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Evaluation of Rutting Potential of Polymer Modified Asphalt Binder Using Multiple Stress Creep and Recovery Method

Ahad Ali[1*], Zia ur Rehman[2], Umer Farooq[2], Muhammad Waseem Mirza[3]

1. *Department of Civil Engineering, University of Engineering and Technology, Lahore.*
2. *Department of Transportation Engineering and Management, University of Engineering and Technology, Lahore.*
3. *Pavement Manager, Parsons, Doha, Qatar*

* **Corresponding Author:** Email: alizeshan48@yahoo.com

Abstract

Asphalt is a viscoelastic material as its properties depend on the temperature, loading and aging conditions. High temperature causes flexibility in asphalt concrete as a result the mix is more susceptible to the rutting and the low temperature causes the stiff asphalt and the thermal cracking problem is more significant in this case. This research is aimed at evaluating the rutting susceptibility of neat and polymer modified asphalt by Performance Grading Plus test Multiple Stress Creep and Recovery test (MSCR). MSCR is effective for neat and polymer modified asphalts and also it is blind to the modification type. In this research asphalt neat samples of KRL (40-50, 60-70, 80-100) and ARL (60-70, 80-100) were used. ARL (60-70) was modified with Elvaloy® RET (Reactive Elastomeric Terpolymer) and KRL (60-70) was modified with Elvaloy® AC (Acrylate Terpolymer). Polymer percentages used for ARL (60-70) were 0% (neat), 1.35%, 1.70% and 2.0% whereas for KRL (60-70) was 0% (neat), 2.50%, 3.50% and 4.5%. Dynamic Shear Rheometer (DSR) was used to carry out MSCR test at stress levels of 100Pa and 3200Pa and at temperatures of 58ºC, 64ºC, 70ºC and 76ºC. Performance of asphalt was evaluated by analyzing the non-recoverable creep compliance (Jnr), Peak strain and Percent recovery. Modified temperature grade of asphalt were determined by comparing the actual Jnr value to the Jnr=9.46 as it corresponds to the G/Sin δ =1000Pa. Results showed that neat sample of KRL compared to neat samples of ARL were found good to prevent rutting as they showed less peak strain, more percent recovery and less Jnr value. Polymer modification improved the properties of asphalt as it showed decreasing trend of peak strain, increasing trend of the percent recovery and also decreasing trend of Jnr values. Further high temperature grade bumping happened for polymer modified asphalts.*

Key Words: Rutting; Multiple Stress Creep and Recover (MSCR); Polymer Modification; Modified Temperature Grade

1. Introduction

The hot mix asphalt (HMA) industry has been facing challenges to meet the demands of increased traffic flows and commencement of China Pakistan economic corridor (CPEC). Exposure to high temperature [1] and increased wheel loads [2] deteriorating the road surfaces and cause the premature failure of roads in Pakistan. Mostly flexible pavements are used in Pakistan for surfacing the roads. Therefore it is needed to evaluate the mixes for long term performance bearing the heavy wheel loads.

Main ingredient of hot mix asphalt (HMA) are aggregate and asphalt binder. In mix percentage asphalt is small compared to the aggregate but it effects the pavement performance more compared to aggregate. As the environmental factors sun radiations, heat affect asphalt more compared to aggregate.

Asphalt being a viscoelastic material is highly dependent on the temperature, loading and the aging conditions [3]. Viscosity of the asphalt is highly affected by the temperature. At low temperature it becomes stiff and behaves like a solid resulting cracking problem in the pavement during the winter season. At high temperature it behaves like a liquid and causes flexibility in asphalt concrete as a result the pavement is more susceptible to the rutting [4][5]. Rutting of asphalt pavement is one of the most common forms of road failure. Permanent deformation of bituminous layer has a significant contribution to rutting and is due to the combination of densification and shear deformation [6]. For bituminous mixture, well compacted during construction, it has been found that shear failure is the primary cause of rutting. Shear deformation of bituminous mixture is due to the viscous behavior of material and manifests itself as ridges adjacent to the wheel path. When the wheel load is applied on the element of bitumen in a pavement, it causes some deformation in the material. After the load has passed, part of the deformation will be recovered and some remain in the material as permanent deformation. Accumulation of these permanent deformation results in pavement rutting.

