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Studying the Behavior of Asphalt Mix and Their Properties in the Presence of Nano Materials

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Abstract**—**Due to rapid development, increase in the traffic load, higher traffic volume and seasonal variation in temperature, asphalt pavement shows distresses like rutting, fatigue and thermal cracking etc. because of this pavement fails during service life so that bitumen needs to be modified with some additive. In this study VG30 grade bitumen modify with addition of nanosilica with 1% to 5% (increment of 1%) by weight of bitumen. Hot mix asphalt (HMA) have higher mixing, laying and rolling temperatures which leads to higher consumption of fuel. To address this issue, a nano material named ZycoTherm which is chemical warm mix asphalt (WMA) additive is added to bitumen. Nanosilica modification (NSMB) results in the increase in stability compared to unmodified bitumen (UMB). WMA modified mix shows slightly higher stability than UMB and NSMB in a lower bitumen content. The Retained stability and tensile strength ratio (TSR) is more than 75% and 80% respectively for both mixes. Nanosilica with WMA has more resistant to temperature susceptibility, moisture susceptibility and short term aging than NSMB.

Keywords**—**HMA, nanosilica, NSMB, temperature, TSR, UMB, WMA.

I. Introduction

TRANSPORTATION contributes to the social, cultural and economic development of any country. For a developing nation such as India, roads and highways are preferred as primary modes of transportation. It is a fact that bituminous material, such as bitumen, is mainly used on a large scale and in huge quantities for construction and maintenance of roads results in degradation of environment and depletion of natural resources such as raw materials etc., so it is necessary to stimulate the application of nano materials for asphalt pavements for evaluating mechanical and physical properties and as well as durability of asphalt pavement. In the HMA higher mixing, laying and rolling temperatures, leading to higher consumption of fuel [1]. WMA technology is alternate of the HMA [2]. It is reported by Butz et al. that WMA can reduce production and laying temperatures 10°C to 40°C depending upon the method and additive used [3]. The advantages of nanosilica modified WMA over nanosilica hot mix such as energy consumption is reduced for heating of materials in mixing period, and this issue results in decrease of fuel consumption, reduce the emissions of toxic fumes and gases from hot mix plants, decreased binder aging during production. So it has environmental, operational and economic benefits. Hence, in this study, nanosilica is expected to improve the binder quality and longevity of pavement whereas WMA additive is expected to decrease the mixing, laying and rolling temperatures that will be safe and environmental friendly.

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II. Literature Review

The utilization of nano material in bituminous pavement started late. Nano technology is used as a new material, device and system at the molecular stage. Several nano materials have been utilized for modification of bitumen, such as nanosilica, nanoclay, nanofibres, nano tubes etc. One least dimension of nano particle is less than 100 nanometer (nm). Nano materials have high specific surface and high reactivity due to their small size. From the above benefits, nano materials are important solution for distresses of bituminous pavement [4]. Galooyak et al. [5] studied the performance of Bituminous Concrete mixes using nano silica and Sasobit WMA additive. Marshall Method of mix design was adopted and specimen were prepared for optimum bitumen content with 0%, 2%, 4%, and 6% of Nano-silica content with 2% Sasobit by weight of bitumen. It can be observed that the value of resilient modulus has been enhanced by increasing the contents of Nano-silica from 0 to 6%. Rut depth after 10,000 cycles was determined for modified and neat bituminous mixes. Ghasemi et al. [6] studied the physical and mechanical properties of asphalt cement using various percentages of SBS (5%) and nano-SiO_2 powder (0.5% to 2% with constant increments of 0.5%). The result showed that penetration and softening point decreases and increases, respectively, by the increase of the percentage of nano-SiO_2 in the modified binders. The Marshall stability increases with the nano-SiO_2 content. The TSR of the specimens prepared with different nano-SiO_2 contents after completion of one freeze–thaw cycle. The TSR values of the mix improve with increase in nano-SiO_2 content. The highest TSR value as 0.91 at 2% nano-SiO_2 and lowest TSR value 0.7 at conventional mixtures. TSR value showed that the nano-SiO_2 is more effective than SBS for moisture damage. The stiffness modulus of the mixture increased, by increasing the nano-SiO_2 content. The stiffness modulus of nano-SiO_2 mixture is 2.3 times higher than the control mixture.

