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Research Article

Application of Nano Silica to Improve Self-Healing of Bitumen Mixtures

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Keywords

Bituminous Mix,
Healing Index,
Marshal Test,
Nano Silica,
NSMB.

Abstract

Rutting and cracking are two common modes of failures in asphalt pavements. Due to increase in traffic volume and traffic loads, asphalt pavements get deteriorated gradually during their service life. Deterioration of asphalt pavements can be eliminated/minimized by enhancing the quality of bitumen and with modified bitumen. The use of nano materials as an additive because of its special characteristics is one of the self healing technique which have the potential to improve the pavement performance, extending its life span and also eliminating the need for pavement maintenance. This research work investigates the performance of nano silica in asphalt pavement. Experiments were conducted on bitumen and modified bitumen (addition of nano silica of different percentages, 2%, 4%, 6%, 8% and 10% with bitumen) in order to find the optimum nano silica content for preparing Marshal Mix. It was found that, for 6% of nano silica in modified bitumen, gave improved properties among other percentages of nano silica contents that are examined. Nano silica modified bituminous mix (NSMBM) samples were prepared for various bitumen contents, i.e., 4.5%, 5% and 5.5% and conducted marshal stability test. This study concludes that, the results obtained from marshal test gives higher stability value (10. 32 kN to 20.18 kN) and lesser flow value (4.48 mm to 2.60 mm) for Modified bituminous mixes over unmodified bituminous mix samples. Finally, the healing index was also determined based on theoretical approach and obtained 80 % healing rate for modified bituminous mix. Further investigations can be carried out on long term effects of NS in asphalt pavements as well as test rest periods for different temperatures and different loads.

1. Introduction

With increase in countries population and increase in traffic volume causes pavements to experience the continuous loading which leads to pavement distress problems. The challenge for road engineers is to develop a sustainable asphalt mixture that reduces the likelihood of the pavement system failure by developing new road materials and new methods in road construction and maintenance [2, 3, 19, 20]. Since 2008, the incorporation of self-healing technology into asphalt pavements has been advancing and gaining importance in recent times [4, 5]. Self-healing technology had become an alternative solution for road maintenance, where the damage is repaired by an internal healing system [14, 1]. Rise in temperature will increase the healing effect of asphalt concrete; as a result of healing, the service life time of asphalt concrete will increase [13]. However, it is well known that, the healing of asphalt concrete is a temperature dependent phenomenon, and the healing mechanism has been reported by many researchers as increase in the test temperature results in increasing the healing rate and shifts the recovery response to a shorter time [11]. A trial section was constructed on Dutch motorway A58, in December 2010, and applied induction healing technique in real porous asphalt road which results in survival of train section for the three winters perfectly [12]. Cracks can be healed internally with the application of self healing material in asphalt concrete when subjected to rest periods with its mechanical properties [12]. Since 1960s, numerous studies were conducted on self healing asphalt concrete [11] and found cracking as one of the major failure modes of it [16].

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Repeated traffic loads causes damage eventually in reducing the fatigue life by forming the micro cracks within the asphalt concrete pavement [16, 20]. Conversely, during rest periods, relaxation of stresses due to visco-elasticity and the healing of micro-damage occur simultaneously in asphalt concrete [10]. Road pavements degradation is a consequence of the traffic loading, climate effects and depending on the materials used and the construction quality as it is anticipated in time or postponed. Asphalt concrete fatigue damage process can be considered as the internal micro crack's initiation, aggregation and development. Asphalt molecules spontaneously carry out interfacial infiltration, adsorption and molecular diffusion that reduce the surface energy; thereby, its motive force is derived from the vander walls force of crack interfacial molecule and the chemical adsorption of hydrogen bond [18] signifies the crack self healing mechanism in asphalt concrete. Bitumen is a material with self-healing characteristics, i.e., the ability to close existing micro cracks, depending on its viscosity and the temperature, the bitumen flows to the crack can be partially or completely closed if enough time is provided between traffic loads [6, 7, 8, 9]. However, this process may take several days to be completed at normal pavement temperatures [15].

