PERFORMANCE EVALUATION OF COMPOSITE ASPHALT BINDER

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ABSTRACT

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To modify bitumen properties for countering problems of increasing traffic loads and environmental conditions, Nano materials have proven themselves as promising materials with remarkable performance. In this study, multi component phase evaluation of binder modified with composite of Carbon Nanotubes and Graphene Nanoplatelets was done. Conventional binder tests were performed on modified samples also dynamic shear rheometer test was conducted to investigate rheology of bitumen modified with Nano particles. It was found from test results that increasing amount of Nano composite particles lead to increase in stiffness of the bitumen which is an indication of improved rutting resistance. Increment in Complex shear modulus and rutting factor within high temperature range also depicted improved high temperature performance.

INTRODUCTION

Almost all road construction worldwide is carried out with conventional asphalt as an essential constituent (Lesueur, 2009). Properties of asphalt have a great influence on performance of pavements (Qin et al., 2014). Ordinary pavement can barely meet functioning requirement due to growing traffic. The heavier axle loads and rise in traffic loads in combination with potential environmental conditions result in prevailing severe circumstances on highway system such as development of rutting, fatigue cracking, stripping and reflective cracking (Airey, 2002). Therefore researchers are profoundly focused on enhancing asphalt binder properties. Consequently, asphalt pavement performance can considerably be improved.

In literature, different asphalt modifiers are used such as polymers and additives like fly ash or lime has been applied frequently (Golewski, 2017). Different types of asphalt modifiers like crumb rubber and polymers are also applied to enhance mechanical properties of ordinary asphalt. Although modifiers can enhance asphalt performance but due to growing heavier loads, severe environmental conditions and rise in cost of asphalt, there is need for more research to address these issues (Amin et al., 2016b). Therefore, researchers are trying to find out innovative modifiers to significantly improve pavement performance. In recent years nanotechnology has emerged as a sophisticated technique. Owing to exceptional success of Nanotechnology in other engineering fields, researchers have diverted their attention to introduce cutting-edge Nanotechnology in improving pavement performance (Li et al., 2017).

Researchers have used Nano materials separately and in composite form to modify properties of traditional asphalt binder. Amirkhanian et al formulated the results of the experiments which showed that the blending of Nano particles was useful in increasing the viscosity, failure temperature, phase angle, and viscous and elastic modulus values and rutting resistance of the binders (Amirkhanian et al., 2011).In addition, Ameri et al. explained that cracking that occurs as a result of induced load is one of the core problem at intermediate temperatures. Carbon Nanotubes (CNTs) were thus used as binder modifier and it was confirmed that they can significantly improve the fracture and fatigue resistance of asphalt mixtures (Ameri et al., 2016). By employing molecular simulation, a comparative research was done by Zhou et al. to investigate the influence of Graphene Nanoplatelets (GNPs) and CNTs on asphalt binder. Thermo-mechanical properties of asphalt revealed extensive enhancements after the blending of graphene or carbon nanotubes with asphalt binder (Zhou et al., 2017). Moreno-Navarro et al. found that inclusion of graphene in asphalt binder matrix resulted in an improved elastic response of binder as graphene possess remarkable properties. It lessened temperature susceptibility and reduced heat transfer process in the bitumen when exposed to hot environment (Moreno-Navarro et al., 2018). Goli et al investigated the impact of CNTs modified binder on SBS modified asphalt. Due to the strong and greater interaction between the CNTs and SBS modified asphalt, an extensive improvement in storage stability was perceived. Moreover, the physical and rheological properties of the CNTs modified binder were upgraded (Goli et al., 2017). Saltan et al., evaluated the performance of HMA and bitumen by altering bitumen with Nano materials in accordance with mix design procedure of Superpave TM. All Nano modified HMA samples were found as highly resistive to moisture in comparison to control sample except samples which were modified with SiO2 doped CNT at 5% (Saltan et al., 2018). Shu et al. found that the decomposition and volatilization rate of saturates and aromatics was significantly lessened and better thermal stability of bitumen was to be improved with the inclusion of nanoparticles. Fluorescence microscopy tests showed that

MWCNTs addition resulted in better dispersion of SBS and storage stability of the bitumen binder (Shu et al., 2017). Fang, C. et al have found that both high and low temperature performance of Nano particles composite modified asphalt had been improved effectively. Results confirmed that composite modified asphalt decrease temperature susceptibility as compared to isocyanate and base asphalt (Fang et al., 2016).

