# Performance of Pavements under Extreme Loading and Temperature Conditions using Polymer Modified Bitumen

Kamran Muzaffar Khan[1] and Ali Asghar[2]

**Abstract**

Roads and pavements in Pakistan are prone to varying temperature and extreme loading conditions throughout year which results in disintegration, rutting, development of stresses in road. Accumulated strain, Resilient strain, Creep stiffness and Modulus of resilience of asphalt concrete mixes have been studied by changing temperatures at 500KPa loading to understand the pavement behaviour under high temperature. Tests were performed using Universal Testing Machine (UTM 5P) on the mixes prepared in the laboratory. Polymer Modified Bitumen (PMB) is used in 50% mixes to compare the behaviour of in situ Asphalt Concrete mixes with and without PMB under same temperature & loading conditions. Binder 60-70 was used in all mixes. Percentage of PMB used was 3.0%, 3.5%, 4.0%and 4.5% for mixes. The results of laboratory tests on asphalt mixes under the influence of load, environmental and mix variables are studied and presented in this search. Main properties have been tabulated and analysis has been made, which shows certain important results. Tests have been performed at 40°C and 55°C for 60-70 binder and PMB separately..UTM-5P was used to study the Accumulated strain, resilient strain, Creep stiffness and Modulus of resilience of each sample. Results obtained from the tests depicts that PMB shows better performance as compared to the ordinary mixes.

**Key Words :** Polymer modified bitumen, Accumulated strain, Resilient strain, Creep stiffness, Modulus of resilience.

## Introduction

There have been different problems associated with the performance of asphalt in the high temperature areas of country. Asphalt having dual nature of ductility and flow, behaves as liquid at extreme temperature and shows ductile nature at low temperature. The main cause of failure of pavements in Pakistan is rutting due to high variations in temperatures, uncontrolled heavy axle loads and limitations of pavement design procedures to meet local conditions. Several ways of failure that an asphalt pavement may experience are rutting, fatigue cracking and low-temperature cracking. Repeated, heavy traffic loads can permanently deform an asphalt pavement causing rutting. Such occurs during the warm climates due to a decrease in asphalt viscosity. Low-temperature cracking occurs at sub freezing temperatures when the viscosity of asphalt is high and is caused by the tensile stress that develops as a result of shrinkage. Whereas, Fatigue cracking is caused due to cyclic loading under repeated stress. For a pavement to resist rutting, fatigue cracking and low-temperature cracking, it must perform well under a wide range of environmental conditions. Use of Polymer Modified Bitumen (PMB) has shown better results in the field of pavement construction as it better addresses the relevant premature failures (Fatigue Cracking, Rutting, and Low Temperature Cracking), hence asphalt can sustain more.

## Bitumen Composition and Structure

Bitumen is a complex combination of predominantly hydrocarbon nature. The composition depends on the origin of crude oil and the processes used during bitumen manufacture. The chemical composition of the bitumen is highly complex and its analysis is very difficult. Generally bitumen can be divided into two main chemical groups:-

a) Asphaltenes
b) Malatenes

[1]Associate Professor, CED UET Taxila, [2]Taxila Institute of Transportation Engg., UET Taxila
Corresponding author: [1]kamran.muzaffar@uettaxila.edu.pk

**Asphalt Modifiers**

Elvaloy is “an ethylene glycidyl acrylate (EGA) terpolymer that chemically reacts with asphalt. Roads using Elvaloy have been in use since1991”.Witczak et. al, (1995) investigated the behavior of Elvaloy modified asphalt concrete mixes. They used two asphalt binders of different grades and each of them was modified with 0%, 1.5% and 2%, Elvaloy by weight of asphalt binder.

**Selection of source of material**

Following sources for materials were selected:-

Aggregate from Margalla Hills, Bitumen (60-70) from Attock Oil Refinery and (PMB) from Attock Oil Refinery and Following test were carried out for aggregates.

a) Abrasion Test b) Soundness test c) ductility of bitumen d) Penetration Test e) Softening point

**Bitumen Content Variation**

Table 1 : Percentage of Binders used

| Binder %Used | MOULD COMPACTED | |
|---|---|---|
| | 60 - 70 | P M B |
| 3.0 | 9 | 9 |
| 3.5 | 9 | 9 |
| 4.0 | 9 | 9 |
| 4.5 | 9 | 9 |

**Molding of Sample**

Hot mix sample prepared at 155°C was placed in the mould and compacted with 10 lb hammer with 75 blows each side. The sample was ejected after 24 hrs and 2 samples of each binder variation were tested for its stability and flow.

