Evaluation of the rheological characteristics of asphalt modified with Nano material

Bilal Ahmad[1],Engr. Waqas Haroon[2], Khan Zaman[3], Rasool Shah[4],Dr. Malik Muneeb Abid[5]

1. Corresponding Author. BS student, Department of Civil Engineering, International Islamic University, Islamabad, Pakistan.
   Email: bilalahmadmomand945@gmail.com
2. Author. MS Lecturer, Department of Civil Engineering, International Islamic University, Islamabad, Pakistan.
   Email: waqas.haroon@iiu.edu.pk
3. Author.BS student, Department of Civil Engineering, International Islamic University, Islamabad, Pakistan.
   Email: khan.zaman@gmail.com
4. Author. BS student, Department of Civil Engineering, International Islamic University, Islamabad, Pakistan.
   Email: rasoolshah37@gmail.com
5. Author. Assistant Professor, Department of Civil Engineering, International Islamic University, Islamabad, Pakistan.
   Email: muneeb.abid@iiu.edu.pk

Abstract

Nano technology is using in all over the world and it has a great effect on characteristics of asphalt. A Nano technology is one of the active research areas in a number of disciplines like Civil Engineering and Construction Materials. A modifier Nano silica (NS) is used by different researchers to start focus on the modification of Pavement materials. The objectives of this study were to enhance the role of Nano technology in Pavement Engineering applications on the basis of its rheological parameters. This paper focus on how to improve the conventional and rheological characteristics of modified binder using Nano Silica (NS). Incorporating of Nano silica (1%, 3%, and 5% by weight of binder) in binder had improved the physical properties of bitumen. Frequency sweep test was performed by using Dynamic Shear Rheometer (DSR) to evaluate complex modulus, phase angle and rutting resistance characteristics of binder. The result showed that by adding 3% NS, penetration and ductility had decreased by 18.29% and 30.1% respectively while the softening point had increased 7.53%. The test result of the DSR showed that rutting resistance had improved 35% by using 3% NS. The optimum percentage of 3% NS was recorded on the basis of rutting resistance values.

Keywords: Nano Silica (NS), Dynamic Shear Rheometer, Rheological and Rutting Resistance.

1. INTRODUCTION:

Asphalt concrete mixture consists of mainly two major components; aggregates and binder(Read and White oak, 2003). Out of total weight of asphaltic mixture, 95% by weight of asphaltic mixture represents the aggregate components and remaining 5% shows the binder component. The binder proportion is small but it has a greater effect on characteristics of obtained mixture (Ahmed, 2007). Many researchers are focusing to enhance the performance of binder which ultimately improve the quality and characteristics of asphalt concrete mixture. Different modifiers were used by them such as clay, rubbers, polymers etc. to enhance mixture characteristics(Chen, Liao and Lin, 2003; Ahmed, 2007). Currently, Nano technology is using in all over the world and it has a great effect on characteristics of asphalt. In Civil engineering it has been used in 1986 in publication of the book Engines of Creations. It has been used in different fields like medicine, water treatment as well as in Transportation Engineering. Researchers start focus on using Nano Silica in different pavement layers (A. Ahmed and T. Mahmood, 2015; Issa, 2016). Rut is a longitudinal grove in roads that is caused by the repeated loads of vehicles mainly at high temperature(Yusoff et al., 2014). Nano silica is mixed with bitumen at a temperature of 160°C in proportion of 1%, 3% and 5% by weight with homogenizer at velocity of 2000rpm(Enieb and Diab, 2017). It has been observed that rutting resistance is improved by incorporating Nano silica in binder. Nano silica act as a filler in mix design due to which it improves the properties of asphalt .The importance of nano silica particles is that it posses oxidizing properties which accelerate oxidizing reaction in the bitumen binder. Advantage of nano silica is that they give us low cost production and enhance performance of asphaltic concrete. As high grade bitumen are used in cold areas, so by modifying these bitumen with nano silica they get stiffer and can also be used in warm areas. As compared to the project estimated cost for the maintenance, the cost used for modifying bitumen is lesser so we can built more durable pavements which will resists the major distresses like rutting,(Mokhtar F. Ibrahim Hassan D. Hassanin(2018)

2. OBJECTIVES:

The main objectives of the research are given below:

1. To improve the physical properties of modified Nano Silica binder.
2. To improve the rheological characteristics of Modified Nano Silica binder.
3. To determine the optimum content of Modified Nano Silica binder on the basis of rutting resistance value.

