MATTER: International Journal of Science and Technology
ISSN 2454-5880

Patidar et al, 2018

Volume 4 Issue 1, pp.73-87

Date of Publication: 16th March 2018

DOI-https://dx.doi.org/10.20319/mijst.2018.41.7387

This paper can be cited as: Patidar, A., Sarkar, D., & Pal, M. (2018). Study The Behavior Of Asphalt Mix And Their Properties In Presence Of Nano Materials. MATTER: International Journal of Science and Technology, 4(1), 73-87.

STUDY THE BEHAVIOR OF ASPHALT MIX AND THEIR PROPERTIES IN PRESENCE OF NANO MATERIALS

Aman Patidar
NIT Agartala, Tripura, India
aman.patidar0@gmail.com

Dipankar Sarkar
NIT Agartala, Tripura, India
dipankarnita@gmail.com

Manish Pal
NIT Agartala, Tripura, India
mani_nita@yahoo.co.in

Abstract

The rapid increase in the traffic load, higher traffic volume, daily and seasonal variation in temperature led to pavement 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 with 0.15% by weight of bitumen is added unmodified bitumen (UMB) and Nanosilica modified bitumen (NSMB). This research work is conducted on nanosilica and ZycoTherm modified bitumen to study the physical and mechanical properties of binders and asphalt mixes. The effects of nanosilica and

ZycoTherm on physical properties of the binder that is improve softening point, penetration index, viscosity and decrease in penetration value and ductility value of bitumen and also reduce the aging and temperature susceptibility. NSMB results in the increase in stability compared to UMB. WMA modified mix shows slightly higher stability than UMB and NSMB in a lower bitumen content. Using Marshall Mix Design Method selected best trial mixes are NSMB-3% and NSWMA-3%.The optimum bitumen content of NSMB-3% and NSWMA-3% are found to be 4.50% and 4.40% whereas stability 17.30kN and 17.45kN respectively. Tensile strength ratio (TSR) is more than 80%, loss in mass is less than 1% and retained stability is more than 75% for both these mix. NSMB-3% and NSWMA-3% have more resistant to temperature susceptibility, and moisture susceptibility compared to UMB, WMA and other NSMB and NSWMA trial mixes.

Keywords

HMA, Nano silica, NSMB, Temperature, TSR, UMB, WMA

1. 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 modifiers for asphalt pavements for evaluating mechanical and physical properties and as well as durability of asphalt pavement.

The utilization of nano materials in bituminous pavement started late. In the recent years, nano materials are gradually used for modification of asphalt (Fang et al., 2013). Nano materials emanated as the solution to intensify the performance and durability of materials used in the construction. Some researchers investigated that the addition of nano materials in bitumen improved the performance of asphalt mix such as rutting, fatigue and moisture resistance (Ameri et al., 2013). Moghadas et al., 2012, used zycosoil as an anti-strip agent and investigated the characteristic performance of bituminous mixture. It is resulted that fatigue life improved and reduced the void content in bituminous mixes. The effect on the conventional bitumen due to addition of Nano SiO2 and Nano TiO2 was investigated and prepared samples of different percentages of Nano SiO2 and Nano TiO2 to determine the penetration and softening point of the modified bitumen. By increasing the content of Nano SiO2 and Nano TiO2, the penetration value reduced and penetration index and softening point value increased (Chao and Huaxin, 2009).

In the hot mix asphalt (HMA) higher mixing, laying and rolling temperatures, leading to higher consumption of fuel (Behl et al., 2013). WMA technology is alternate of the HMA (Doyle et al., 2013). It is reported by Butz et al., 2001, that WMA can reduce production and laying temperatures 10°C to 40°C depending upon the method and additive used. Rohith, and Ranjitha, 2013, investigated the Marshall parameters of HMA samples prepared at 155˚C compared with WMA samples prepared at 130˚C and 115˚C using zycotherm as the nanomaterial. It was resulted that the Marshall parameters were slightly increased with the addition of zycotherm nanomaterial. In the stone matrix asphalt (SMA) utilization of Nano-SiO2 and SBS both are resulted that improve the physical and mechanical properties of bitumen and bituminous mixes (Santagata et al. 2015, Yao et al. 2013). The advantages of nanosilica modified warm mix asphalt 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.