Conventional asphalt binder possess visco-elastic behaviour. The viscous and elastic component of conventional asphalt binder is collectively called as multi component phase. The multi component phase plays a key role in performance of asphalt binder under different temperatures and loading time. Therefore a detailed analysis of multi-component phase of asphalt binder modified with external material is also required. For this research Nano composite material is employed for modification of bitumen binder. The CNTs and Graphene were combined in different percentages to form composite material which was then blended with bitumen sample. The modified samples were then tested to determine physical and rheological properties. The main objective of this study was to evaluate multi component phase of modified asphalt binder at different temperatures and frequencies using DSR test.

MATERIAL

Binder

Bitumen binder of 60/70 penetration grade was bought from Attock oil refinery limited. 60/70 penetration grade is mostly used in Pakistan for asphalt pavement construction. The basic bitumen binder properties are given in Table 1.

Table 1. Basic properties of neat bitumen

Sr. No.	Property	Test Value	Specifications
1	Softening Point (°C)	48	ASTM D5
2	Penetration (0.1mm, 25°C)	64	ASTM D36
3	Ductility(cm) (25°C)	101	ASTM D113

Nano composite

Nano grapheme and Nano CNT were brought from USA. Both Nano Graphene and Carbon Nano tubes were combined to form Nano composite materials. Both materials were combined in different percentages as shown in the table 2 [Percentages of Nano composite was chosen based on literature. As studied conducted on GNPs and CNPs revealed that they individually perform better at smaller percentages so combination of both was also selected in small percentage range(Ahmad et al., 2018; Hafeez et al., 2019). However, it is important to mention here that the results may be different at other or higher percentages]. Sample ID’s are also given in this table.

Table 2. Sample ID's and percentages used to modify neat bitumen

Percentage GNP + Percentage CNT	Sample ID
0% GNPs and 0% CNTs (Neat Binder)	NB
1% GNPs and 0.5% CNTs	GNP1CNT0.5
1% GNPs and 1.0% CNTs	GNP1CNT1
2% GNPs and 0.5% CNTs	GNP2CNT0.5
2% GNPs and 1.0% CNTs	GNP2CNT1

1. Carbon Nano Tubes and Nano Graphene were blended in percentages as given before with bitumen binder using dry mix technique. Dry mix technique included addition of Nano Composite in bitumen binder directly and then Nano Composite is dispersed at high frequency using high shear mixer. For homogeneous dispersion of Nano composite particles within base binder, the blending was done at 3000 RPM and temperature of 158±5 ◦C for 45 minutes. A vortex type movement generated by high shear mixer ensures fast, homogeneous and aggressive mixing (Hasan et al., 2012). Also 3000 RPM [The 3000 RPM for Nano composite was selected based on literature. For Homogenous mixing of CNTs in asphalt binder, 3000 RPM using high shear mixer was recommended (Ahmad et al., 2018). However, the dispersion of GNPs in asphalt binder was found to be easy (Hafeez et al., 2019). So, 3000 RPM was selected for homogenous dispersion of Nano composite which proved to be fruitful in this study] is usually chosen for high shear mixer (Amin et al., 2016a). After modification of bitumen with Nano composite material, the modified samples were then subjected to conventional binder tests i-e Penetration, softening point and ductility. Frequency sweep and PG were also executed using advance binder testing apparatus known as Dynamic Shear Rheometer (DSR).

EXPERIMENTAL PROGRAM

Conventional

Penetration test

Penetration Test for determination of consistency or degree of hardness of bitumen binder, penetration test was performed following AASHTO T 49-97 standard. The respective test was performed under the standard test conditions for neat bitumen sample and Nano composite modified bitumen samples. Penetration was determined by measuring penetration distance of standard needle of 100g weight into each sample. The pull speed and loading time was 50 mm/min and 5 s respectively. Each sample was placed in water bath for 1 hr. and 30 min. with temperature maintained at 25°C. The final penetration of each sample was then noted down in units of tenth of mm.

