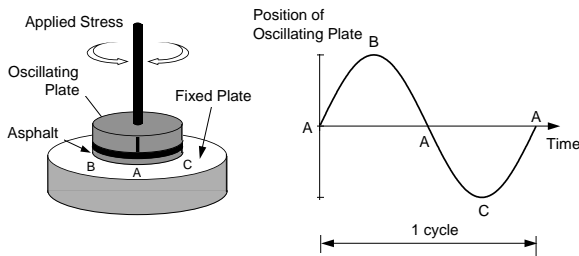
$$\gamma_{\max} = \frac{\theta r}{h} \quad (6)$$

$$G^* = \frac{\tau_{\max}}{\gamma_{\max}} \quad (7)$$

$$\delta = \text{time lag} \quad (8)$$

Where,

- $\tau_{\max}$  = maximum applied shear stress
- T = maximum applied Torque
- R = radius of specimen
- $\theta$  = deflection angle
- h = specimen height
- $G^*$  = complex shear modulus
- $\Delta$  = phase angle



**Figure 2:** Operational Mechanism of DSR Test

Tests were conducted on each asphalt sample at a single frequency of 10.0 rad/sec according to AASHTO TP5<sup>1</sup>. Each type of asphalts were tested at 46, 52, 58, 64, 70, 76, 82 °C by using 25 mm diameter

plate with 1 mm gap and at 7, 13, 19, 25, 31, 34 °C by using 8 mm diameter plate with 2 mm gap [2]. The operational mechanism of Dynamic Shear Rheometer is given in Figure [6].

## 6. Discussion and Test Results

The asphalt samples from Attock Oil Refinery and Karachi Oil Refinery were obtained. These includes 60/70, 60/70P and 80/100 grades of Attock and 40/50, 60/70, 80/100 grades of Karachi. All the asphalt samples were tested from intermediate to high temperature. Initially, tests were performed at seven high temperatures, 46, 52, 58, 64, 70, 76, 82 °C, by using 25 mm diameter plate with a gap of 1 mm at a frequency of 10 rad/sec. In the second stage all asphalt samples were tested at six intermediate temperatures, 7, 13, 19, 25, 31, 37, by using 8 mm diameter plate with a gap of 2 mm at a frequency of 10.0 rad/sec. The plots of complex shear modulus and phase angle are given in Figure 3-4.