2. Literature Review

Several nano materials have 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 (You et al., 2011). Galooyak et al., 2015, 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., 2012, studied the physical and mechanical properties of asphalt cement using various percentages of SBS (5%) and nano-SiO2 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-SiO2 in the modified binders. The Marshall stability increases with the nano-SiO2 content. The tensile strength ratio of the specimens prepared with different nano-SiO2 contents after completion of one freeze– thaw cycle. The TSR values of the mix improve with increase in nano-SiO2 content. The highest TSR value as 0.91 at 2% nano-SiO2 and lowest TSR value 0.7 at conventional mixtures. TSR value showed that the nano-SiO2 is more effective than SBS for moisture damage. The stiffness modulus of the mixture increased, by increasing the nano-SiO2 content. The stiffness modulus of nano-SiO2 mixture is 2.3 times higher than the control mixture.

3. Materials and Methodology

3.1 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 mix as mentioned in MoRT&H. The aggregate properties and gradation are shown in Table 1 and Table 2 respectively.

Table 1: *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 2: *Aggregate gradations 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

3.2 Binder

Asphalt binder VG 30 grade bitumen collected from local market is used in this study and various tests are conducted for finding out the physical properties of binder. The binder physical properties are shown in Table 3.

Table 3: *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

3.3 Nano Materials

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 200m2/g approximately and it comprises of 99% to 99.8% of silicon dioxide (SiO2). In this study ZycoTherm, a chemical WMA additive added to bitumen. It is collected from Zydex industries, Gujarat, India. 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.

3.4 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 and Asphalt Institute manual series-2 (MS-2 sixth edition). 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 from 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.

3.5 Stripping Test

The stripping test is conducted according to IS: 6241-1971. 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.

3.6 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.

3.7 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. Indirect tensile strength test is conducted as per AASHTO T283. 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. Tensile Strength Ratio (TSR) is the ratio of indirect tensile strength 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.

4. Result 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 Table 4 and 5.

Table 4: *Properties bitumen After Addition of Nano material*

Type of Binders	Specific gravity	Penetration (0.1mm)	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 5: *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	-0.35

From the above tables, 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 nanosilica modification with and without ZycoTherm.

4.1 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 Table 6 and 7.

Table 6: *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 7: *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

From the analysis of above results, 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% > NSWB-3% > WMA > UMB.