Rutting and fatigue cracking were addressed as the main distresses of flexible pavements [17, 19]. It was found that, limited studies were carried out on use of nano materials as self healing techniques in flexible pavements. In the search of better performance of pavements, we can conduct further investigative studies on effect of nano materials as self healing technique in flexible pavements. This paper mainly focuses on finding the improved properties of bitumen with addition of nano silica at different proportions (2%, 4%, 6%, 8% and 10%) and strength of nano silica modified bituminous mix for various bitumen proportions.

2. Materials

The bitumen used for the present study is of the grade 85/25 and the properties are Specific gravity 1.05, Penetration number 20/30 mm/10, Softening point 80/90, Fire point 200 °C and Flash point 150 °C. Nano material used is nano silica (NS) with density 24 g/m3 and the particle size is of 60 nm with its specific gravity varying from 2.2 to 2.4 and it appears as a white powder.

The nano silica modified bitumen (NSMB) was prepared and the NSMB was tested for penetration number (IS :1203-1978), softening point(IS:1205-1978), flash and fire points (IS: 1209-1978) and marshal value (IRC 111-2009) for the NSMB mixes. The penetration value varies with different percentages of nano silica (2%, 4%, 6%, 8% and 10%) and noticed, increase in nano silica content (up to 6%) results in penetration value reduction and increases beyond 6% of NS usage. The softening point is defined as the temperature at which a bitumen sample can no longer support the weight of a 3.25 g steel ball. The softening point is reported as the mean of the temperatures at which the two disks soften enough and allow each ball enveloped in bitumen, to fall a distance of 25 mm. The softening point test results were also increased with increase in the nano silica content up to 6 % and decreases beyond 6%. As the temperature increases, the strength of the bitumen mix increases resulted from increase in the nano silica content. This will indicate that nano silica can increase its strength. The flash and fire point points are the temperatures where the bitumen catches the flash and fire. If the flash and fire point are less, then the pavements which are used with that material will catch fire at low temperatures. Therefore, the flash and fire points are said to be high. The flash and fire points increases with increase in nano silica content to certain extent. The marshal samples were prepared for NSMB mix and were tested for marshal stability value. The sample was prepared according to the gradations given by IRC 111 for the marshal stability test and the value indicates the strength of the bituminous mix. The marshal stability test was conducted for the optimum content of the nano silica percentage and is compared with the conventional bitumen. The results are increased which indicate the increase in strength. The bitumen content was also a main criterion in this test which is varying from 4.5% to 5.5 %. The strength of the bituminous mix also increases with the increase in percentage of bitumen and thus, optimum temperature was obtained at 6 % of nano silica content and 5.5 % bitumen content.