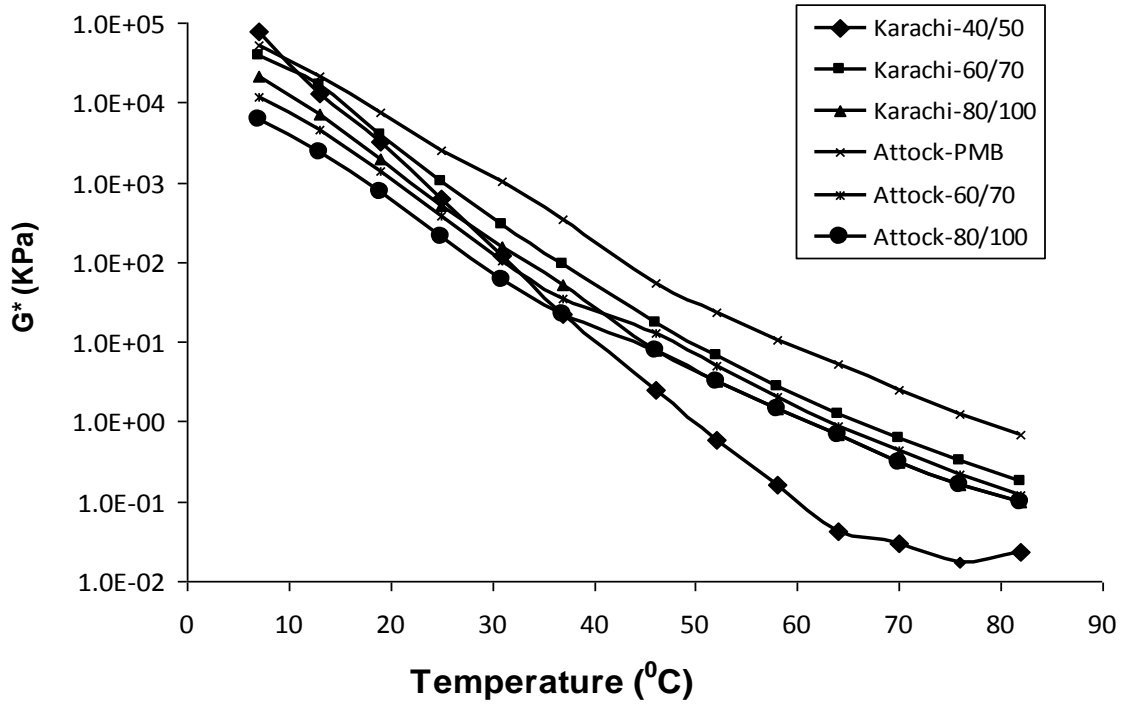
## 7. Analysis of Test Results

In Analysis the elastic modulus ( $G'$ ) or storage modulus and viscous modulus ( $G''$ ) or loss modulus were calculated by using complex shear modulus and phase angle for all six asphalt samples. Elastic modulus was calculated by multiplying complex shear modulus with cosine of phase angle whereas viscous modulus was calculated by multiplying the complex shear modulus with the sine of phase angle. The comparison for viscous and elastic component was made between Attock and Karachi asphalt samples. The comparative plots for viscous and elastic modulus are given in Figure 5-6.

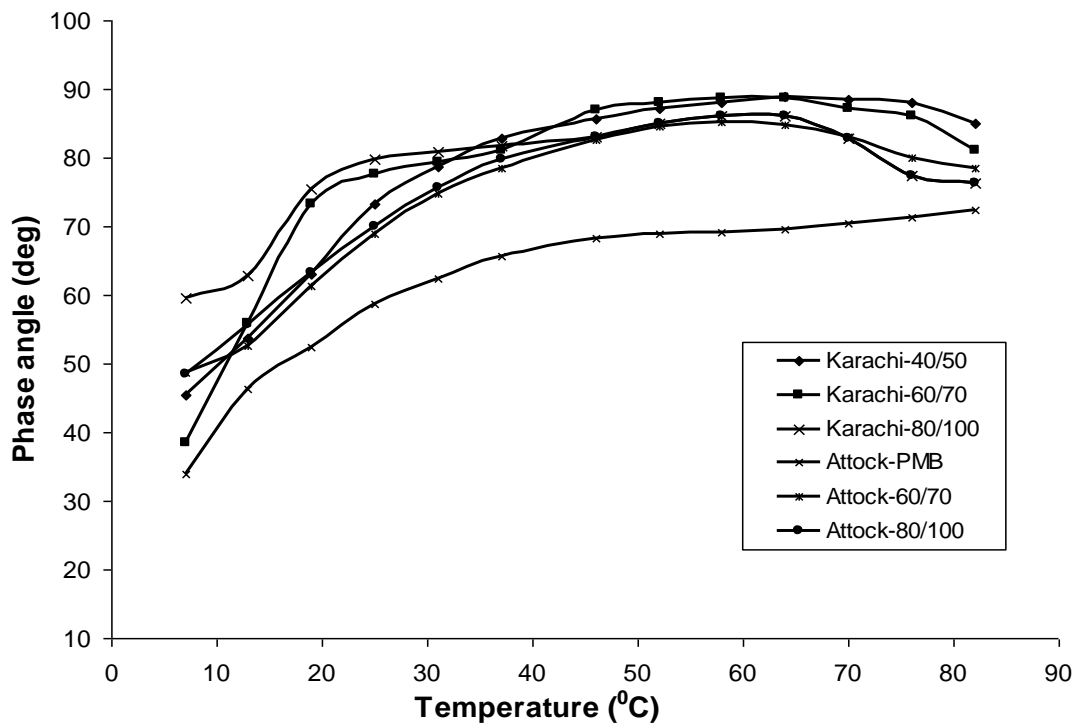
High viscous and high elastic comparison at lower and high temperature between Karachi and Attock Asphalt samples is given in Table 1.

