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Effect of Stress Levels and Temperatures on Creep Compliance of Asphalt Binders

Muhammad Maad Raza[1], Imran Hafeez[2]
[1, 2]Civil Engineering Department, University of Engineering and Technology, Taxila, Pakistan

***Abstract:** Mostly, the laboratories in Pakistan use DSR (Dynamic Shear Rheometer) Test AASHTO T 315 for quality control purposes but it was designed for unmodified asphalt binders, and it gives inadequate results of modified binders. On the other hand, AASHTO T 350 called as multiple stress creep recovery (MSCR) test gives better result for modified binders. MSCR grades of mostly modified binders with additives, nano composites, viscous fluids is determined in this research paper. The effect of these modified as well as unmodified binders on the Creep Compliance factor is also evaluated. To characterize Creep Compliance factor along with Stress Sensitivity and Traffic Loading this test is now used. For evaluating the Stress Sensitivity of modified binders there is development of new factor called as JNR Slope instead of JNR Difference. Jnr Slope gives vast representation of asphalt binders and there is no congestion left between them. The binders which fail in JNR Difference might get satisfactory results from JNR Slope Which gives better results than the conventional way of testing. For determining the rutting behavior of modified as well as unmodified asphalt binders there is usage of peak strain factor at stress level of 100 Pascal, and 3200Pascal relatively. The values of JNR at the stress levels 25 Pascal to 25600 Pascal gives almost linear variation between modified as well as unmodified binders. This research paper is developed to determine Peak strain values, Creep Compliance factors, Stress Sensitivity Factors, And MSCR grading according to the Traffic Loading.*
***Keywords:** Creep Compliance, JNR Difference, JNR Slope, MSCR Grading, Stress Sensitivity, Traffic Loading*

I. INTRODUCTION

For developing the properties of asphalt binders 1987 SHRP (Strategic Highway and Research Program) was carried out. Thus, this SHRP study developed research program for Superpave test methods and properties for asphalt binders. In Superpave system for grading asphalt binders Performance Grade properties were added in 1993. These specifications were also part of American Association of State Highway and Transportation Officials (AASHTO) and as in AASHTO M 320. The Dynamic Shear Rheometer (DSR)-based test method, AASHTO T 315 was used for measuring rutting and fatigue at high temperatures on asphalt binders. [1]

Using the multiple stress creep recovery (MSCR) test, one can assess an asphalt binder's rutting capability. The type of test geometry, the creep and recovery duration, and the number of creep and recovery cycles have all been noted as potential influences on the MSCR test's accuracy. [2]

Three distinct constant loads were applied to polyvinyl chloride specimens at room temperature, and the creep was tracked over time. In comparison to the Weibull model, the suggested and Finley models better describe the creep data. In characterizing the creep data, the proposed one is competitive with the Finley model. [3]. Based on ground tyre rubber and styrene-isoprene-styrene, polymer-modified asphalt (PMA) binders' performance characteristics are assessed (SIS). The foundation binder for the creation of the rubberized PMA binder is the asphalt binder of PG 76-22 modified with styrene-butadiene-styrene (SBS). To describe the asphalt binder's recovery and non-recovery compliance levels. [4]. It has been determined that MSCR is efficient for both clean and polymer-modified asphalts and that it is also indifferent to the type of modification. [5] In order to improve the qualities of asphalt, bone glue should be used at an optimal dose of 9% by weight of asphalt binder. [6] The impact of synthetic and natural fillers on the MSCR test-measured % recovery. [7]

MSCR test is intended to assess the stiffness and recoverability of binders, two rutting resistance methods. [8] The applicability of asphalt binders for various traffic loadings is proposed based on the data on stress sensitivity and creep compliance. [9] .Asphalt binder 60-70 penetration grade was found to have higher temperature sensitivity as compared with other binders. [10] [11] The dynamic oscillatory test's rutting parameters are insufficient to forecast the binder's behaviour under the high strain and yielding that are often caused in asphalt mixtures. [12]

It has been shown that binders with less penetration and more polymer provide better resistance to mechanical loads and environmental factors. [13]

II. OBJECTIVES OF STUDY

The major objectives of the proposed study are:

1) To characterize the high temperature performance of neat and modified asphalt binder.
2) To study the effect of temperature on creep compliance of neat and modified asphalt binders.
3) To study the effect of stress on creep compliance of neat and modified binders.