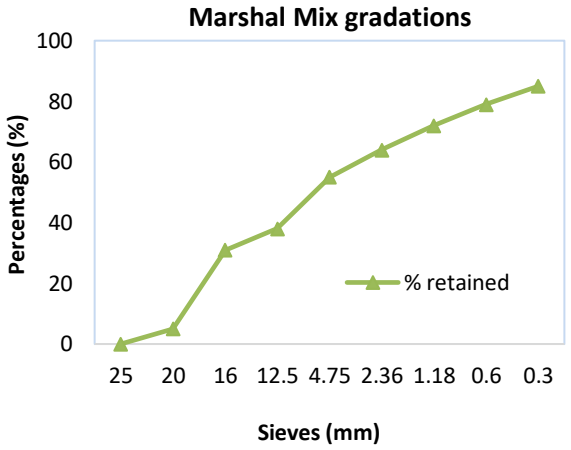

Figure 1. Gradations for Marshal Mixes

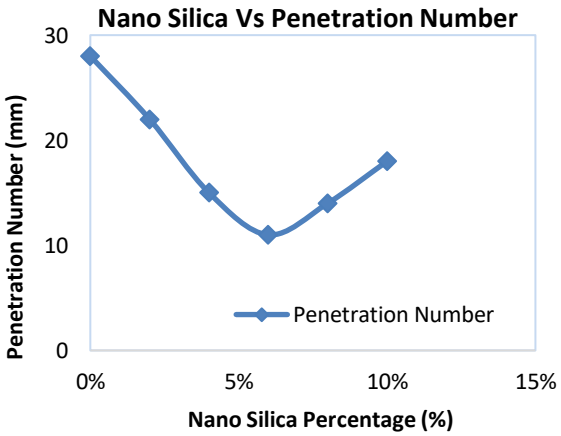

Figure 2. Penetration Test Results-Unmodified and Modified Bitumen

Tests like penetration, softening, flash & fire were conducted for prepared modified bitumen, i.e., nano silica modified bitumen (NSMB). Results from experiments were shown from Figure 2 to Figure 4. Marshal mixes were prepared for various bitumen contents (4.5%, 5% and 5.5%) with an effective percentage of nano silica which is obtained

from previous test results, i.e., 6% of nano silica gives better results than others (2%, 4%, 8% and 10% of nano silica content) that are examined.

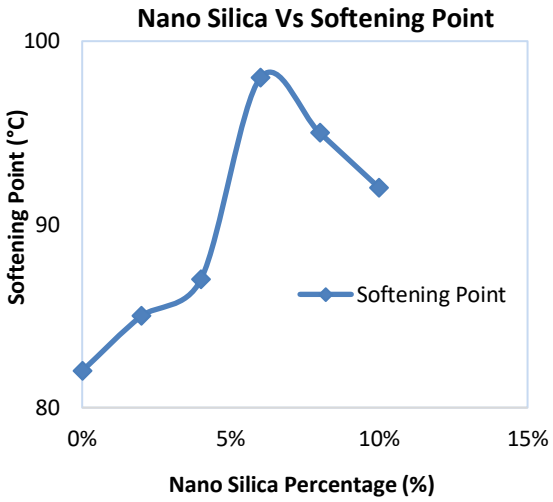

Figure 3. Softening Point –Unmodified and Modified Bitumen

From the above results, it was found that, low penetration value (10 mm), highest softening point (95 °C) and higher flash and fire points (214 °C & 174 °C) were obtained for 6% nano silica content used in bitumen. Thus, it can be considered as an effective percentage of nano silica to be used for preparing the marshal mixes, within the percentages examined (2%, 4%, 8% and 10%).

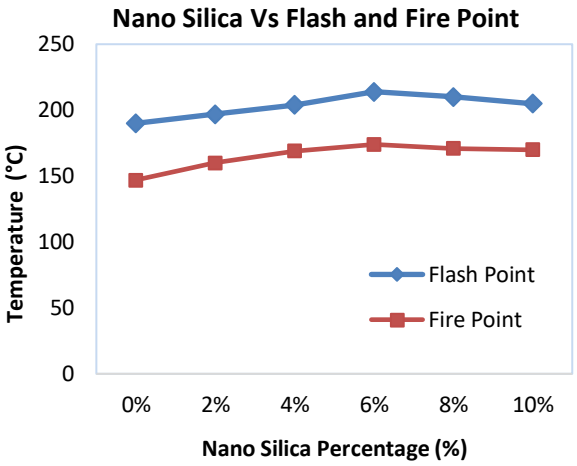

Figure 4. Flash and Fire Test Results -Unmodified and Modified Bitumen

Marshal Mixes were prepared for 4.5 %, 5% and 5.5% bitumen contents with 6% nano silica and stability tests were conducted on the samples prepared in the laboratory (conventional bituminous mixes and nano silica modified bituminous mixes) to determine marshal stability and flow values respectively. The results obtained from the experiments are tabulated as follows,

Table 1. Experimental result for unmodified bituminous mixes and modified bituminous (NSMB) mixes – Marshal Stability Test

MIX	Bitumen Content	G_m (g/cc)	Vv (%)	V_b (%)	VMA (%)	VFB (%)	Stability (kN)	Flow value(mm)
Unmodified Bituminous Mix (Nano Silica 0%)	4.5%	2.34	6.54	10.65	17.19	61.95	10.32	4.48
	5.0%	2.36	5.00	11.92	16.92	70.44	12.11	4.60
	5.5%	2.38	2.62	13.00	15.00	83.56	15.70	4.72
Modified Bituminous Mix (Nano Silica 6%)	4.5%	2.42	4.50	10.38	14.36	72.32	14.25	2.60
	5.0%	2.46	4.00	11.71	13.97	80.42	17.32	3.24
	5.5%	2.43	2.17	12.78	14.90	86.39	20.18	3.90