III. Materials and Methodology

A. Aggregate

Aggregate is collected from local market. The aggregates are processed by washing, drying and sieving. All the aggregates are sieved to the appropriate size according to different tests as per BIS guidelines and selected gradation for

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mix as mentioned in MoRT&H [7]. The aggregate properties and gradation are shown in Tables I and II, respectively.

TABLE I
PHYSICAL PROPERTIES OF AGGREGATE

Properties of Aggregate	Test Results	Test Methods
Flakiness indices	24.60	IS 2386-Part I
Elongation indices	22.10	
Crushing Strength Test	29.59	IS 2386-Part IV
Los Angeles abrasion value	28.44	
Impact test	25.09	
Water absorption	1.00%	IS 2386-Part III
Specific gravity	2.78	

TABLE II
AGGREGATE GRADATION FOR ASPHALT CONCRETE

Sieve Size (mm)	% Passing Range	% Passing (Selected Gradation)
19	100	100
13.2	100-90	95
9.5	88-70	79
4.75	71-53	62
2.36	58-42	50
1.18	48-34	41
0.6	38-26	32
0.3	28-18	23
0.15	20-12	16
0.075	10-4	7

B. Binder

Asphalt binder VG 30 grade bitumen collected from local market is used in this study. The binder physical properties are shown in Table III.

TABLE III
PHYSICAL PROPERTIES OF BINDER

Properties of Bitumen	Test Results	Test Methods
Specific gravity	1.00	IS: 1202-1978
Penetration, 0.1mm, Min.	46.33	IS: 1203-1978
Softening Point, C, Min.	52.60	IS: 1205-1978
Ductility, Cm, Min.	>100	IS: 1208-1978
Viscosity@135°C, cSt, Min.	353.16	ASTM D4402-15
RTFO Loss in mass, %	-0.61	ASTM D2872-12

C. Nano Material

In this investigation two types of nano materials have utilized. Nanosilica is collected from Beechems, Kanpur, India. The nanosilica has milky white colour, specific surface area is $200m^2/g$ approximately and it comprises of 99% to 99.8% of silicon dioxide (SiO_2). In this study ZycoTherm, a chemical WMA additive added to bitumen. It is collected from Zydex industries, Gujarat, India [8]. It has pale yellow colour and flash point greater than 80°C. When nanosilica and 0.15% WMA additive is added into bitumen then their names are NSMB-X% and NSWMA-X% respectively. Here X represents percentage of nanosilica.

D. Marshall Method of Mix Designs

The Marshall test is performed to evaluate the optimum bitumen content (OBC) of the bituminous mix. The test is conducted according to the ASTM: D 6927-15 [9] and Asphalt Institute manual series-2 (MS-2 sixth edition) [10]. In the Marshall mix design three samples are prepared at each bitumen content. The Marshall samples are prepared on six different bitumen contents each starting form 3.5% with constant increment of 0.5% upto 6.0% at mixing and compaction temperature corresponding to viscosity 0.17±0.02 Pa-S and 0.28±0.03 Pa-S respectively. The OBC is determined from plotting the graphs for each trial blend. Then calculate the average bitumen content corresponding to maximum stability, 4% air voids and maximum unit weight is considered to evaluate the OBC of the mixes.

E. Stripping Test

The stripping test is conducted according to IS: 6241-1971 [11]. In this test, bitumen coated aggregate is immersed into the water for 24 hours at 40°C. After 24 hours the stripping is observed and the percentage of stripping is noted. The stripping value should be less than 10% for the bituminous concrete as per MoRT&H specification.

F. Retained Stability

Retained Marshall stability is a measure of reduction in strength due to presence of water on the mix. Retained Marshall stability samples are prepared at OBC of mix. Retained Marshall stability is the ratio of Marshall stability of conditioned sample to the unconditioned sample. Unconditioned samples are placed in water bathe for 30 minutes at 60°C and conditioned samples are placed in water bath for 24 hours at 60°C before Marshall test. The minimum retained Marshall stability value required for bituminous concrete mix is 75% as per MoRT&H specification.