A. Research Methodology

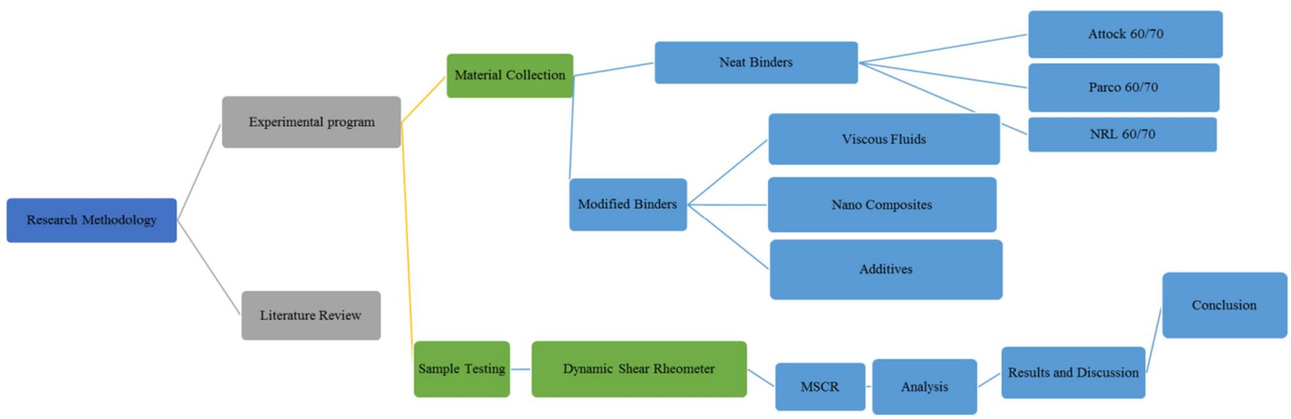

Fig.1 Research Methodolgy

III. MATERIALS AND METHODS

In this research paper neat binders from Attock Refinery limited (ARL),National Refinery Limited(NRL), Pak-Arab Refinery(PARCO),Carbon Nanotubes(CNT),Carbon Nanoparticles(CNP), Graphene, Graphene NanoPlatelets (GNP),Chlorinated Paraffin(C.P),Bio Oil, Eaton Regent(E.R),Bone Glue,Chemseal, Chemaflex, Permalastic, Expanseal, Sulphur and Plastic are used as shown in Table 1.

Table 1 Materials Selection

Neat Binders	Binders with NANO COMPOSITES	Binders with VISCUS FLUIDS	Binders with ADDITIVES	Stress(Pascal)	Temperature °C
NRL 60/70	CNT	1.CHLORINATED PARAFIN	SULPHUR	25-25600	64
PARCO	CNP	2.BIO OIL	PLASTIC	25-25600	64
ARL 60/70	GRAPHENE	3.OLIVE OIL		25-25600	64
	GNP	4.E.R		25-25600	64
		5. BONE GLUE		25-25600	64
		6. CHEMSEAL		25-25600	64
		7.CHEMFLEX		25-25600	64
		8. PERMALASTIC		25-25600	64
		9. EXPANSEAL		25-25600	64

A. Experimental Program

Creep Compliance is the factor which is used to evaluate the viscous behaviour of binders at higher temperature. Viscous behaviour of mostly neat and modified binders becomes very critical at higher temperature and heavy loading due to trucks. This viscous behaviour affects the workability and performance of pavements and cause its early failure in the form of rutting.

For a particular stress cycle, Jnr is computed by dividing the non-recoverable strain with the stress applied for that cycle.

$$JNR = avg.\gamma u/\tau \qquad (1)$$

B. MSCR Test

This test is performed on DSR instrument which is used for multiple stress creep recovery test in this test as the name indicates multiple stress so there are almost 11 stress levels on which this test is performed. The MSCR test consists of applying repeated creep and recovery of shear stress for a short duration of 1s and then removing the stress for 9s. This is repeated for 10 cycles using different stress levels.The non-recoverable creep compliances (Jnr) is computed at each stress levels and temperatures to characterize the stress dependency and temperature sensitivity of neat and modified binders.

Multi-stress creep recovery test, using the dynamic shear rheometer. Anton Paar DSR with its parallel-plate geometry loading device and a control and data acquisition system were utilized for conducting the MSCR test in the present study. This DSR can maintain the test temperature from −30 to 120 ◦C by its Peltier system and capable of measuring the dynamic shear modulus from 100 Pa to 10 MPa. Specimens were tested in replicates using a 25-mm disc and with 1-mm gap setting at temperatures of 58,64, 70, and 76 ◦C (PG of asphalt binders) and at a stress range At each stress level there are 10 numbers of cycle, And each cycle is of 10 seconds in which there are 2 parts. The first one second part is called as the creep portion and the remaining 9 second part is called as the recovery partition of this test.