**Polymer Modified Bitumen (PMB)**

Polymer modified bitumen, obtained from Attock Refinery Limited, Rawalpindi; having the base AC of penetration grade 60-70 modified with 1.3% Elvaloy has been used. Specifications of PMB are shown in Table 2.

Table 2 : Specifications of PMB

| Sr. No | Test Description | PMB | Max/Min |
|---|---|---|---|
| 1 | Flash Point, °C | 232 | Min |
| 2 | Softening Point, °C | $60\pm2$ | Min |
| 3 | Torsional Recovery | 12 | Min |
| 4 | Viscosity @ 165°C, Pa*S | 0.75 | Min |
| 5 | Loss on Heating, wt % | 0.6 | Max |

**Gradation of Aggregates**

Aggregates have been collected from Margala; near Taxila as per specifications of NHA Class-A Asphaltic Base Course. The aggregates were weighed accordingly in the Highway Lab of UET Taxila on an electric balance, hence forming a total of 7000 in each Mix Sample.NHA ClassA aggregate details qualifying the 0.45 Power Curve Criteria are as below in table 3.

Table 3: Aggregate Gradations (NHA Class-A)

| S. No. | Sieve Size | | Master Band | | Trial Blend , Weight = 7000 gms | | | |
|---|---|---|---|---|---|---|---|---|
| | Mm | Inch | Min(% Passing) | Max(% Passing) | Trial Blend, Material Passing (%) | Material Retained (%) | | Weight Retained (gms) |
| 1 | 0 | 0 | ----- | ----- | ---- | 5 | ( In Pan ) | 350 |
| 2 | 0.075 | (No.200) | 2 | 8 | 5 | 6.5 | ---------- | 455 |
| 3 | 0.3 | (No.50) | 5 | 12 | 11.5 | 18.5 | ---------- | 1295 |
| 4 | 2.36 | (No.8) | 23 | 35 | 30 | 16 | ---------- | 1120 |
| 5 | 4.75 | (No.4) | 35 | 50 | 46 | 19.5 | ---------- | 1365 |
| 6 | 9.5 | 3/8 inch | 56 | 70 | 65.5 | 24.5 | ---------- | 1715 |
| 7 | 19 | 3/4 inch | 90 | 100 | 90 | 10 | ---------- | 700 |
| 8 | 25 | 1 inch | 100 | 100 | 100 | 0 | ---------- | 0 |
| **Total** | | | | | | **100%** | | **7000gms** |

The aggregates were thoroughly mixed at a temperature range of about 150°C to 155°C and then Bitumen (Penetration Grade 60-70) confirming to Performance Grades at pavement temperatures up to 64°C at 4.3 % of the total aggregate sample was accordingly mixed in order to prepare a trial blend A. The Rheological Tests on binder were conducted on a DSR machine.

**Procedure**

**1 Uni-Axial Load Strain test**

The Uni-Axial Load Strain Test Results may include the following data relevant to the mix's performance under loads, temperatures and frequencies.

Accumulated Strain

Resilient Strain

Creep Stiffness

**Resilient Modulus**

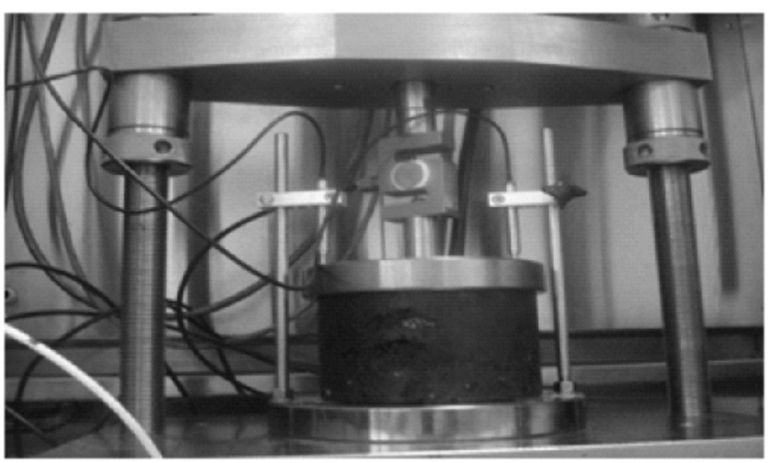

Figure 1: UTM-5P Testing Apparatus

These properties of the mix determine the stability of the mix against temperature, loading and time of loads acting on the pavement.