G. Indirect Tensile Strength

The indirect tensile strength (ITS) test predicts the susceptibility of bituminous concrete mixes to moisture damage. In this study moisture destruction is determined from Modified Lottman i.e. ITS test on dry, wet and frozen-thawed samples. ITS test is conducted as per AASHTO T283 [12]. In this test three groups of three specimens are prepared at OBC. The dry group samples are tested with no conditioning, the wet group samples are conditioned for 24 hour at 60ºC then tested and freeze-thaw group samples are conditioned for freeze cycle for 16 hour at -18±3ºC followed by thaw cycle for 24 hour at 60ºC in water bath. All the samples are kept in water bath at 25ºC for 2 hours. TSR is the ratio of ITS of conditioned sample i.e. wet and freeze-thaw ITS to the unconditioned sample i.e. dry ITS. The minimum recommended TSR value is 80% according to MoRT&H Specification and IRC: 111-2009 [13].

IV. RESULTS AND DISCUSSIONS

In this study, specific gravity test, penetration test, softening point test, ductility test, viscosity test, rolling thin film test were carried out on UMB and NSMB (with and without WMA additive). The results of the test are presented in Tables IV and V.

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TABLE IV
PROPERTIES BITUMEN AFTER ADDITION OF NANO MATERIAL

Type of Binders	Specific gravity	Penetration (0.1 mm)	Softening Point (°C)
UMB	1.000	46.00	53.00
NSMB-1%	1.003	44.16	55.80
NSMB-2%	1.009	42.83	57.00
NSMB-3%	1.015	39.33	58.50
NSMB-4%	1.021	38.33	59.60
NSMB-5%	1.028	37.50	60.40
WMA	1.020	44.93	54.85
NSWMA-1%	1.032	42.43	56.4
NSWMA-2%	1.038	40.7	57.5
NSWMA-3%	1.049	38.5	58.7
NSWMA-4%	1.058	37.1	59.9
NSWMA-5%	1.064	35.4	60.8

TABLE V
EFFECT OF NANO MATERIALS ON THE BITUMEN PROPERTIES

Type of Binders	Ductility (cm)	Viscosity@ 150 °C (cSt)	RTFO Mass Loss (%)
UMB	>100	189.63	-0.51
NSMB-1%	98.50	225.93	-0.49
NSMB-2%	96.13	241.44	-0.44
NSMB-3%	89.63	256.93	-0.44
NSMB-4%	84.05	238.48	-0.45
NSMB-5%	76.80	230.86	-0.47
WMA	97.63	292.07	-0.36
NSWMA-1%	95.81	348.48	-0.32
NSWMA-2%	91.32	387.47	-0.32
NSWMA-3%	98.38	411.13	-0.32
NSWMA-4%	75.42	368.21	-0.33
NSWMA-5%	72.57	334.35	-0.035

From Tables IV and V, it is observed that an increase in softening point, penetration index, viscosity and decrease in penetration value and ductility of bitumen due to addition of nanosilica with and without ZycoTherm. This means that the nanosilica with and without ZycoTherm reduce aging of bitumen and also reduce temperature susceptibility of bitumen. The stiffness is increased at lower and higher temperature due to NSMB with and without ZycoTherm.

A. Marshall Test Results

The mechanical and volumetric parameters of mix are evaluated from the Marshall test. After that OBC of mix is calculated then all the parameters are determined at their OBC. The best trial mix chooses on the basis of Marshall mix design among UMB, WMA, NSMB and NSWMA mixes for further study. Marshall parameters are listed in Tables VI and VII. From the analysis of the tables, it is observed that NSMB and NSWMA mixes have performed better than UMB and WMA mixes. From the different trail of NSMB and NSWMA mixes it is found that NSMB-3% and NSWMA-3% have the maximum stability value and it has also optimized the bitumen better than other NSMB and NSWMA mixes respectively. All the other parameters of NSMB-3% and NSWMA-3% are within the range as mentioned in MoRT&H specification. The sequence of performance of mixes according to the Marshall mix design results in increasing order as NSWMA-3% > NSMB-3% > WMA > UMB.