IV. RESULTS AND DISCUSSION

A. Peak Strain Value

The Figure 2 shows the relation between samples and peak strain value when the stress applied is of 3200 Pascal. on the X axis there is demonstration of samples and on the y axis there is demonstration of peak values of strain. From the samples of neet binders the maximum value of peak strain please of ARL which is a 448. From these samples of nanocomposites CNP shows the maximum value of peak strain Of 435. From the samples of additives crumb rubber Indicates maximum value of 386 peak strain. From the samples of viscous fluids the value of maximum peak strain of about 634 of bio oil sample. From the overall point of view The modified asphalt binder from the viscous fluids Bio Oil shows the maximum peak strain value of 634 while Parmalastic shows minimum value of 3.46 peaks strain. Which means that binders modified with viscous fluids Shows the maximum and minimum value of peak strain. From this it is clear that with the increase of stress level from 100 Pascal to 3200 Pascals The behaviour of asphalt binders also changes from the trend line of 3200 stress level Pascal it is clear that it becomes normal when the stress increases as shown in the figure 2 there is a straight line. With the modification of asphalt binders with different nano composites ,additives, viscous fluids the behaviour become more complex as the stress increases.

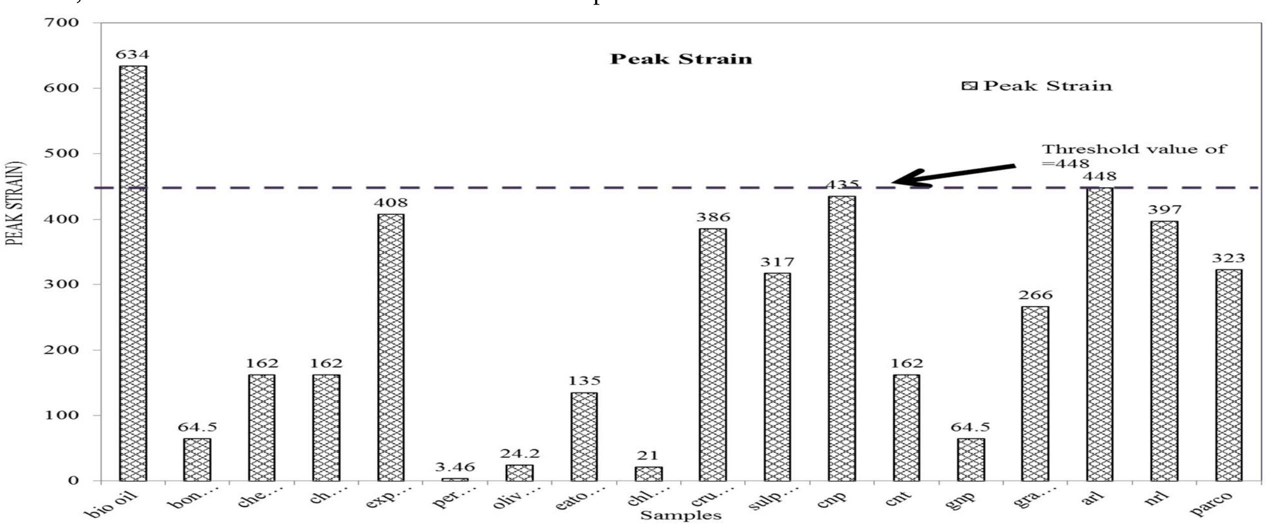

Fig.2 Graph of Peak Strain at 3200 Pascal

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B. Creep Compliance

Creep compliance is a factor which is used to evaluate different characteristics of asphalt binders. And it is most effectively used for predicting the rutting behaviour of asphalt binders.Creep compliance factor is also best because it can check in the behaviour of asphalt binders with variety of stress levels. In past,rutting behaiviour of asphalt binder was evaluated from the complex modulus but in modern researches it is considered that creep compliance is the best factor for evaluating rutting behaviour of asphalt binder.