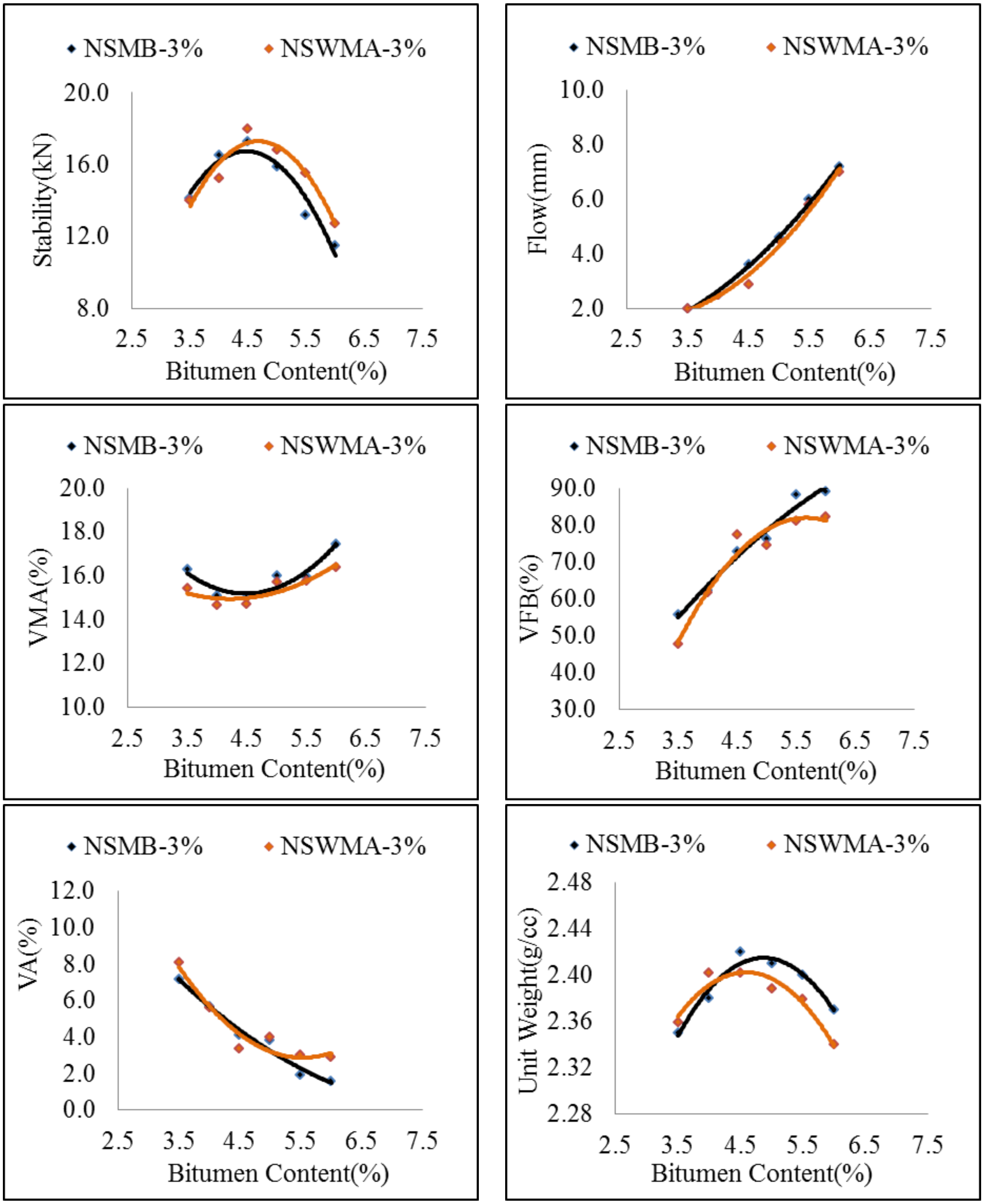

Figure 1: *Mechanical and volumetric properties of mix at 3% nanosilica with and without WMA additive*

4.2 Stripping Test Results

The stripping values of the UMB, WMA, NSMB-3% and NSWMA-3% mixes are shown in Figure 2.

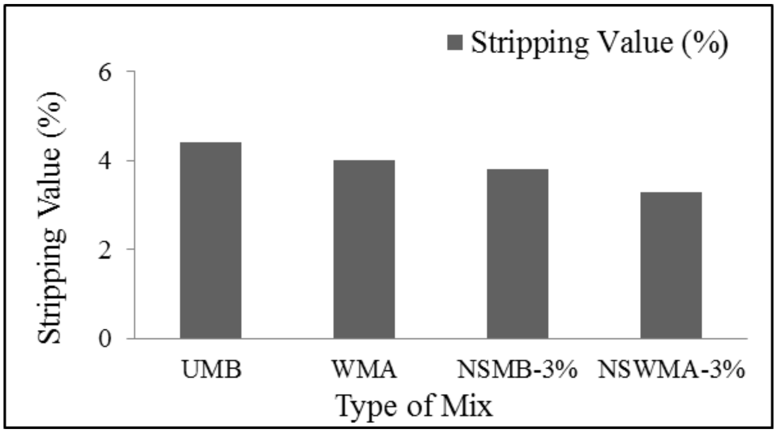

Figure 2: *Stripping Value of different mixes*

The above figure 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%.

4.3 Retained Stability Values

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

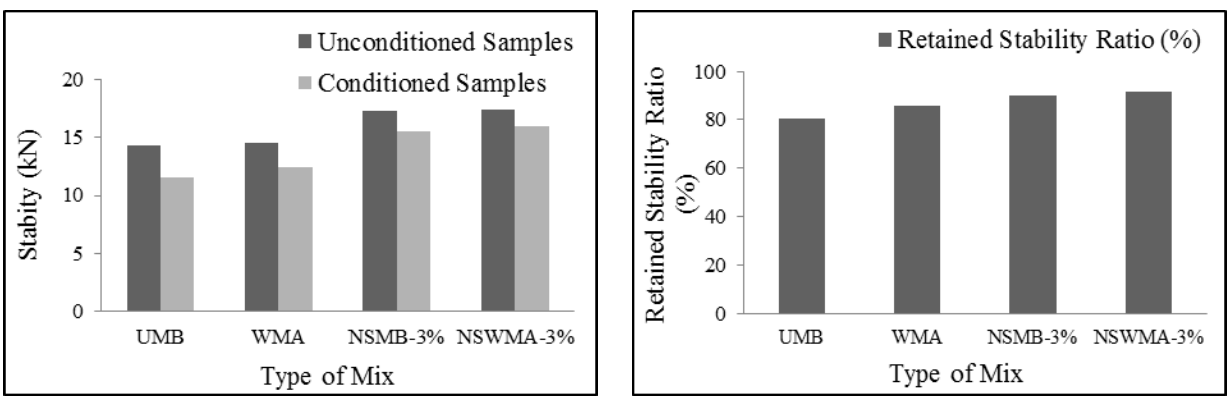

Figure 3: *Stability and Retained Stability Ratio of different mixes*

From the above figure 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.