**Table 1:** High viscous and high elastic comparison

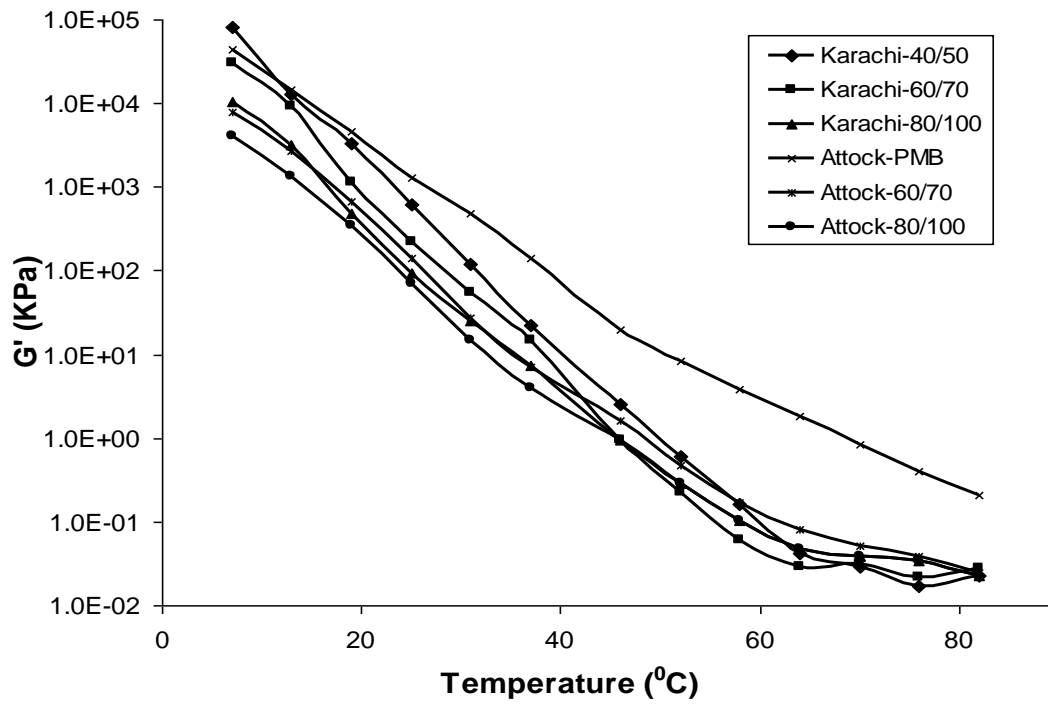
Asphalt	Low Temperature		High Temperature	
	High Viscous	High Elastic	High Viscous	High Elastic
Attock-PMB & Karachi 40/50	Karachi 40/50	Karachi 40/50	Attock PMB	Attock PMB
Attock 60/70 & Karachi 60/70	Karachi 60/70	Karachi 60/70	Karachi 60/70	Karachi 60/70
Attock 80/100 & Karachi 80/100	Karachi 80/100	Karachi 80/100	Karachi 80/100	Karachi 80/100



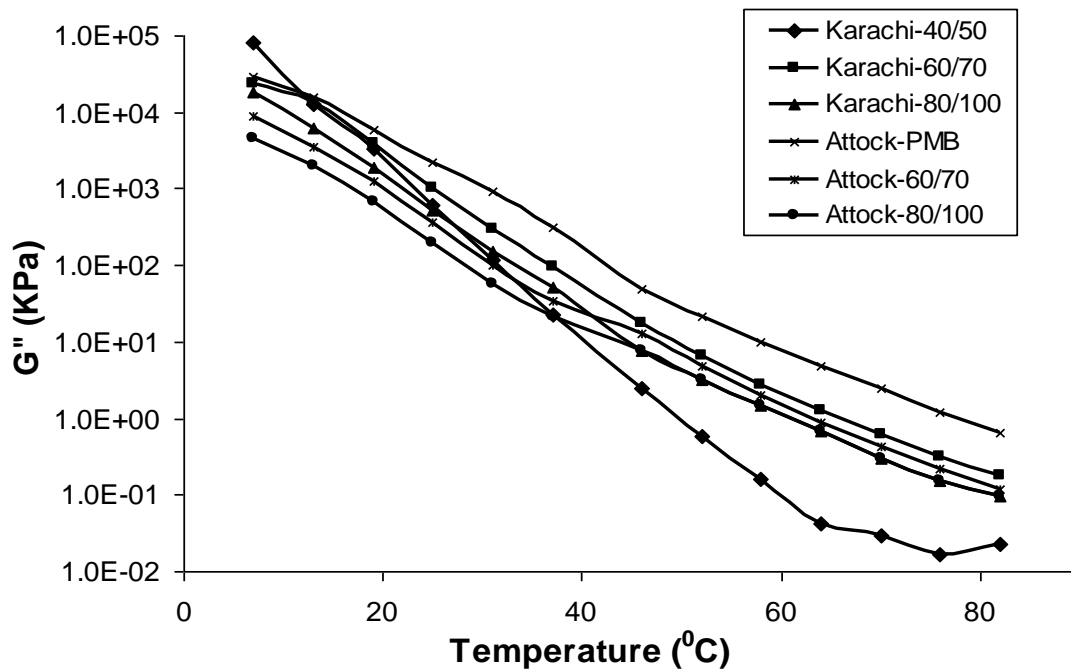
**Figure 3:** Complex shear modulus vs. Temperature