3. MATERIALS:

3.1 BITUMEN:

The bitumen used in this research is of Penetration grade 80/100 procured from National Refinery Limited (NRL) Karachi, Pakistan.

3.2 NANO SILICA:

Nano silica (SiO_2) is also known as Silicon dioxide. It is in the form of powder. The properties are given in the Table1.

Table 1: Properties of Nano Silica

Properties	
Chemical formula	SiO_2
Molar mass	60.08 $gmol^{-1}$
Melting point	>1600 °C
Boiling point	2230 °C
Form	Nano powder
Surface Area	spec. surface area 175-225 m^2/g
Diameter	25-30nm

4. METHODOLOGY:

The test methodology of the research is given in Figure 1:

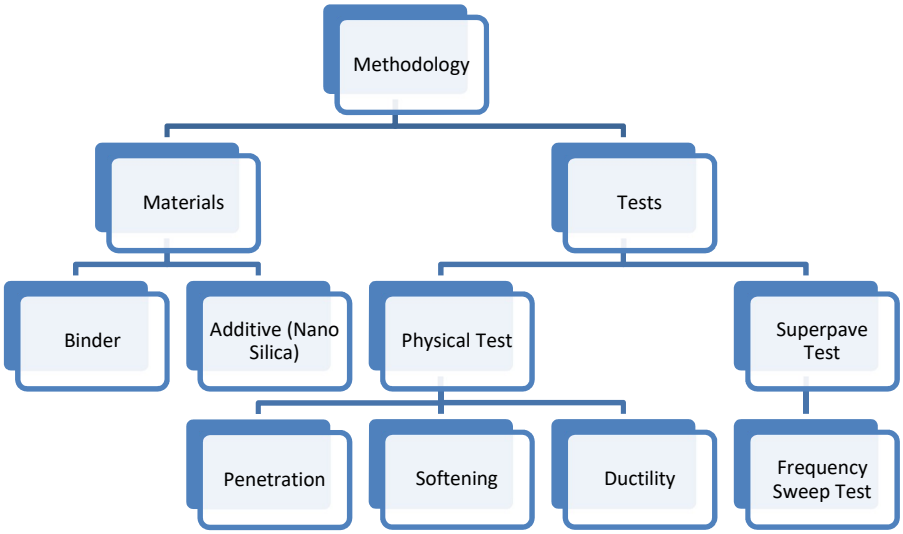

Figure 1: Methodology

5. TESTING PROGRAM

This section we briefly explains the tests performed for the evaluation of rheological properties of bitumen. Experiment is categorized into two section (i.e) conventional tests and advance tests. The conventional tests determine the physical properties while the advance test evaluates the rheological properties.

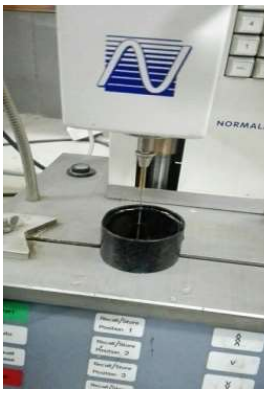

Figure 2: Penetrometer

Figure 3: Ring and Ball Apparatus

Figure 4: Ductilometer

Figure 5: DSR

5.1 PENETRATION TEST:

Penetration test was performed in accordance with ASTM standard (D5/D5M-13, 2013) as shown in Figure 2. The main purpose of this test is to determine the penetration grade of binder.

5.2 SOFTENING TEST:

The main purpose of this test was to determine the consistency of binder in accordance with ASTM standard (ASTM D36/ D36M-14e1, 2014) as shown in Figure 3.

5.3 DUCTILITY TEST:

The ductility test was performed to determine the tensile nature of binder in accordance with the (D113-17, 2017) as shown in figure 4.

5.4 FREQUENCY SWEEP TEST:

Frequency Sweep Test was performed on Dynamic Shear Rheometer (DSR) machine as shown in figure 5 to determine the viscoelastic behavior and rutting resistance of binder in accordance with the (AASHTO T 315-10, 2010). The range of frequencies used for this test was 10 to 0.1 Hz and temperature range was 22°C to 82°C.Strain limit for base binder was kept 12%.