Higher traffic loads with severe loadings have paved the way of asphalt manufacturers to produce the polymer modified asphalt to make the pavements more durable. A lot of research on G*/Sin δ parameter have showed that this high temperature parameter is not suitable for evaluating the rutting behavior of polymer modified asphalt binders [7] [8]. It is true that G*/Sin δ can show the visco-elastic characteristics of the neat asphalt binders but not for polymer modified asphalt binders. In order to evaluate performance of the polymer modified binders in Superpave grading system (AASHTO MP 19-10) [9] new specification of performance grade (PG) plus test were introduced. The multiple stress creep and recovery (MSCR) is the new PG-Plus test that is performed using AASHTO TP 70 [10]. Dynamic shear rheometer is used to conduct this test. It has a parallel plate geometry with spindle of 25mm diameter and gap of 1mm. Stress levels for loading and unloading are 100Pa and 3200Pa with loading cycle time of 1s and unloading of 9sec. At each stress level total number of loading and unloading cycle are ten. Form this test we analyze the non-recoverable creep compliance (Jnr) and percent recovery (% recovery) that are used for further evaluation of rutting potential of asphalt.

2. Objectives and Scope of Work

The main objective of this research was to carry out MSCR test to evaluate the rutting potential of neat and polymer modified binders. Neat binder used were ARL (60-70, 80-100) and KRL (40-50, 60-70, 80-100). ARL (60-70) and KRL 60-70 were modified with polymers. ARL (60-70) was modified with Elvaloy® RET (Reactive Elastomeric Terpolymer) at polymer percentages of 0% (neat), 1.35%, 1.70% and 2.0% and KRL (60-70) was modified with Elvaloy® AC (Acrylate Terpolymer) at polymer percentages of 0% (neat), 2.50%, 3.50% and 4.5%. MSCR test was performed on these binders. A total of 88 samples of neat and modified binders were prepared for this study. Comparative rutting evaluation was made for neat binders based on their non-recoverable creep compliance (Jnr) value and percent recovery. For polymer modified binders Jnr and percent recovery graphs were made. As Jnr value of 9.46 equates to G*/Sin δ =1000Pa, modified temperature grade were determined by comparing the modified binder Jnr value to Jnr of 9.46.

3. Materials and Experimental Work

3.1 Asphalt

Asphalt used in this research was from Attock Oil Refinery ARL (60-70, 80-100) and form Karachi Oil Refinery and KRL (40-50, 60-70, 80-100).

3.2 Polymer

Polymers used in this research were from the DuPont™ Elvaloy® RET (Reactive Elastomeric Terpolymer) and Elvaloy® AC (Acrylate Terpolymer) present in the form of pallets that are being used commercially modifying asphalt binder all over the world.

Elvaloy® Polymers are used in asphalt as modifiers and these are also designated as “reactive ethylene terpolymer”. Ethylene molecule is the main component along with the butyl acrylate and glycidylmethacrylate molecule for the reaction of the Elvaloy® polymers with the asphalt binder when they are mixed at high temperatures. Their reaction produces a stable polymer modified asphalt with enhanced properties [11] [12] [13].

3.3 Mixing Procedure

The asphalt was heated in its container at 165°C until it was fluid enough to pour. After that to homogenize the sample it was stirred and poured into mixing container. Required temperature was maintained for 10 minutes before blending the polymer. Pre weighted amount of polymer Elvaloy® RET was added at the rate of 10g/min. The blend was stirred for two hour continuously. For Polymer Elvaloy® RET (Reactive Elastomeric Terpolymer) 0.2% (weight percent of the asphalt) phosphoric acid was added to the blend, and was stirred for 15 to 30 minutes more. In order to avoid the lumps in the mixture acid was added after fully dissolving the Elvaloy® RET otherwise the polymer will not dissolve properly. To track the time of reaction of asphalt and polymer track the viscosity of mixture by rotational viscometer. With the reaction of polymer viscosity of asphalt increases but as the reaction completes viscosity will not increase any further. By utilizing this technique proper blending time was found out to be 2 hour. After the mixing the blend was shifted to containers and was covered. Each sample was place in oven at 165°C for 90 minutes for temperature curing of the blend [14].