**Test of samples in lab on UTM 5 for repeated Uniaxial Load Test**

The samples were first of all measured. Then the temperature of UTM was adjusted and samples were placed inside UTM and settings for the sample were made. After placing and setting the sample, the parameters for sample testing were amended on software as under:

a. Load Applied = 500Kpa
b. Pulse Period = 2000
c. Pulse width = 500
D. Terminal Pulse Count = 1200

Table 4: Based upon above parameters following test results for various Binder Contents of bitumen 60 70 and PMB were achieved.

| Binder Content | Value of | A/U | Temp 40ºC | | Temp 55ºC | |
|---|---|---|---|---|---|---|
| | | | 60-70 | PMB | 60-70 | PMB |
| 4.5 | Accumulated Strain | % | 0.2274 | 0.1331 | 0.6268 | 0.2005 |
| | Resilient Strain | % | 0.1338 | 0.1061 | 0.1690 | 0.1022 |
| | Creep Stiffness | Mpa | 24.6310 | 48.9870 | 47.55 | 68.83 |
| | Resilient Modulus | Mpa | 135.7740 | 465.53 | 306.02 | 476.23 |
| 4.0 | Accumulated Strain | % | 0.2013 | 0.1468 | 0.5134 | 0.1892 |
| | Resilient Strain | % | 0.1685 | 0.0621 | 0.1769 | 0.1406 |
| | Creep Stiffness | Mpa | 49.6700 | 169.88 | 51.65 | 144.62 |
| | Resilient Modulus | Mpa | 295.15 | 806.32 | 283.34 | 813.35 |
| 3.5 | Accumulated Strain | % | 0.2464 | 0.2040 | 0.6396 | 0.2046 |
| | Resilient Strain | % | 0.1141 | 0.0452 | 0.1124 | 0.1673 |
| | Creep Stiffness | Mpa | 39.9620 | 57.560 | 49.54 | 70.96 |
| | Resilient Modulus | Mpa | 435.8570 | 842.32 | 312.27 | 496.08 |
| 3.0 | Accumulated Strain | % | 0.1831 | 0.0872 | 0.6663 | 0.1527 |
| | Resilient Strain | % | 0.1405 | 0.1098 | 0.1745 | 0.1171 |
| | Creep Stiffness | Mpa | 40.21 | 53.71 | 47.35 | 67.74 |
| | Resilient Modulus | Mpa | 430.2090 | 653.904 | 325.29 | 467.2700 |

**Graphical representation**

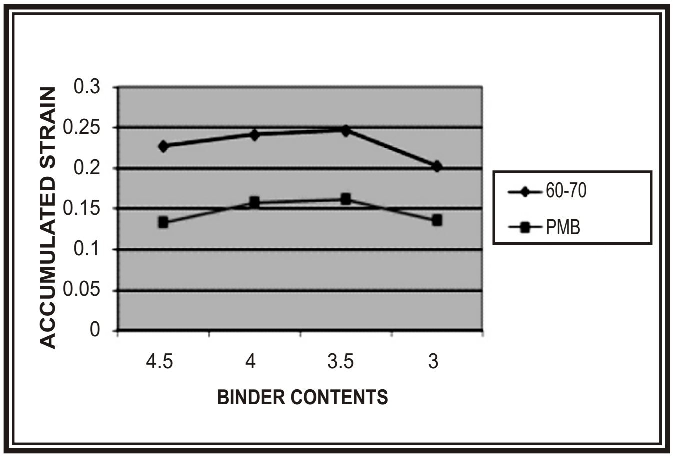


Figure 1(a): (Relationship b/w Accumulated strain & Binder content at 40°C)

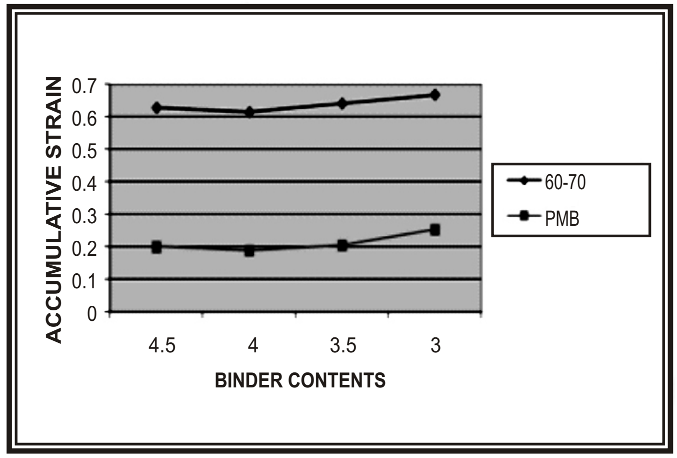


Figure 1(b): (Relationship b/w Accumulated strain & Binder content at 55°C)