6. TESTING RESULTS:

6.1 CONVENTIONAL BINDER TESTING:

The conventional physical properties test results are given in Table 6.1:

Table 6.1 Conventional Testing Results for shear mixed Binder

Test	Base Binder	1% NS	3% NS	5% NS
Penetration (0.1mm)	82	74	67	63
Softening Point (◦C)	46.5	48	50	52
Ductility (cm)	103	83	72	58

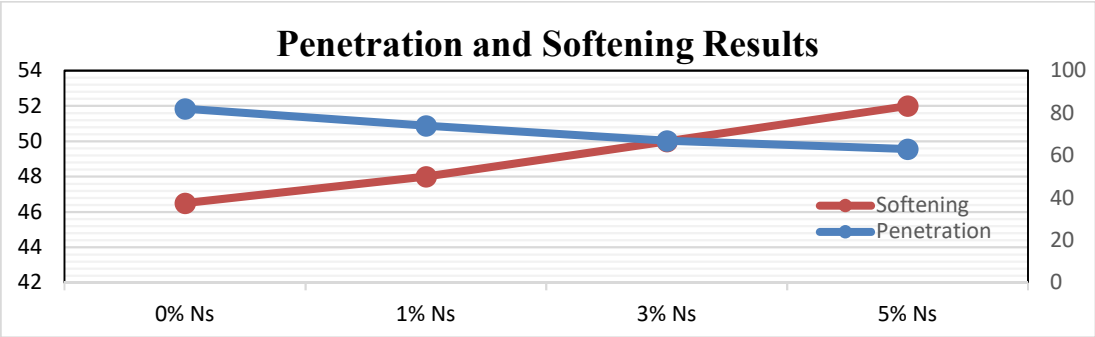

Figure 6: Penetration and Softening Results

Figure 6 illustrated that penetration of the bitumen had decreased by increasing the percentage of Nano Silica. The penetration values of 1% NS and 3% NS showed that it had become 9.76% and 18.29% stiffer respectively than neat bitumen. The overall 23% reduction in penetration value was recorded as result in adding 5% NS. Figure 6 results illustrated that softening point of the bitumen increased by adding NS. The incorporation of NS 1%, 3% by wt. of binder had increased the softening point 3.225% and 7.53% in comparison with neat binder. Similarly, by adding 3% of NS had increased the 4.16% as compared with 1% of NS. Thus results concluded that incorporating 5% NS in base binder had increased the overall softening point 10.58% in comparison with neat binder.

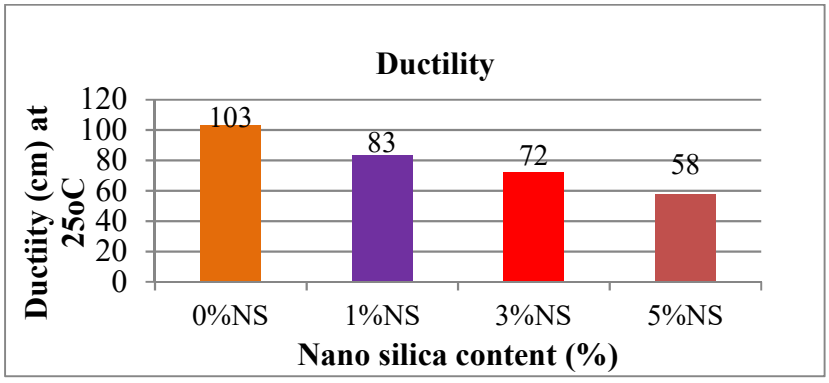

Figure 7: Ductility Test Results

Graphical representation of Figure 7 illustrated that 1%, 3 and 5% NS had significantly decreased the ductility values 19.42%, 30.1% and 44% respectively. There is the significant reduction in the ductility and is reduced by 44% by adding 5% Nano silica in bitumen.