TABLE VI
MARSHALL PARAMETERS OF DIFFERENT MIXES

Type of Mixes	VA (%)	VMA (%)	VFB (%)	Unit weight (kN/m^3)
UMB	4.50	16.00	72.00	23.63
NSMB-1%	4.30	15.60	72.41	23.79
NSMB-2%	4.22	15.20	72.21	23.90
NSMB-3%	4.10	15.02	73.69	23.96
NSMB-4%	4.20	15.01	71.99	24.02
NSMB-5%	4.20	15.20	72.40	24.10
WMA	4.20	15.10	72.00	23.90
NSWMA-1%	4.15	15.17	72.76	24.05
NSWMA-2%	4.00	14.71	72.84	24.08
NSWMA-3%	3.80	14.68	74.08	24.20
NSWMA-4%	4.00	16.00	75.00	24.20
NSWMA-5%	4.00	15.90	74.80	24.26

TABLE VII
OBC, STABILITY AND FLOW OF ASPHALT MIXES

Type of Mixes	OBC	Stability (kN)	Flow (mm)
UMB	5.00	14.00	3.90
NSMB-1%	4.83	14.60	3.75
NSMB-2%	4.70	16.10	3.65
NSMB-3%	4.50	17.30	3.60
NSMB-4%	4.60	15.20	3.60
NSMB-5%	4.65	14.10	3.60
WMA	4.70	15.00	3.40
NSWMA-1%	4.60	15.00	3.26
NSWMA-2%	4.50	16.50	3.00
NSWMA-3%	4.40	17.45	2.80
NSWMA-4%	4.50	15.75	2.80
NSWMA-5%	4.50	14.70	3.00

B. Stripping Test Results

The stripping values of the UMB, WMA, NSMB-3% and NSWMA-3% mixes are shown in Table VIII.

TABLE VIII
STRIPPING VALUE OF DIFFERENT MIXES

Type of Mix	UMB	WMA	NSMB-3%	NSWMA-3%
Stripping Value (%)	4.4	4.0	3.8	3.3

Table VIII shows that the addition of nanosilica and WMA additive in the UMB stripping value of mixes are reduced. As per MoRT&H stripping value should not more than 5%.

C. Retained Stability Values

The retained stability of the UMB, WMA, NSMB-3% and NSWMA-3% mixes are shown in Table IX.

Fig. 1 shows that the addition of nanosilica and WMA additive in the bitumen retained stability of mixes are improved. All the values fulfill the criteria of MoRT&H specification.

D. Indirect Tensile Strength Results

The ITS test is performed on selected mixes and the test results are shown in the following section.

From Fig. 2, it is observed that the UMB dry, wet and freeze-thaw ITS values are increased due to addition of

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nanosilica and also increased due to addition of WMA additive. It is also observed that the addition of nanosilica with and without WMA additive result in improve in the TSR. All the values fulfill the criteria of MoRT&H specification.

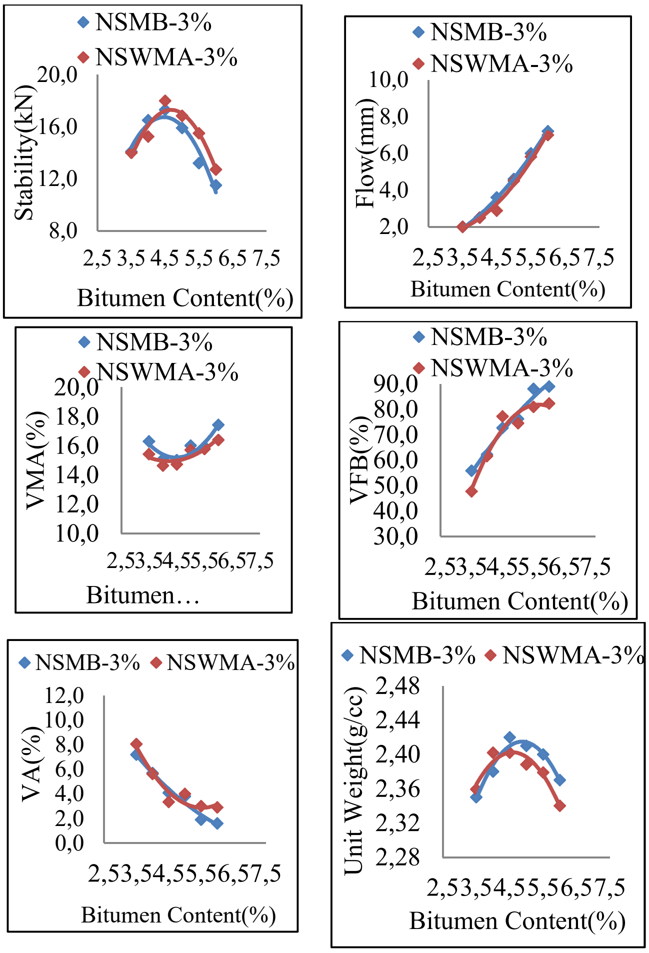

Fig. 1 Mechanical and volumetric properties of mix at 3% nanosilica with and without WMA additive