**Figure 4:** Phase angle vs. Temperature



**Figure 5:** Comparative Plot between Attock and Karachi Asphalt Samples for  $G'$



**Figure 6:** Comparative Plot between Attock and Karachi Asphalt samples for  $G''$

The prediction model as given in Eq. 3 was used to predict the phase angle for all asphalt samples by using their VTS and  $G^*$  values. A comparison was made between the phase angle obtained from test results and the phase angle obtained from prediction model of phase angle. The predicted phase angle is relatively higher than test results at all temperatures.

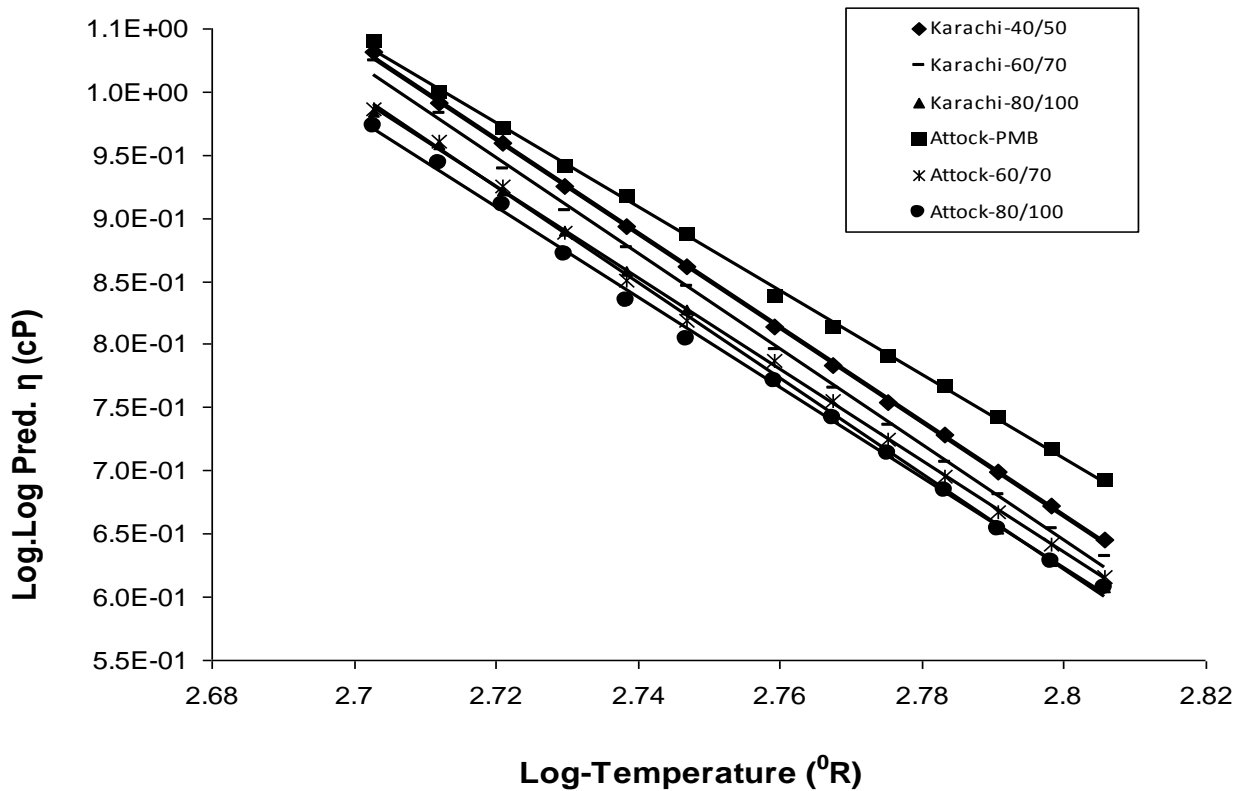
Binder viscosity was calculated by using Eq. 4 and then VTS analysis was performed for all the six asphalt samples. For VTS analysis log-log of viscosity ( $\eta$ ) was plotted against log of temperature in Rankine to determine temperature susceptibility of asphalt. The VTS plot between Attock and Karachi asphalt samples is given as in Figure 7.