4.4 Indirect Tensile Strength Results

The ITS test is performed on selected mixes and the test results are shown in the Figure 4.

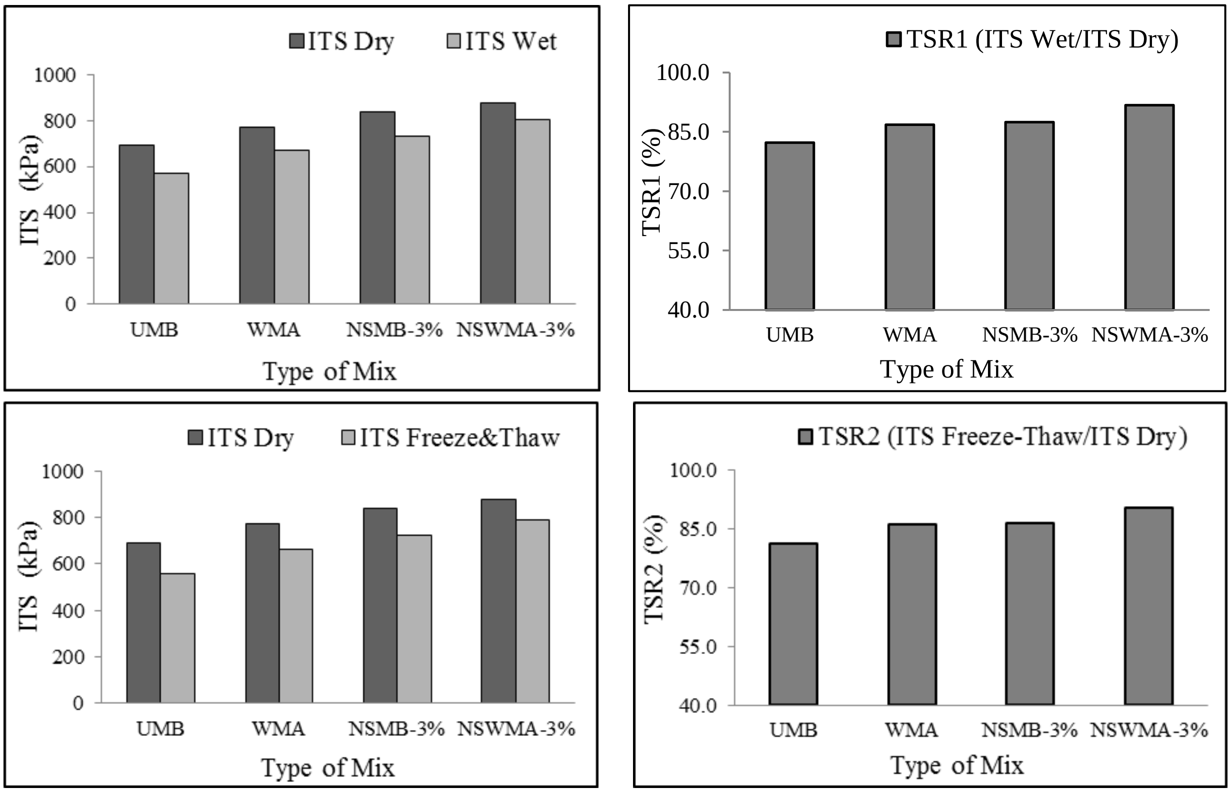

Figure 4: *Different ITS and TSR values of different mixes*

From the figure 4, it is observed that the UMB dry, wet and freeze-thaw ITS values are increased due to addition of 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 tensile strength ratio (TSR). All the values fulfill the criteria of MoRT&H specification.

5. Conclusions

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.

- From the values 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 as compared to UMB. 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 as compared to UMB. The air void of the

mix gradually reduces upto 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 compare 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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