Figure 1: Elvaloy® RET polymer beads (Asphalt Mix Design Lab, Department of Transportation Engineering, U.E.T. Lahore)

3.3 Multiple Stress Creep and Recovery Test

Figure 2: Bohlin dynamic shear rheometer (Asphalt and Concrete Mix Design Lab, Department of Transportation Engineering and Management, U.E.T. Lahore)

Dynamic shear rheometer is used to conduct multiple stress creep and recovery (MSCR) test by using test standard (AASHTO TP 70). DSR equipment has a parallel plate geometry with 25mm and 8mm spindle at the top and a base plate. Stress level of 100Pa and 3200Pa are used for this test. Haversine loading was applied on the sample for loading time of 1 second and a creep period of 9 second. This loading was applied for 10 cycles for each stress level. At the start of test 10 cycle of creep and recovery are applied at stress level of 100Pa and then continue the test at stress level of 3200Pa for 10 more cycles. Non recoverable creep compliance (Jnr) and percent elastic recovery are calculated from this test. These are used to evaluate the stress dependency of polymer modified binders. In the research the test temperature used for conducting the test were 58°C, 64°C, 70°C and 76°C.

Figure 3 shows General loading and unloading cycle graph of output. First part of the graph shows the 1 second loading cycle also called the creep loading and the second part shows the 9 second unloading cycle which shows the recovery of asphalt sample in 9 seconds.

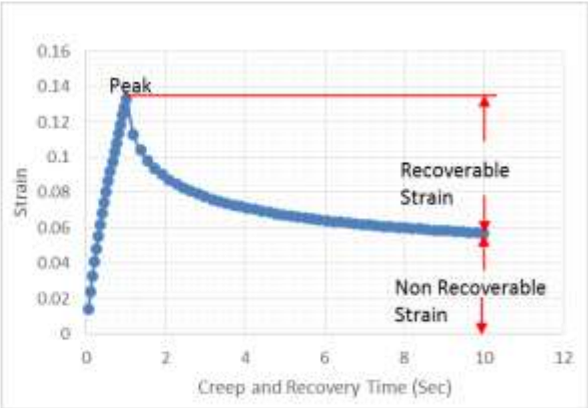

Figure 3: Result from 1 cycle of creep and recovery

The MSCR results is percent recovery (% Recovery) calculated by Equation (1) and non-recoverable creep compliance (Jnr) calculated by Equation (2).

$$\text{Percent Recovery} = \frac{\text{Recoverable Strain}}{\text{Peak Strain}} \quad (1)$$

$$\text{Jnr} = \frac{\text{Non Recoverable Srain}}{\text{Stress Level}} \quad (2)$$

4. Analysis and Results

MSCR test results were analyzed and compared on the basis of peak strain analysis, percent recovery and non-recoverable creep compliance and after analysis modified grade of bitumen were determined.

4.1 Peak Strain Analysis

Peak strain is the maximum strain achieved during loading phase of the test. This parameter tells us that how much deformation the pavement will undergo under certain stress level it tells us about the stiffness of certain asphalt. Less peak strain is desirable to prevent rutting during the service life of the pavement.

From Figure 4 and 5 it is clear that peak strains in neat sample of ARL (60/70 and 80/100) is high compared to the samples from KRL (40/50, 60/70, 80/100). At the temperature of 580C the strain of the sample is low but at higher temperatures the peak strains are high. In sample of modified ARL (60/70) peak strain decreases. With the increase in polymer content the deformation decreases due to increase in the stiffness. Similarly the same behavior in the neat and polymer modified samples of KRL (60/70) with the increase in polymer content peak strain further decreases. Therefore, it is clearly observed that neat samples of KRL are good to prevent rutting than the neat samples of ARL. At the stress level of 3200Pa value of peak strain is high as compared to the stress level of 100Pa because of the increased creep loading asphalt behavior is more elastic.