TABLE IX
RETAINED STABILITY RATIO OF DIFFERENT MIXES

Type of Mix	UMB	WMA	NSMB-3%	NSWMA-3%
Stability at 60ºC after 30 min. (kN)	14.3	14.5	17.3	17.45
Stability at 60ºC after 24 hours (kN)	11.52	12.44	15.56	16.01
Retained Stability Ratio (%)	80.53	85.8	89.92	91.75

V. CONCLUSION

The results obtained from the present work indicate that the behaviour and performance of bituminous mix can be improved by nanosilica with and without WMA additive. The following conclusions are drawn from the present investigation.

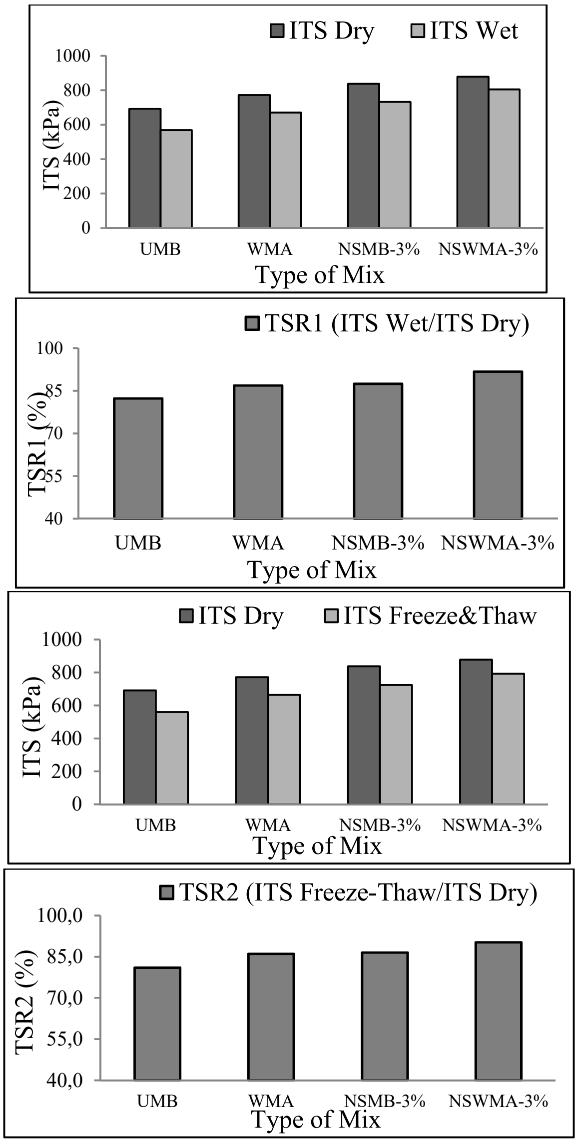

Fig. 2 Different ITS and TSR values of different mixes

- From the trends of penetration, softening point and penetration index shows that nanosilica with and without WMA additive modified bitumen results in improved the stiffness at lower and higher temperature. Due to the nanosilica modified bitumen also reduces the susceptibility to temperature.
- Due to addition of nanosilica along with and without WMA additive in the binder the stability value of the mix increases, flow decreases. The air void of the mix gradually reduces up to 3% nanosilica content only when mixed with bitumen. Results show that NSMB-3% and NSWMA-3% are best performing mix in its classes.
- Addition of nanosilica and WMA increase the retained stability. When WMA additive added to the NSMB, its give better result compare to UMB and NSMB mixes. All the values are within limit as mentioned in MoRT&H specification.
- Due to addition of nanosilica along with or without WMA

additive in the binder, the moisture sensitivity of the mix reduces compared to normal bituminous mix. NSWMA-3% shows better moisture resistance in cold climate and in hot climate as well. This means WMA mix is most resistive to moisture sensitivity in all weather condition.

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