Softening point test

Using ring and ball apparatus, softening point test on each bitumen sample was executed following standard AASHTO T53-96. The temperature at which the bitumen sample can't bear the weight of 3.5 grams steel ball is termed as softening point. First of all, brass rings were filled up with bitumen samples and then put into liquid bath. The steel balls were then set on to brass rings after which heat was applied to complete assembly uniformly at an increasing rate of 5°C/min. Softening point was then noted down at a temperature or point where two disks softened and steel balls descended by 1 in.

Ductility test

Ductility test on each sample was carried out using ductilometer following standard AASHTO T51-94. The lengthening of a bitumen sample (elongation) under the applied tensile pull. First of all, moulds were filled up with bitumen sample. Then the filled up moulds were positioned in ductilometer. Under specific conditions i-e 25°C temperature and 50 mm/min. speed, with the help of stretching action applied on clips from both sides, elongation of each sample is obtained. The elongated distance of clips before breakage of bitumen sample is recorded as ductility value.

RHEOLOGICAL

Dynamic shear rheometer

PG and frequency sweep was executed at various temperatures range with the help of dynamic shear rheometer following AASHTO 315. The selected temperatures for frequency sweep (FS) were 22°C, 34°C, 46°C, 58°C, 70°C and 82°C. The FS was executed in strain control mode. The frequency exerted for each temperature ranges from 0.1 Hz to 10 Hz. 10% and 0.45% strain was applied for modified bitumen samples and neat bitumen sample respectively. For temperatures below 40°C, plate diameter of 8mm with 2mm gap was utilized whereas for temperatures greater than 40°C, plate diameter of 25 mm with 1 mm gap was utilized. PG was conducted at 10 Hz frequency and failure temperatures for each sample was recorded at a point where $G^*/\sin\delta$ lessened than 1 Kpa. For PG, plate dia of 25 mm was utilized.

RESULTS & DISCUSSION

Conventional physical tests

The results obtained from penetration, softening point and ductility are given in Figure 1 and figure 2 respectively. It was found from the results that with increase in the percentage of Nano composite particles, the penetration values decreased. As compared to neat binder, the penetration values reduced by 10.94%, 18.75%, 25% and 31.25% with increasing percentage of Nano composite particles up to 3% (combined). Also ductility values reduced by 13.86%, 21.78%, 28.71% and 33.66% with addition of percentage of Nano composite particles in binder up to 3%. The lower penetration values with increase in percentage shows that increasing percentage of Nano composite particles makes consistency of bitumen binder stiffer. Consequently, it also reduces ductility values (Figure 2) and makes bitumen binder more resistant to mechanical damage (Jahromi and Khodaii, 2009).