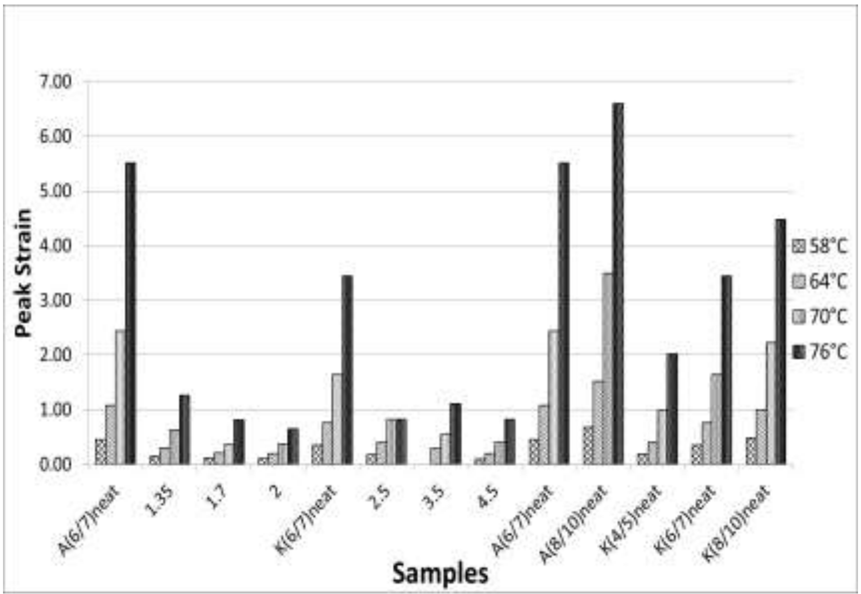

Figure 4: Peak strain at 100Pa

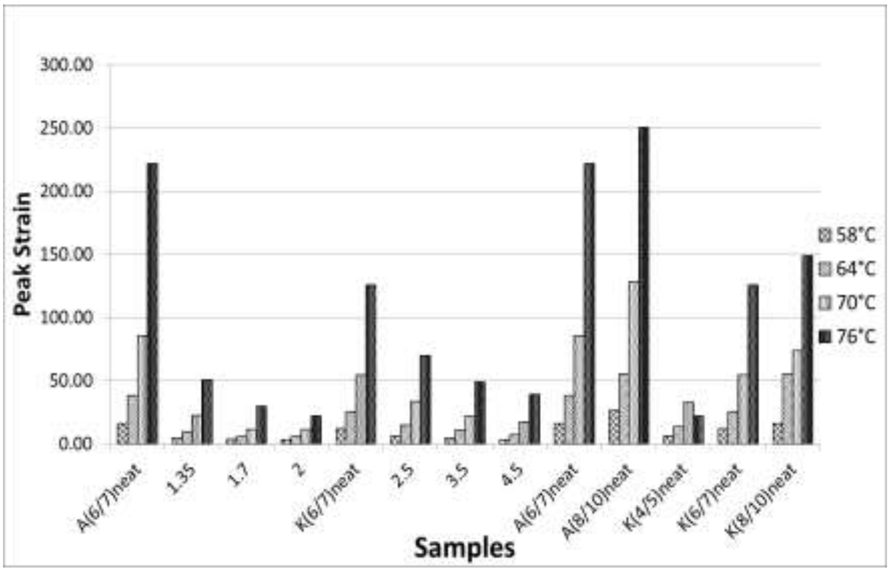

Figure 5: Peak strain at 3200Pa

4.1 Percent Recovery

Percent recovery represents the elasticity of the asphalt samples. High elasticity in asphalt is desirable for preventing both the rutting and fatigue phenomenon. Higher values of percentage recovery is the representation of high elasticity of that sample as more will be the elasticity, more will be the recovery of strain upon releasing the stress.

From Figure 6 and 7 it is clear that percentage recovery in neat samples of both ARL and KRL is almost zero and even negative at high temperature. They do not show any recovery against the strains. For the neat samples temperature does not affect the percent recovery but modified samples show the decreased percent recovery with increase in temperature. In polymer modified asphalt samples with the increase in polymer content recovery increases abruptly. In case of polymer modified ARL the percentage recovery has increased much more as compared to the polymer modified KRL asphalt. At the stress level of 3200Pa the percent recovery value has decreased slightly compared to the stress level of 100Pa because increased loading on asphalt sample has caused increased creep and asphalt has recovered less.