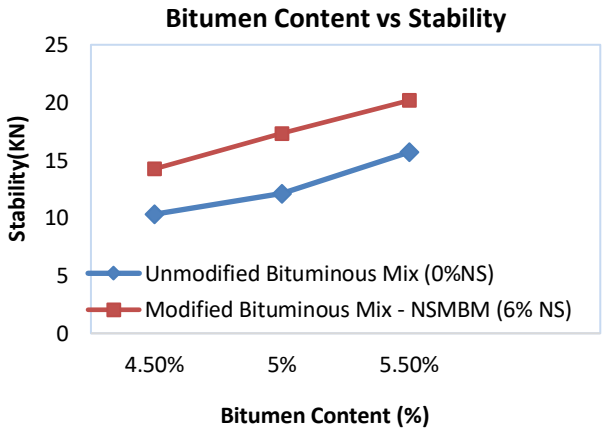

Figure 5. Marshal Stability Values for Unmodified and Modified Bituminous Mixes

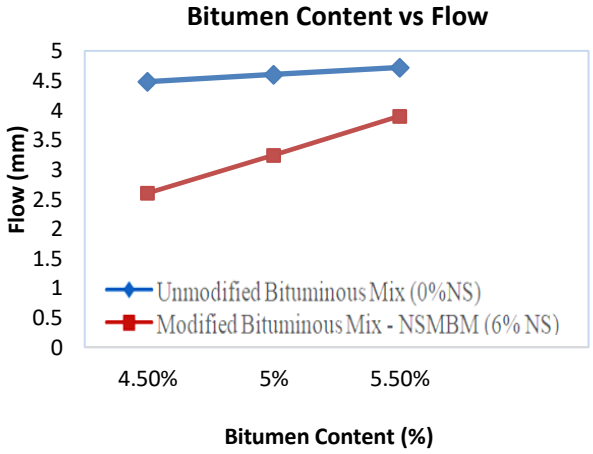

Figure 6. Flow Values for Unmodified and Modified Bituminous Mixes

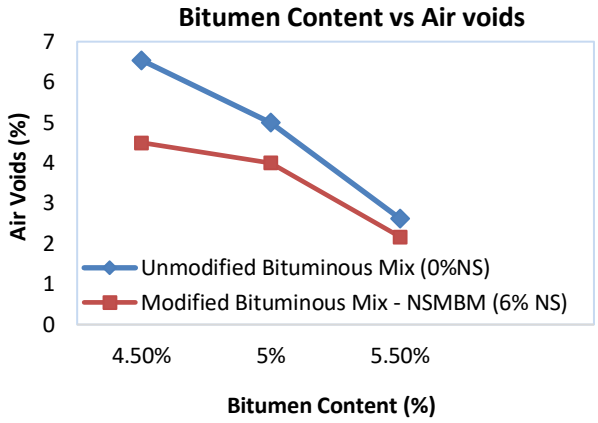

Figure 7. Air Voids for Unmodified and Modified Bituminous Mixes

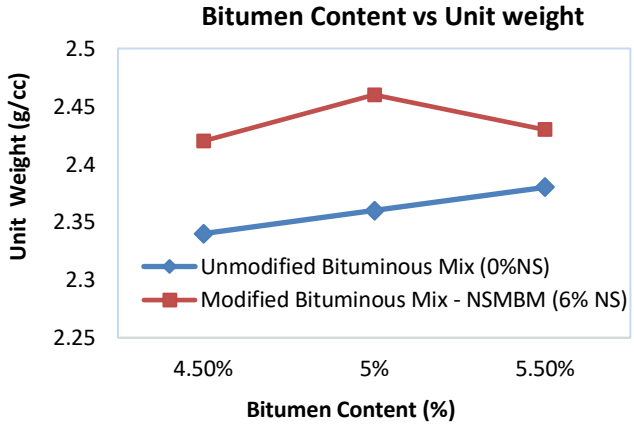

Figure 8. Unit Weight Values for Unmodified and Modified Bituminous Mixes

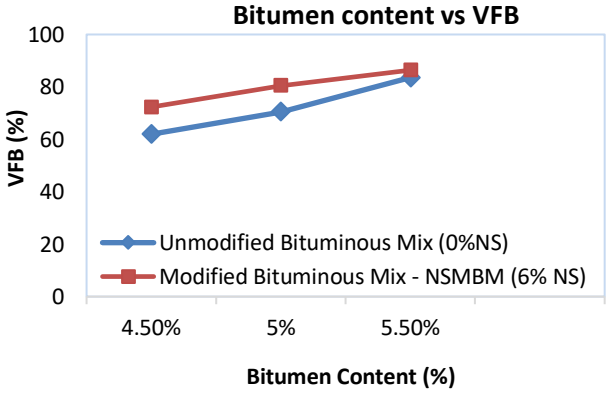

Figure 9. Voids Filled in Bitumen for Unmodified and Modified Bituminous Mixes

3. Theoretical Approach of Healing Index Test

Healing index is the crack filling ability of the nano silica modified bituminous mix in which bitumen is mixed with different proportions of the nano silica and then, the healing indexes are calculated. The healing index for modified bituminous mixes will be calculated by using the following formula

$$H.I = \frac{M_{R(AH)} - M_{R(AF)}}{M_{R(0)} - M_{R(AF)}} \quad (1)$$

where, $M_{R(0)}$ is resilient modulus at the start of damage phase (undamaged);

$MR_{R(AF)}$ is resilient modulus at the end of damage phase (after fatigue);

$MR_{R(AH)}$ is resilient modulus at the end of healing phase (after healing).

- ✓ The healing index was found for nano silica modified bituminous (NSMB) mix, i.e., 80% (for effective percentage of nano silica used, 6%).
- ✓ As the healing index rate obtained was 80 %, which indicates that the damage occurred will be healed up to 80% internally by its self healing technique**.**

It was also inferred that, the healing is only possible for micro and nano cracks. Therefore, macro cracks are seldom healed by this technique i.e., with the addition of nano silica content. The healing is achieved by the rest periods and the above value was taken after one-hour of the rest period

4. Conclusions