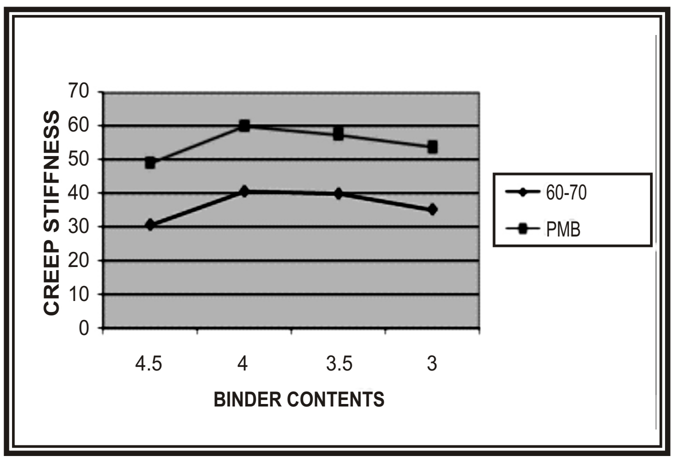


Figure 2(a): (Relationship b/w Creep stiffness & Binder content Binder 40°C)

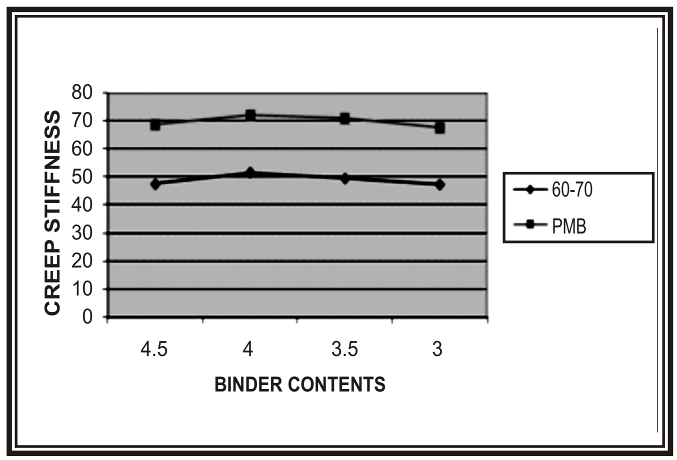


Figure 2(b): (Relationship b/w Creep stiffness & Binder content at 55°C)

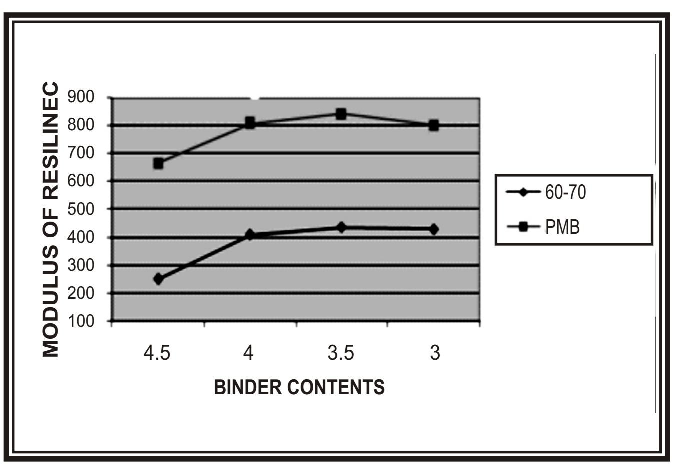


Figure 3(a): (Relationship b/w Modulus of Resilience & Binder content at 40°C)