6.2 Frequency sweep Test:

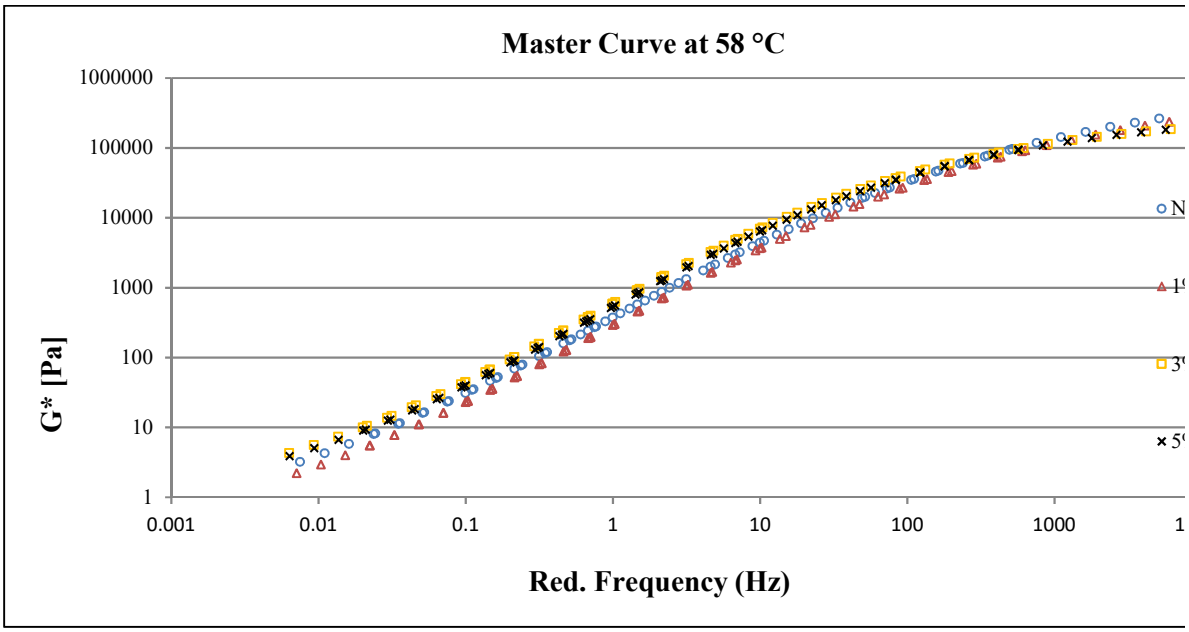

Figure 8: Master Curves Drawn at 58 °C

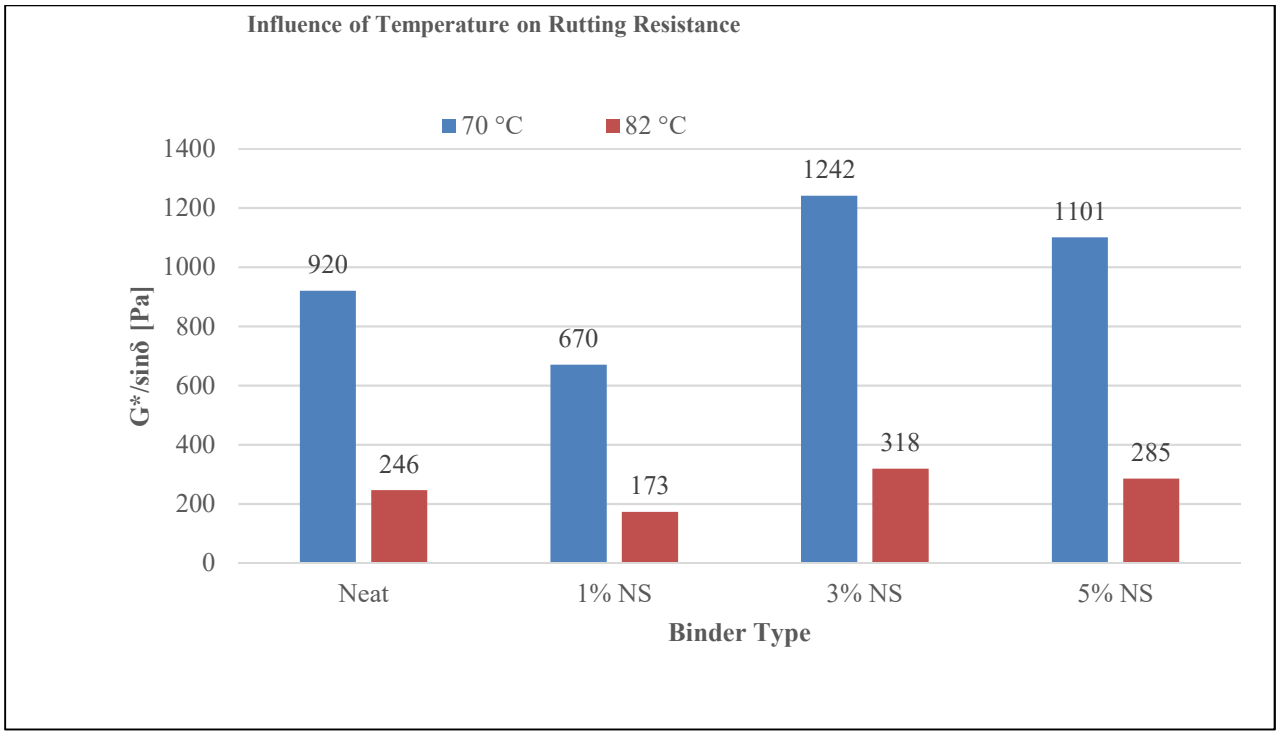

Figure 9: Influence of Temperature on Rutting Resistance

Master curves drawn in Figure 8 shows a relationship between reduced frequency and G*.Master curves were drawn at 58 °C by using sigmoidal parameters. Master curves showed that by adding 1% NS had decreased the complex modulus values while 3% NS had increased the complex modulus (G*) values at lower frequencies while decreased the G* at higher frequencies. It's confirmed that the performance of 3% NS had not only significantly improved the performance of binder at higher temperature but also improved its low temperature characteristics. Similarly, modification by 5% NS showed that by adding the quantity of NS would decrease the high and low temperature performance of pavement.