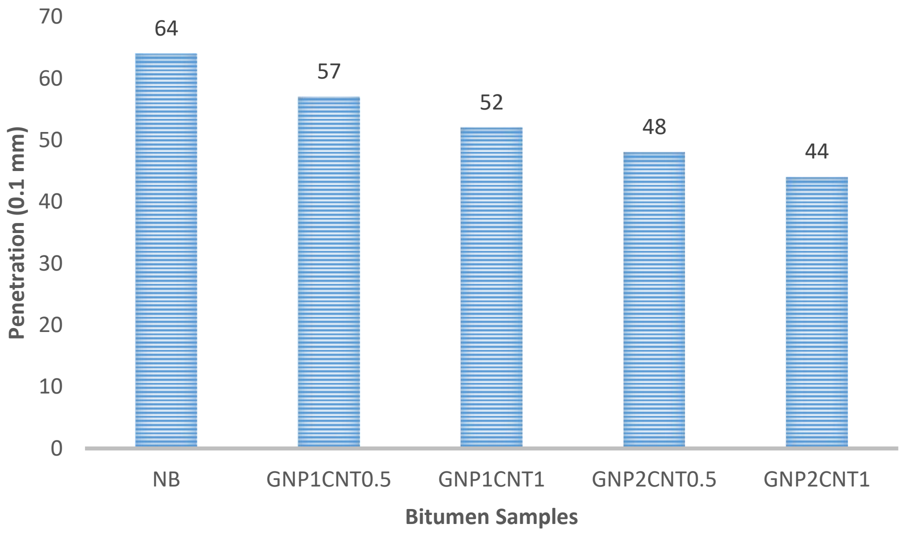

Figure 1. Penetration values of bitumen samples

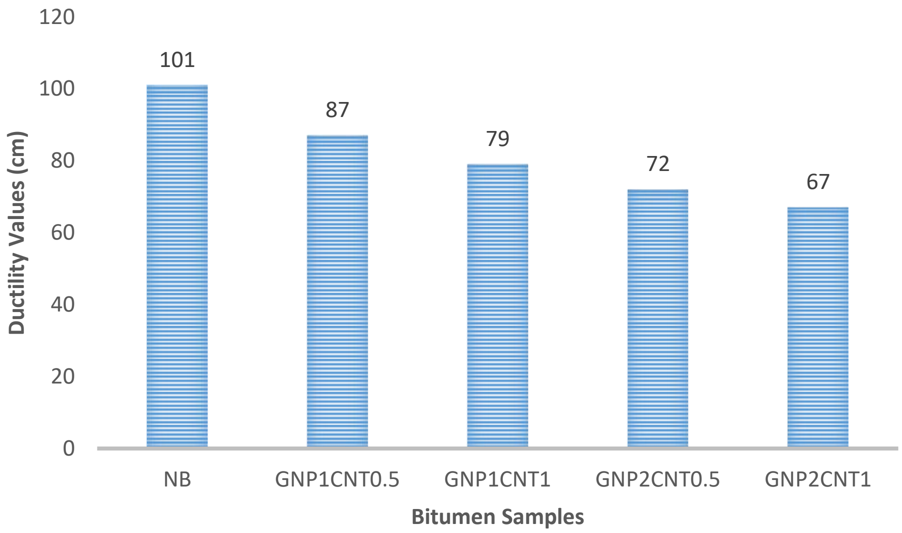

Figure 2. Ductility values of bitumen samples

By adding more percentage of Nano composite particles, the softening point of bitumen binder rose (Figure 3). The percentage improvement of 6.25%, 14.58%, 18.75% and 31.25% was noted with increasing percentage of Nano composite particles up to 3%. This trend is favorable for bitumen binder, as it makes it more resistant to permanent deformation. Bitumen binder with elevated softening points shows more viscous behavior as viscosity and softening points are closely related to each other (Zapién-Castillo et al., 2016).

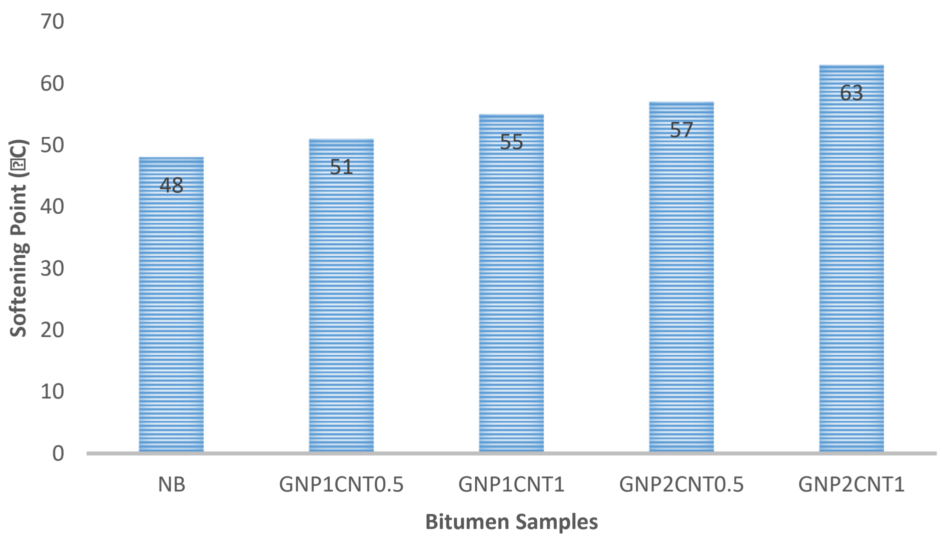

Figure 3. Softening point of bitumen samples

For quantitative evaluation of temperature susceptible behaviour of modified bitumen samples, Penetration index values were also calculated using equation given below (Ehinola et al., 2012)

$$PI = \frac{20-500A}{1+50A} \qquad (1)$$

Where $$A = \frac{log(800)-\log(Pen\ at\ T)}{SP-25} \qquad (2)$$

Where T shows temperature of penetration test (25◦C),Pen at T shows the penetration corresponding to desirable temperature T (0.1 mm), SP shows the softening point of bitumen binder (◦C), and Pen at SP shows the corresponding penetration value at the softening point which is assumed as 800 (0.1 mm).