Conventional bitumen and modified bitumen with the addition of nano silica at different proportions were tested in the laboratory to find the strength parameters and found that, 6 % of nano silica (NS) with bitumen gave good results among the percentage proportions (2%, 4%, 6%, 8% & 10%) of NS examined. Modified bitumen mixes i.e., nano silica modified bituminous (NSMB) mix with 6% nano silica were prepared for 4.5%, 5% & 5.5% bitumen and conducted marshal stability test for the samples, results showing the improved stability and flow values for NSMB over Conventional mix. Some of the conclusions drawn from the experimental results are as follows,

- ✓ Penetration number decreases with increase in nano silica content (up to 6%) and increases with high amount of nano silica content (beyond 6% and till 10% which is considered for the present study).
- ✓ The penetration number for 6 % nano silica content (modified bitumen) is 11 mm, as the penetration number of bitumen without nano silica (unm 3 1 bitumen) is 28 mm (reduction in penetration noticed with the addition of nano silica – Refer Figure 2).
- ✓ The softening point increases with nano silica content and maximum was obtained at 6% nano silica content, i.e., 95 °C (Refer Figure 3).
- ✓ The flash and fire points also increase with respect to nano silica content up to 6%. The flash and fire points obtained for 6% NS are 214 and 174 degrees (Refer Figure 4).
- ✓ The marshal stability value increases from 10.32 kN to 20.18 kN for unmodified bituminous mix to modified bituminous mix (6% NS), indicating the increase in its strength property (Refer Table 1 and Figure 5).
- ✓ The healing index rate was 80 % for 6 % of the nano silica content.

Thus, results conclude that, 6 % nano silica content is the optimum percentage that can be mixed with the bitumen content to make an efficient pavement which is capable of self-healing.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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