In Fig. 3 there is relation between stress applied and Jnr values. On X axis there is increase of stress levels from 25 Pascal to 25600 Pascals.The range of this stress levels is 25, 50, 100, 200, 400, 800, 1600,3200,6400,12800,and 25600 Pascals.While on Y axis there is increase of JNR values which is obtained from taking average of strain to stress ratio for different types of neat binders. The trend line of each binder is indicated in the figure which shows that with the increase of stress level there is an increase in the Jnr values. The trendline of PARCO which is in between them shows that PARCO has an average Value of Jnr in between them. NRL asphalt binder is showing the maximum value JNR, while ARL binder is showing minimum value of Jnr with the increase of stress level. Nanocomposites asphalt binders includes CNP,CNT,GNP and Graphene. This graph shows with the increase of stress level Jnr values increases And GNP asphalt binders shows maximum value of JNR. While Graphene shows minimum value of Jnr with increase of stress level. This means that there is direct relation between stress levels and JNR values.

Additives includes sulfur and crumb rubber. With the increase of stress levels crumb rubber shows maximum value of Jnr while sulphur shows minimum value of JNR. viscous fluid asphalt binders includes Bio Oil, Bone Glue, Chemflex, Chemseal, Expenseal, Permalastic, Chlorinated paraffin ,Eaton Regent, and Olive oil. with the increase of stress level Bone glue shows maximum value of JNR while Olive oil shows minmum value of JNR with the increase of stress level. The trend lines of each asphalt binders is shown in the figure. There is clear indication of the behaviour of different asphalt binders when applied at different stress levels. There are 2 ways to evaluate Creep complience factor. The first one is called as conventional method in which there is evaluation of JNR at 100 pascal and 3200 pascal stress while the second one is called as non conventional method in which there is evaluation of JNR values at different stress levels.