VTS analysis shows that the Attock PMB (polymer modified bitumen) has lesser temperature

susceptibility as compared to Attock 60/70 and Karachi 40/50, 60/70. Similarly Attock 60/70, 80/100 is less susceptibility to temperature as compared to Karachi 60/70, 80/100. The results of VTS analysis are given in Table 2.

**Table 2:** Results of VTS analysis

Asphalt Type	VTS	A	$R^2$
Karachi 40/50	3.7261	11.097	0.999
Karachi 60/70	3.7863	11.247	0.998
Karachi 80/100	3.7756	11.194	0.999
Attock PMB	3.3228	10.014	0.999
Attock 60/70	3.6238	10.781	0.998
Attock 80/100	3.5751	10.633	0.998



**Figure 7:** VTS Plot between Attock and Karachi Asphalt samples

## 8. Conclusions

1. There is significant effect of polymer in reduction of temperature susceptibility as temperature susceptibility of Attock PMB is lesser as compared to virgin asphalts so making it more suitable binder to use in extreme climatic conditions.
2. The Attock 60/70P asphalt has high stiffness and elasticity as compared to Attock 60/70 and Karachi 40/50, which means it, has more resistance to permanent deformation in high temperature region of Pakistan.
3. Attock virgin asphalt samples are less susceptible to temperature as compared to Karachi virgin asphalt samples but Karachi virgin asphalt samples are more elastic as compared to Attock virgin asphalt samples both at high and low temperature.
4. Witczak prediction model has good applicability in prediction of viscosity and phase angle for Pakistani asphalts.

## References

- [1] AASHTO M 320; Standard Specification for Performance-Graded Asphalt Binder, (1994), FHWA-SA-94-068.
- [2] AASHTO TP5<sup>1</sup>; Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using Dynamic Shear Rheometer, (1994), FHWA-SA-94-068.
- [3] D. A. Anderson, D. W. Christensen, H. U. Bahia, R. Dongre, M. G. Sharma, C. E. Antle, and C. E. J. Button; Binder Characterization and evaluation, Vol. III, Physical Characterization, and Strategic Highway Research Program report, SHRP A-369, (1994), Washington, D.C.
- [4] Javed Bari and M. W. Witczak; New Predictive Models for the viscosity and complex shear modulus of asphalt binders for use with the Mechanistic Empirical Pavement Design Guide, Transportation Research Board 2007 Annual Meeting CD-ROM.
- [5] F. L. Roberts, P. S. Kandahal and E. R. Brown; Hot Mix Asphalt Materials, Mixture Design, and Construction, 2nd Edition, Lanham Maryland: NAPA Education Foundation, (1996).
- [6] SUPERPAVE Asphalt Mixture Design; Lecture Notes, National Asphalt Training Center, Demonstration Project 101, Federal Highway Administration Office of Technology Applications, Washington D.C, (1994).
- [7] Waheed Uddin; Visco-elastic Characterization of Polymer Modified Asphalt Binders of Pavement Applications, the University of Mississippi, USA, Vol 13. Applied Rheology, (2003).