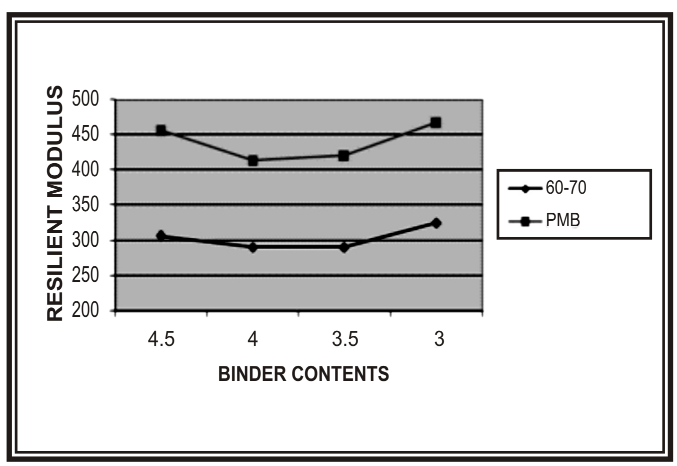


Figure 3(b): (Relationship b/w Modulus of Resilience & Binder content at 55°C)

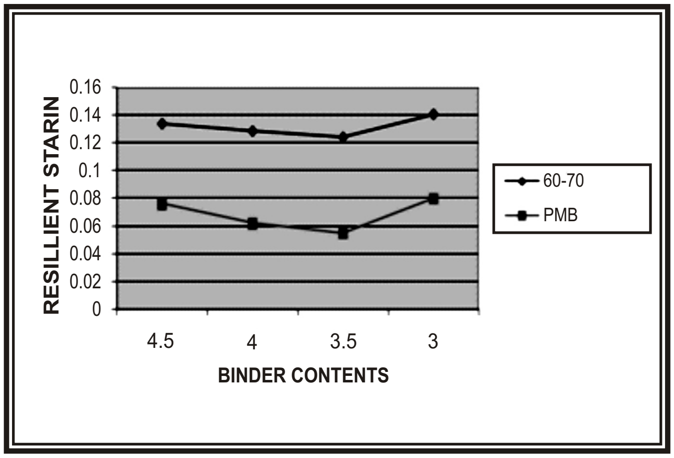


Figure 4(a): (Relationship b/w Resilient strain & Binder content at 40°C)

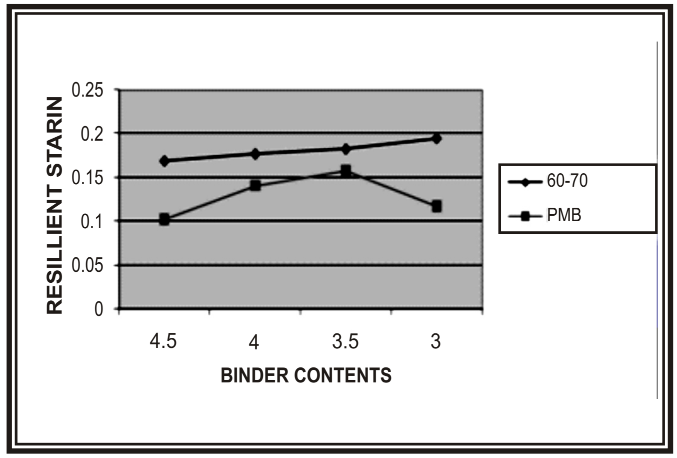


Figure 4(b): (Relationship b/w Resilient strain & Binder content at 55°C)

**Results and Analysis**

Results obtained from the graphical representation have been given below:-

Accumulated strain at 40°C has been represented in the graph 1(a). From this graph it is observed that the level of accumulated strain was found to be more in 60-70 binder as compared to the PMB binder. This accumulated strain is more in both cases at binder contents 3.5 and it decreases as contents amount is increased or decreased from binder content 3.5. This indicates that at constant temperature for a particular binder content 3.5 accumulated strain is maximum for both 60-70 and PMB samples.

Accumulated strain at for same binder content and 60-70 samples has been represented in graph 1(b). It is observed that value of accumulated strain has been observed to be less even at 55°C in the PMB sample. Although rate of change has been approximately same in both samples yet level of accumulated strain is less which is important As a matter of fact about 30% of accumulated strain is reduced by using Polymer modified bitumen.

It is observed that there has been change in accumulated strain for both PMB and 60-70 samples at 40°C and also there has been smooth change in the accumulated strain for 55°C. This shows that the behavior of accumulated strain is temperature dependent as temperature increases its rate of change becomes smooth.

It was also observed that there has been more change in accumulated strain at both 40°C and 50°C for binder content 3 to 3.5 where as for both 40°C and 50°C there has been smooth change in accumulated strain. This also depicts that there has been certain specific value of binder content which gives designed accumulated strain. On comparison of both graphs it is observed that there has been inverse relation of temperature at 40°C and 55°C. Unquestionably the value of accumulated is less for PMB.