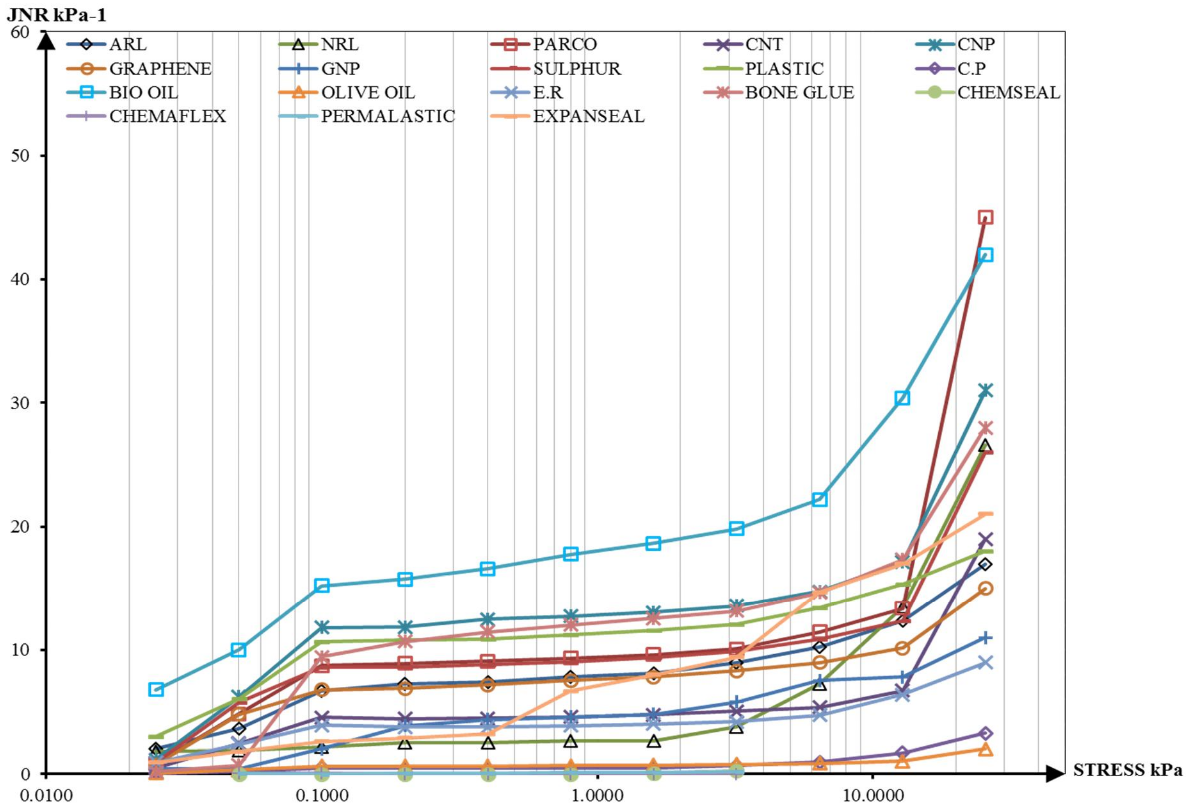

Fig.3 Graph between JNR And Stresses

C. JNR at Stress of 3200 Pascal

In this there is discription of JNR values at the stress level of 3200 pascal. In Figure 4, there is evaluation of JNR values. From the samples of neat binders NRL shows the maximum value of JNR 13.53k/Pa,while ARL has minimum value of JNR 8.95k/Pa.From the samples of CNP has maximum value of JNR 13.59k/Pa while GNP has minimum value of JNR 2.02 k/Pa. From the samples of additives Crumb Rubber has maximum value of JNR 12.06k/Pa,while sulphur has minimum value of JNR 9.91k/From the samples of viscous fluids Expanseal has maximum value of JNR 36.5k/Pa ,while Chemaflex has minimum value of JNR 0.0011k/Pa. From all the samples the maximum value of JNR is for Expanseal which is 36.5k/pa and minimum value is of Chemaflex and both of them belongs to Viscous fluids samples.

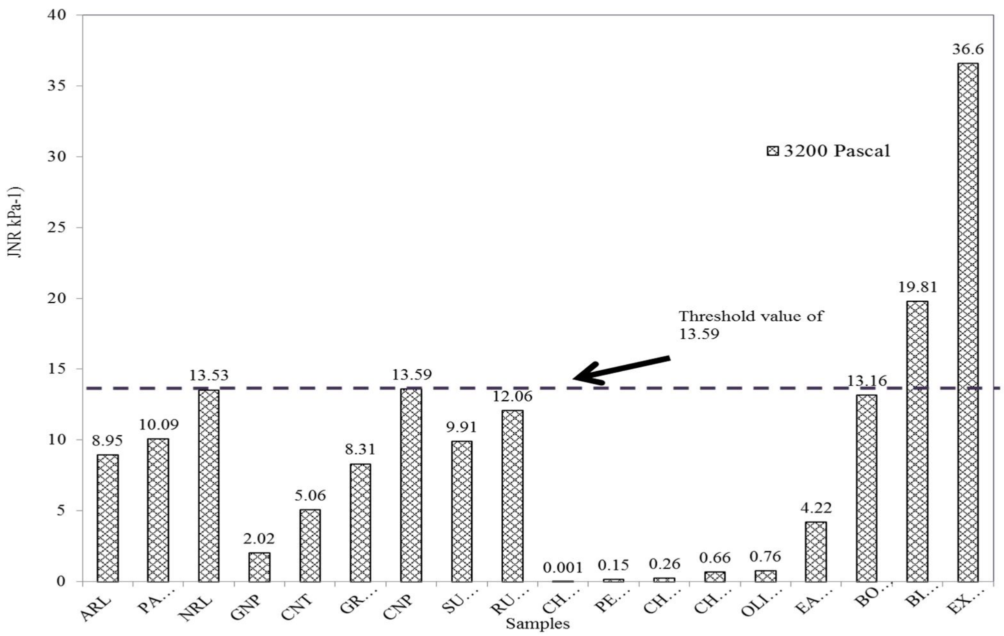

Fig.4 Graph at 3200 Pascal Stress

With the increase of stress from 100pascal to 3200 pascal from the samples of Neat binders PARCO has maximum value when the stress is at 100 pascal while at 3200pascal stress NRL has maximum value of JNR. NRL has minimum value when stress was 100pascal .

From the samples of nano composites with the increase of stress from 100Pascal to 3200 Pascal the same pattern is followed CNP has maximum value of JNR and GNP has minimum value of JNR.From the samples of additives also the same pattern is followed Crumb Rubber has maximum value of JNR and Sulphur has minimum value of JNR. From the sample of viscous fluids while moving to higher stress Expanseal has taken place of Bio oil for maximum value of JNR and also Chemaflex has taken place for minimum value of JNR instead of Permalastic and Chemseal .

D. Stress Sensitivity at JNR Difference

JNR Difference is defined as the ratio of difference of JNR value at 3200 pascal stress and 100 pascal stress to the JNR value at 100 pascal stress and the whole factor is multiplied by 100 to get the percentage of it.

$$JnrDifference = \frac{[Jnr3.2 - Jnr0.1]}{Jnr0.1} * 100 \qquad (2)$$

It is used for conventional method of testing of MSCR test. This JNR Difference is called as the the stress Sensitivity factor there is checking of different asphalt binders that whether the samples are suitable for their application in the practical field of road construction. There is specific value of this factor from the standards of strategic highway and road research Program so that to check whether asphalt binders is suitable or not. According to SHRP the value for stress sentivity is less than 75%. The binders below this value is considered as suitable for Road research Program.