In general, Higher PI values depicts low temperature susceptibility of bitumen binder. The PI values generally lies within a range of -2 to +2. If PI value of bitumen binder is below -2, the bitumen binder is considered as high temperature susceptible as such type of bitumen binders shows brittle behavior within low temperature range as a result of which transverse cracking may occur in asphalt pavement in low temperature regions (Enieb and Diab, 2017).

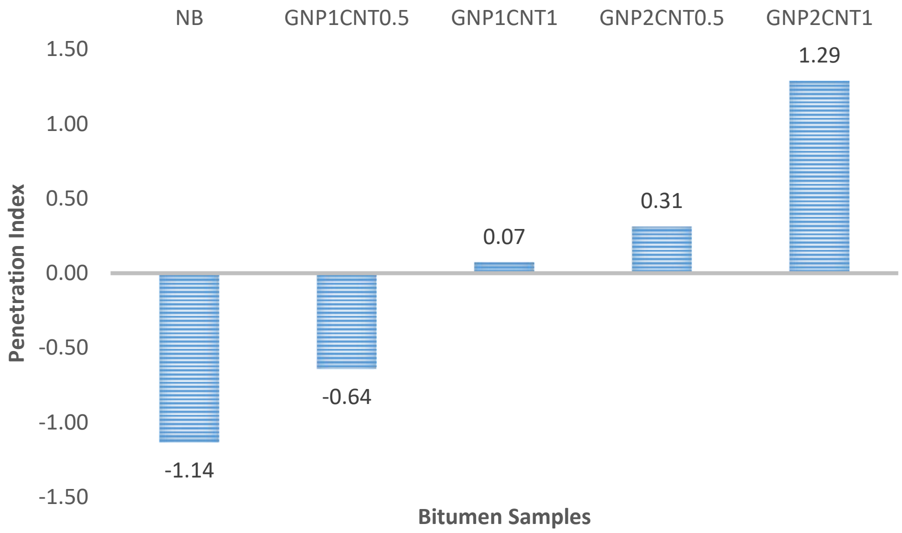

Figure 4. Penetration index of bitumen samples

The PI values are shown in Figure 4. It can be noted that the PI values lies within acceptable range i-e -2 to +2 and with increase in percentage of Nano Composites, the PI values of bitumen binder increased which is an indication of low temperature susceptibility of bitumen binder modified with Nano composites.

Rheological behaviour

DSR test was executed to scrutinize the rheological behavior of asphalt binder samples modified with Nano composites at a wide range of temperatures (from intermediate to high) for various frequencies. Failure temperatures for different percentages of Nano composites are shown in table 3 which depicts that with introduction of more percentage of Nano composite, the failure temperature increases. Failure temperature can be defined as the temperature at which G*/Sinδ reduces below 1 kPa for asphalt binder (Ali et al., 2017). The failure temperature of neat binder was 61°C so the upper PG of neat binder was 58. For samples GNP1CNT0.5 and GNP1CNT1, PG changes to 64. With further increase in the percentage of Nano composites i-e for samples GNP2CNT0.5 and GNP2CNT1, the PG further changed to 70. It means that total of 3% of Nano composite dosage resulted in pumping of PG from 58 to 70. According to hot climatic conditions in Pakistan, PG 70 is usually recommended (Mirza et al., 2016).

Table 3. Failure temperatures & PG's of bitumen samples

Bitumen Samples	Failure Temperatures	PG
NB	61.7	58
GNP1CNT0.5	66.5	64
GNP1CNT1	67.8	64
GNP2CNT0.5	72.4	70
GNP2CNT1	74.5	70

The determination of storage and loss modulus at selected range of various frequencies and temperatures is done by DSR test (Jamal et al., 2018). The results obtained from DSR test were fitted and master curves were constructed using sigmoidal function at a reference temperature of 58°C. The complex modulus (G*) and rutting factor (G*/Sinδ) was used as a tool to study the multi component phase of modified and conventional asphalt binder. The master curves for G* representation are given in Figure 5 which indicates that there was significant increase in G* values with increase in Nano composites percentage. The highest values were obtained for GNP2CNT1. This trends depicts that with increase in dosage of Nano composite, the stiffness of the binder was enhanced and consequently permanent deformation resistance was improved within high temperature range (Ahmad et al., 2018).