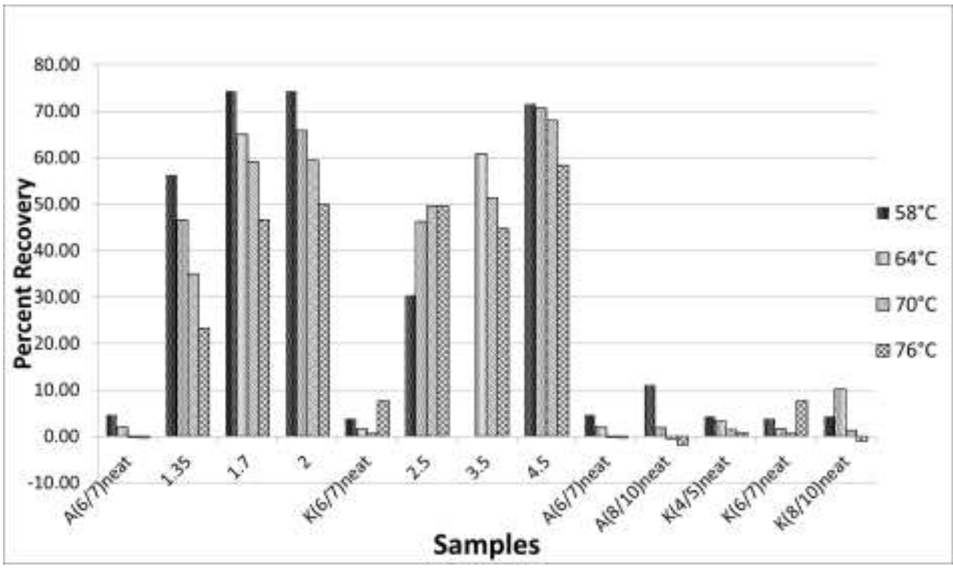

Figure 6: Percent recovery at 100Pa

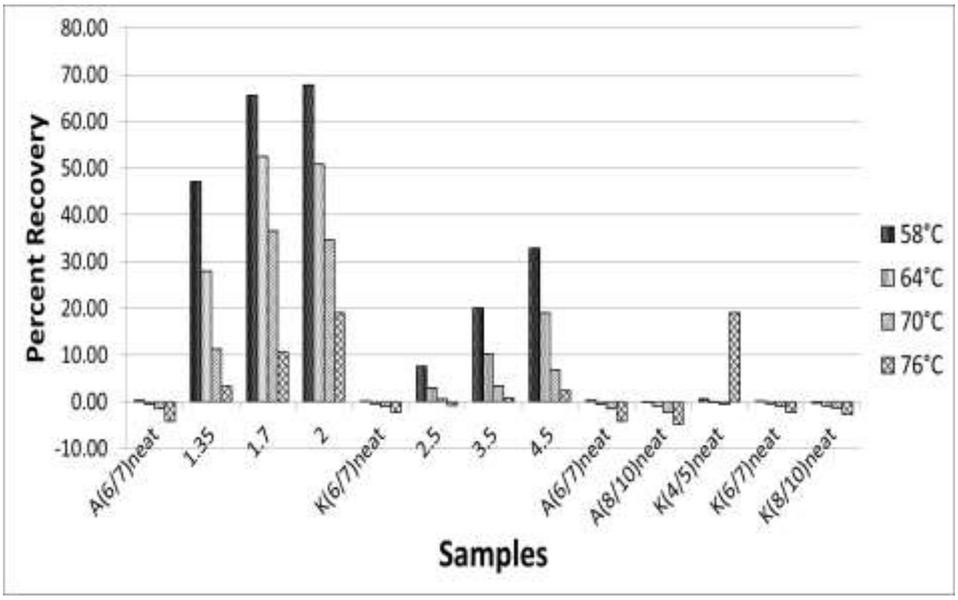

Figure 7: Percent recovery at 3200Pa

4.3 Non Recoverable Creep Compliance

This parameter is used with the multiple stress creep and recovery therefore this is helpful in predicting the rutting of the neat as well as the polymer modified binders.