E. Stress Sensitivity at JNR Slope

Researchers have find out another factor for the evaluation of stress Sensitivity as it is a graphical method and it seems suitable to JNR Difference.

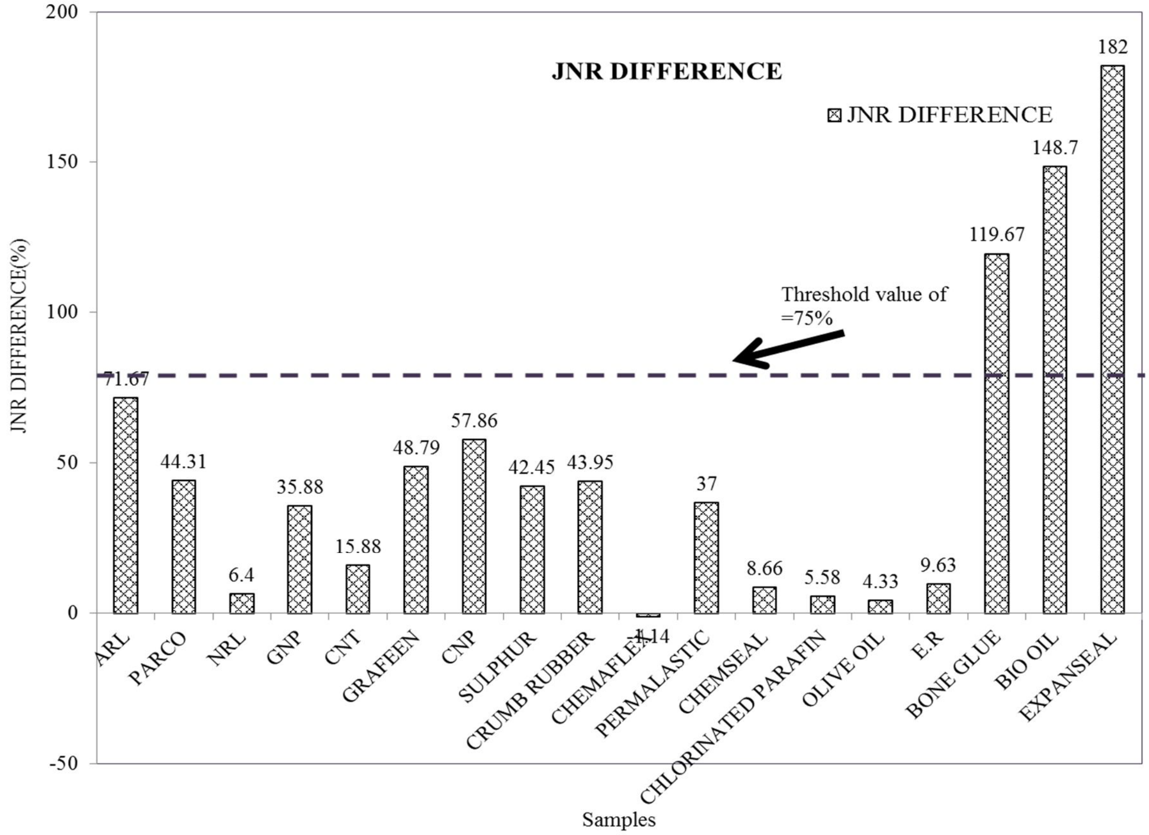

Fig. 5 Graph between Jnr Difference

JNR Slope is derived as the Ratio of difference of JNR value at 3200 pascal stress and 100 pascal stress to the value of effective range of overall stress value . Which is considered as 3.1 as in most of the cases. The formula for JNR Slope is given below.

$$JnrSlope = \frac{[Jnr3.2 - Jnr0.1]}{3.1} * 100 \qquad (3)$$

It is according to the AASHTO T 350 (MSCR Test). This factor is effectively applied in the paper of Advanced Pavement Laboratory. There's evaluation of this factor in this paper as well. First of all there is comparison of different sample according to this factor. JNR value at stress of 3200pascal is considered as conventional value as there is comparison of both JNR Difference and JNR Slope is done with this values for different samples of asphalt binders. This will give us clear indication that the positives aspects of both of these factors. This will lead towards the stress Sensitivity of pavement structure.