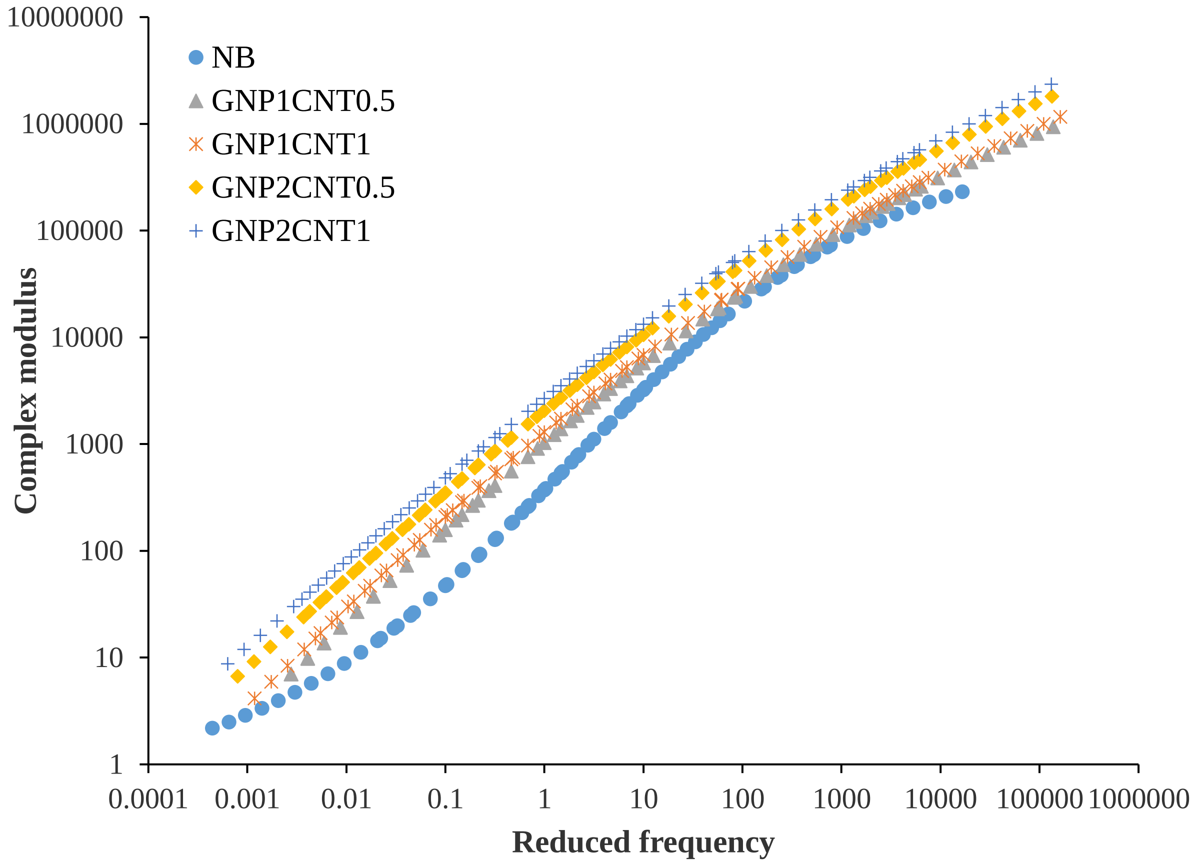

Figure 5. Master curves showing complex modulus at reduced frequencies

SHRP defines G*/Sinδ as the rutting factor which represents bitumen binder resistance to permanent deformation and rutting within high temperature range (Jin et al., 2018). The master curves representing G*/Sinδ at a reference temperature of 58°C are shown in Figure 6. It is clear from the curves that increasing percentage of Nano composites had significantly enhanced rutting factor. GNP2CNT1 sample gave highest enhancement in the rutting factor. With improvement in this parameter with increased concentration of Nano composites, it can be concluded that the resistance of bitumen binder is improved against rutting at elevated temperatures (Ahmad et al., 2018).