From Figure 8 and 9 Jnr in neat sample of ARL is two times higher compared to the samples of KRL. KRL (40/50) show least value of Jnr=20.0 whereas the KRL (80/100) show peak value of Jnr=45.0 at temperature of 76°C. At temperature of 580C the Jnr of samples is low but with the increase in temperature Jnr increases due to less recovery of induced strains. For neat samples of ARL 60/70 Jnr=55 and with the addition of 2% polymer content it has reduced to Jnr=4.0 at temperature of 76°C. At the stress level of 100Pa Jnr value are lower but for the increased stress level of 3200Pa the value of Jnr increases which shows decreased elastic response of asphalt.

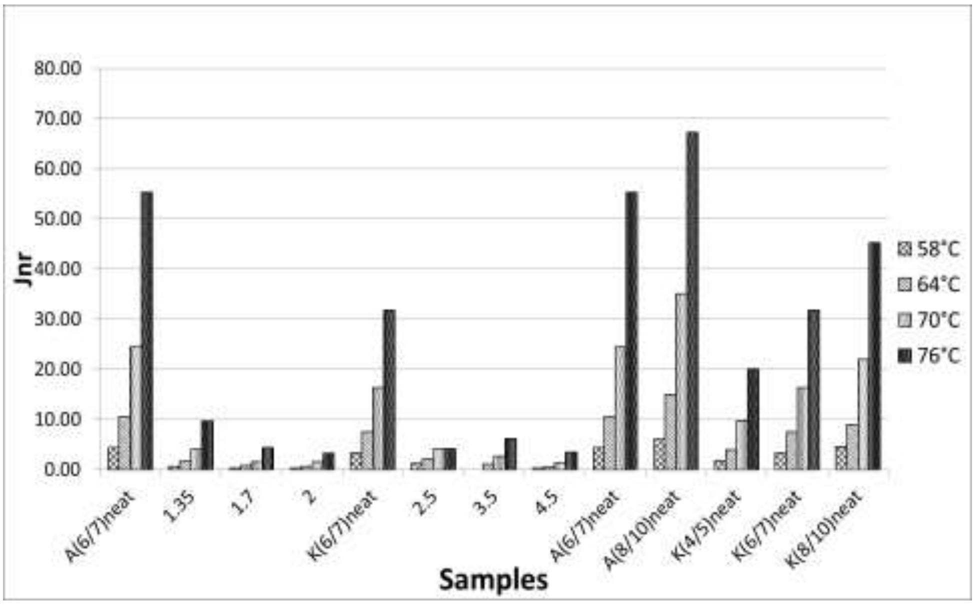

Figure 8: Jnr at 100Pa

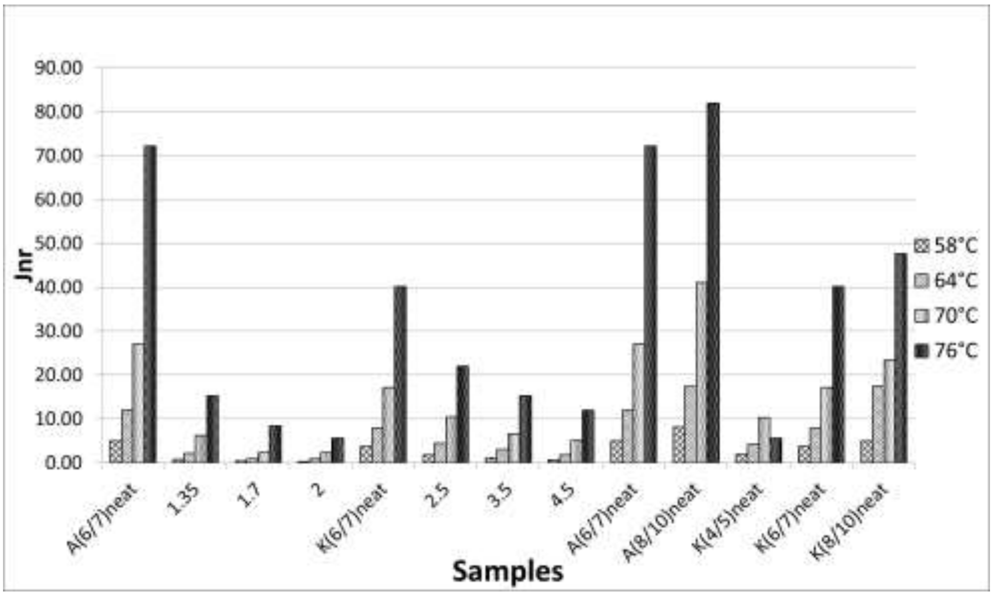

Figure 9: Jnr at 3200Pa

4.4 Modified Temperature Grade

For determining the modified temperature grade criteria for rutting parameter G*/Sin δ =1000Pa that corresponds to the value of Jnr is 9.46 for unaged binder. By comparing the value of Jnr=9.46 from actual value the modified temperature grade of neat and modified asphalt were determined and mentioned in Table 1.

From the Table 1 when we see the ARL 60-70 with 0% polymer content has performance temperature of 62.94°C and when it is modified with 1.35% polymer content its modified temperature is 74.67°C. It means neat asphalt and modified asphalt with the 1.35% polymer content can perform well in area where the pavement temperature is less than 62.94°C and 74.67°C without rutting. It is also clear as the polymer percentage is increased the modified temperature of asphalt has also increased accordingly. At 2% polymer content with ARL 60-70 the modified temperature is 80.84°C which is much higher than the neat sample of ARL 60-70 which is 62.94°C.

Neat sample of KRL 60-70 has the performance temperature of 65.60°C and sample modified with 2.5% polymer content has modified temperature of 73.16°C. When 4% polymer is added to KRL 60-70 sample the modified temperature increased to 80.11°C. Therefore polymer has improved the KRL 60-70 and modified temperature of asphalt.