Figure 9 illustrated the influence of temperature on Rutting Resistance G*/sin δ (RR) values. RR values of all the four binders were compared on 10 Hz frequency at temperature of 70 °C and 82°C. RR values at higher temperature 70°C confirmed that 3% NS and 5% NS had passed the Superpave Rut Resistance Criteria (G*/sin δ ≥ 1.00 kPa) (Institute, 2001)at 70°C. Thus it concluded that rutting resistance was improved by 35% and 19.67% at 3% and 5% Nano silica. Thus optimum percentage recommended to use modifier is 3% NS. The results of literature review shows that the most suitable NS content is 3% which decreases the flow values and increases the marshal stability,(Ahmad M. Sawan.,2017).

7. Conclusions:

- Ductility and penetration of Bitumen was reduced while softening point was increased by incorporating Nano silica in bitumen as shown by the results of conducting conventional tests of bitumen.
- The optimum content of modified NS bitumen noted was 3%.
- The Rutting resistance was improved to be 35% as compared with Neat bitumen.

8. Recommendations:

The recommendations are given below:

- Rutting depth on modified NS asphaltic mix may be evaluated in laboratory by using Hamburg Wheel Tracking Test.
- Ageing tests may be performed on modified NS binders to determine the high temperature performance grade of binder.
- **Acknowledgement:** We would like to thanks Engr. Waqas Haroon who assists us in this research work. We are also thankful to lab Engr. Rana Shahid who helps us performing experimental works.

REFERENCES:

A. Ahmed, L. S. and T. Mahmood, L. O. (2015) 'Influence of Mineral Fibers Properties on the Performance of Hot Mix Asphalt for the Surface Layer of Pavement', *International Journal of Engineering Trends and Technology*, 26(3), pp. 145–151. doi: 10.14445/22315381/ijett-v26p225.

AASHTO T 315-10 (2010) *Determining the Rheological Properties of Asphalt Binder using a Dynamic Shear Rheometer (DSR)*.

Ahmed, L. A. (2007) 'Improvement of Marshall properties of the asphalt concrete mixtures using the polyethylene as additive', *Eng Technol*, 25(3), pp. 383–394.

ASTM D36/ D36M-14e1 (2014) 'Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)', *ASTM International*, 1(D), pp. 1–5. doi: 10.1520/D0036.

Chen, J. S., Liao, M. C. and Lin, C. H. (2003) 'Determination of polymer content in modified bitumen', *Materials and Structures/Materiaux et Constructions*, 36(263), pp. 594–598. doi: 10.1617/13870.

D113-17, A. (2017) 'Standard Method of Test for Ductility of Asphalt Materials', *ASTM International*. doi: 10.1520/D0113-17.

D5/D5M-13, A. (2013) 'Standard Test Method for Penetration of Bituminous Materials', *ASTM International*, pp. 1–5. doi: 10.1520/D0005_D0005M-13.

Enieb, M. and Diab, A. (2017) 'Characteristics of asphalt binder and mixture containing nanosilica', *International Journal of Pavement Research and Technology*. Chinese Society of Pavement Engineering, 10(2), pp. 148–157. doi: 10.1016/j.ijprt.2016.11.009.

Institute, A. (2001) *Asphalt Institute Superpave Mix Design (SP-2) Third Edition*. 3rd edn. USA.

Issa, Y. (2016) 'Effect of Adding Waste Tires Rubber to Asphalt Mix', *International Journal of Scientific Research and Innovative Technology*, 3(5), pp. 61–68.

Read, J. and Whiteoak, D. (2003) *The Shell Bitumen Handbook*. Fifth. Thomas Telford Publishing. doi: 10.1680/sbh.32200.

Yusoff, N. I. M. *et al.* (2014) 'The effects of moisture susceptibility and ageing conditions on nano-silica/polymer-modified asphalt mixtures', *Construction and Building Materials*. Elsevier Ltd, 72, pp. 139–147. doi: 10.1016/j.conbuildmat.2014.09.014.