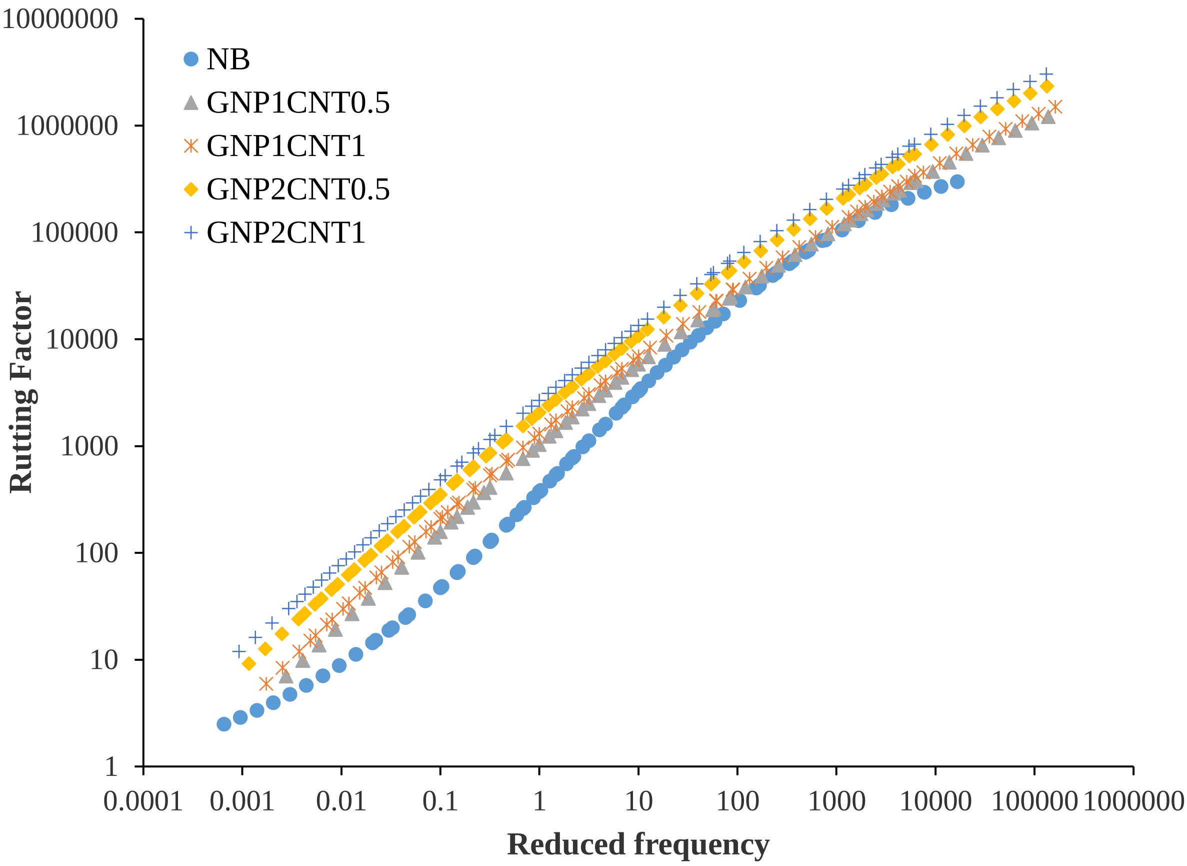

Figure 6. Master curves representing rutting factor at reduced frequencies

CONCLUSION

The following conclusions can be made at the end of this study.

1) Addition of more percentage of Nano composite reduced penetration values, increased softening point and decreased ductility values. These results indicates that stiffness of the bitumen was increased and therefore resistance to rutting.
2) The penetration Index values remained in the acceptable range and increased with increase in concentration of Nano composite which shows low temperature susceptibility of modified bitumen at increased dosage.
3) Multi component phase evaluation showed that addition of more percentage of Nano composite increased stiffness of the bitumen binder which in turn increased resistance against permanent deformation as both Rut factor and Complex shear modulus was increased at high temperatures.
4) GNP combined with CNT (Nano Composite) significantly improves pavement performance and thus it can be concluded that combination of both Nano particles proves itself a remarkable addition in bitumen.

RECOMMENDATIONS

It is recommended that the effect of Nano composite should be investigated on mechanical behaviour of asphalt concrete mixtures.

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