F. Traffic Loading

The assessment of traffic loading is also being done by using the JNR factor. There is allocation of MSCR grade by using the specifications of (AASHTO M332-15). According to this specifications it will give MSCR grade of 'S' to show standard traffic loading when the JNR value at 3.2kPa stress is greater than 2kPa and it represents the traffic intensity of less than 10 million ESALS. It will give MSCR grade of 'H' called as heavy traffic loading when the JNR value at 3.2 kPa stress between (1-2)kPa and shows the traffic intensity of about 10-30 Million ESALS. It will give MSCR grade of 'V.H' to show very heavy loading of traffic when the JNR value at 3.2 kPa stress is between the (0.5-1)kPa and it represents the traffic intensity of more than 30 Million ESALS. When the JNR value at 3.2 kPa stress is between (0-0.5) it represents MSCR grade of 'E' to show extreme traffic loading having traffic intensity more than 30 Million ESALS. Table 2 , shows the values of MSCR grading according to AASHTO specifications.

While in table 2 there is MSCR grading of our samples having different additives, viscous fluids,nano composites and neat binders.

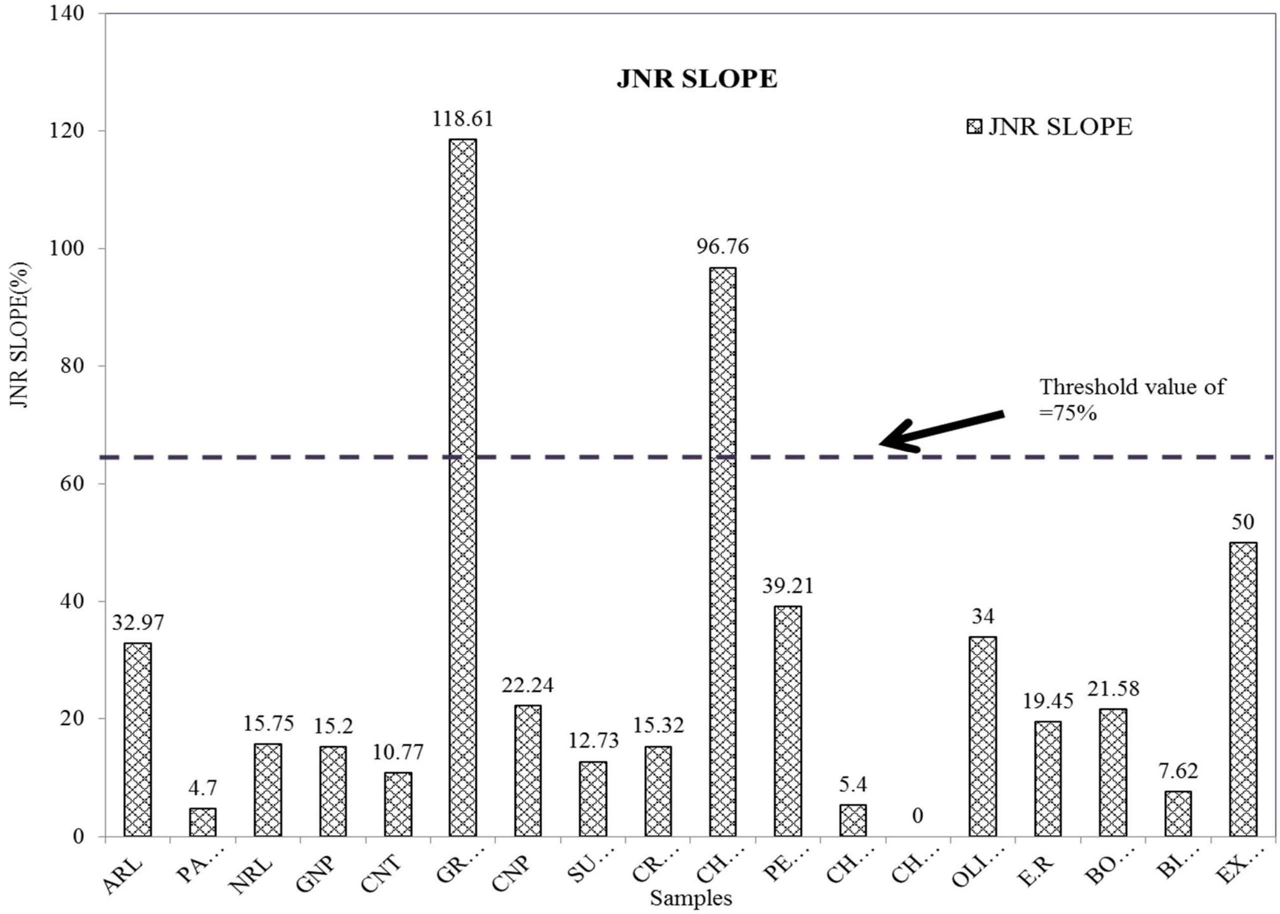

Fig.6 Graph of JNR Slope

Column 1 indicates the name of sample , Column 2 shows the value of JNR at 3.2kPa stress. Column 3 evaluates the MSCR grading of samples according to AASHTO specifications. Column 4 and 5 shows the value of stress Sensitivity according to JNR Difference and according to JNR Slope respectively. Last column gives the grading of samples according to temperature and traffic loading.

V. CONCLUSION

In this paper, complex behavior of bitumen samples having different additives, viscous fluids, nano composites and neat binders are evaluated. The effect of different stress level with the help of MSCR test is determined by using AASHTO specifications. It gives us the actual performance of bitumen sample when it is being performed at the practical level. Peak strain at stress of 100 Pascal and 3200 Pascal is determined to give the rheological performance of bitumen specifically rutting. There is modification in the creep compliance factor for the determination of stress Sensitivity and gets that JNR Slope is better than JNR Difference. This test is performed by using conventional method of testing at conventional stress level. MSCR grading of traffic loading and traffic intensity is also determined in this