Creep Stiffness has been presented in the Graph 2(a) at 40°C. The value of creep stiffness is more for PMB samples as compared to the 60-70 samples. It has been observed that for 40C the creep stiffness shows rapid rate of change with increase in binder contents from 3 to 3.5 and 3.5 to 4, but from 4 to 4.5 there is relatively smooth change in the value of creep stiffness.

Graph 2(b) shows even smoother rate of change in the creep stiffness at 50°C and there has been smooth change as compared to 40°C. There has been increase in value of creep stiffness with the rise of temperature and same for 60-70 samples. The stiffness was found to be more satisfactory in PMB even at higher temperature of 55°C as compared to the 60-70 binder at 55°C.

Overall performance of PMB specimen has been observed to be better both at 40°C and 55°C and in both cases value of Creep stiffness is specific at binder content 4.0.

The behavior of resilient modulus has been presented in the graph 3(a). At 40°C value of resilient modulus show a continuous changing behavior. At binder content 3 to 3.5 for both PMB and 60-70 samples value increases and for 3.5 to 4 this value approximately remain uniform. However from 4 to 4.5 again there is change in the resilient modulus. Comparing rate of change in both PMB and 60-70 at 40°C, it has been observed that for both cases this change has been observed uniform in both.

At 55°C there has been changing behavior of resilient modulus in the PMB samples from 3 to 4.5, where as an approximately uniform behavior in change has been observed in the 60-70 samples. Comparing values of resilient modulus at 40°C and 55°C, it is observed that value of resilient modulus has decreased with rise in temperature. Hence we conclude that resilient modulus is temperature dependent. Result is that resilient modulus of PMB is found much higher than 60-70.

Graph 4(1) shows the temperature effects on resilient strain. Resilient strain is much lesser in the PMB samples than 60-70 at 40°C. Rate of change of resilient is more in PMB samples as compared to 60-70. An abrupt change has been observed in resilient strain from 3 to 4 for 40°C.

At 55°C Resilient Strain Behavior Has been shown in graph 4(b). Value of resilient strain has been recorded to be low for PMB samples as compared to 60-70 samples. However there is gradual decrease in the value of 60-70 samples for resilient strain with the increase in the binder contents from 3 to 4.5. For PMB resilient strain value also decreases but from 3 to 3.5 binder content it increases and then from 3.5 to 4.5 decreases. There has been more decrease in the PMB than 60-70.Resilient strain was also found to be more in PMB and was recorded to be less in the 60-70.

**Conclusions**

Accumulated Strain is less in case of PMB as compared to 60-70 at 40°C and 55°C.

Creep Stiffness is more in PMB as compared to 60-70 at 40C and 55°C.

Resilient Modulus is higher in PMB as compared to 60-70 at 40°C and 55°C.

Creep Stiffness is less in PMB as compared to 60-70 at 40°C and 55°C.

The performance of PMB was found to be far better than 60-70 at high temperature ranges.

Overall performance parameters are also better in PMB than 60-70.

As the performance of PMB was found to be consistent even at a higher temperature, it is concluded that use of PMB gives better performance as compared to 60-70 samples, so it is recommended to use PMB even in the temperature prone pavements.

**Recommendations**

The use of PMB in high temperature zone gives better performance than 60-70.

The use of PMB increases the efficiency of pavements by 30%.

In Pakistan environment use of PMB can result in the better performance of roads and flexible pavements.

As PMB gives better performance so Usage of PMB ensures increase in the age of pavement.

Use of PMB in the southern Punjab will ensure better performance of pavements and roads.

Use of PMB in the colder areas of country will ensure better performance of pavements and roads.

**References**

[1] Asphalt Institute, (1995) "Superpave Level 1 Mix Design," Asphalt Institute Superpave Series No.2 (SP-2), Lexington, KY.

[2] Kamal M. A. , Shahbaz F. , Yasin B.(2005), Resilient Behavior of Asphalt Concrete under Repeated Loading &

Effects of Temperature Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 1329 - 1343

[3] Dr. Ir. AH., de Bondt, ir .R.C.van Rooijen, “Bitumen Performance in pavement sunder extreme climatic conditions”

[4] Imran Hafeez, Mumtaz Ahmed Kamal, “Repeated load permanent deformation behavior of mixes with and without modified bituments”

[5] Jeff A. Jirak, Dr. Robert Statz “Du Point Elvaloy Road Evaluation Report”