Table 1: Modified temperature grade at Jnr=9.46

Sr. No.	Binder	Polymer Content (%)	Temp @ 9.46 Jnr @ 100Pa	Temp @ 9.46 Jnr @ 3200Pa	Average Temperature @9.46 Jnr
1	ARL 60-70	0	63.16	62.72	62.94
2	ARL 60-70	1.35	76.06	73.29	74.67
3	ARL 60-70	1.7	83.29	78.38	80.84
4	ARL 60-70	2	85.61	80.48	83.05
5	ARL 80-100	0	60.85	59.71	60.28
6	KRL 60-70	0	65.68	65.51	65.60
7	KRL 60-70	2.5	76.42	69.90	73.16
8	KRL 60-70	3.5	79.47	72.96	76.22
9	KRL 60-70	4.5	85.36	74.86	80.11
10	KRL 80-100	0	63.57	62.41	62.99
11	KRL 40-50	0	69.97	73.88	71.92

Conclusions

1. Polymers that are reactive type is compatible with KRL samples and form lumps in asphalt. It is concluded that the use of polymer is a function of type from which the asphalt is derived. All polymers cannot be used for all types of asphalts.
2. With the addition of polymers in asphalt the elasticity of asphalt has increased. But non linearity coming into asphalt behavior as neat sample of asphalt show high value of non-recoverable creep compliance (Jnr) but for polymer modified asphalt it is low and trend is nonlinear because of abrupt change.
3. Polymers have positive effects on peak strains, percentage recovery and non-recoverable compliance. Also addition of polymer caused the grade bumping of asphalt binder.
4. Using non recoverable creep compliance (Jnr), as the rutting evaluation parameter, is efficient for evaluating the rutting potential of polymer modified asphalt.
5. On the basis peak strain, percent recovery and non-recoverable creep compliance results, it is concluded that Reactive type polymer (RET) is a better option for asphalt modification for the prevention of rutting.
6. The neat samples of KRL are more efficient than the neat samples of ARL.

7. Polymer modification is more efficient in case of ARL samples as with the less percentage of polymer used. At the same time, the modified temperature improved more relative to the KRL samples which show same improvement against the more percentage of polymer content.

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