paper. There is very vast scope for this type of research specially the use of JNR Slope in modern research Programs.With the increase of stress levels there is increase of creep compliance values as it is indicated in the graphs of binders with additives, nano-composites, viscous fluids and neat binders at low stress values JNR Values are very small and vice versa. At temperature of 64 degree, Binder with viscus fluids gives the maximum value of JNR as it is shown in Expenseal and gives the minimum value in case of Chemaflex binder. Stress sensitivity is determined by using JNR difference factor in which GNP Binder and Chemaflex binders fails because it has value more than 75% as it is indicated in AASHTO T332. Traffic loading is evaluated by using AASHTO M332-15 ,In which MSCR Grades of standard traffic is given to mostly binders, C.P ,Olive oil gives very heavy traffic grade and permalastic, chemseal gives extreme grade of traffic loading.

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Table 2 Suitable Traffic Grades

Sample	Jnr AT 3.2 kPa-1	Traffic Loading	Stress Sensitivity at JNR Diff<75%	Stress Sensitivity at JNR Slope<75%	Suitable temprature limit
ARL	8.95	S	32.97	71.61	64◦C@ **Standard** traffic loading
NRL	13.53	S	47.143	64	64◦C@ **Standard** traffic loading
PARCO	10.09	S	15.75	44.31	64◦C@ **Standard** traffic loading
CNT	5.06	S	10.77	15.88	64◦C@ **Standard** traffic loading
CNP	13.59	S	15.2	57.86	64◦C@ **Standard** traffic loading
GRAPHENE	8.31	S	22.24	48.79	64◦C@ **Standard** traffic loading
GNP	2.02	S	**118.61**	35.48	64◦C@ **Standard** traffic loading
SULPHUR	9.91	S	15.32	42.45	64◦C@ **Standard** traffic loading
CRUMB RUBBER	12.06	S	12.73	43.95	64◦C@ **Standard** traffic loading
CHLORINATED PARAFIN	0.66	V.H	35.86	5.58	64◦C@ **Very Heavy** traffic loading
BIO OIL	19.81	S	30.34	**148.7**	64◦C@ **Standard** traffic loading
OLIVE OIL	0.76	V.H	21.58	4.33	64◦C@ **Very Heavy** traffic loading
E.R	4.22	S	7.62	9.63	64◦C@ **Standard** traffic loading
BONE GLUE	2.02	S	39.21	**119.67**	64◦C@ **Standard** traffic loading
CHEMSEAL	0.26	E	0	8.66	64◦C@ **Extreme** traffic loading
CHEMAFLEX	0	E	**96.78**	11.14	64◦C@ **Extreme** traffic loading
PERMALASTIC	0.15	E	19.45	34	64◦C@ **Extreme** traffic loading
EXPANSEAL	13.65	S	34	182	64◦C@ **Standard** traffic loading

A. Conflicts of Interest

There is no conflict of interest regarding the publication of this paper.

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