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Experimental Analysis of VG-30 Bitumen for Short Term Aging Process using SBS and Nano SiO_2

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Abstract: This paper reviews the application of various filler materials with bitumen to increase the pavement life. Aging of binder is the major draw-back of asphalt pavement for long service life point of view. Generally aging of binder is caused due to climatic condition which ultimately leads to cracks on pavement, rutting, fatigue cracks, which cannot withstand the changing environment and increased traffic loads, finally the pavement of failure takes place. To overcome this problem, modification in the properties of VG-30 bitumen was done by adding Elastomer Styrene-Butadiene-Styrene (SBS) and Nano Silica Powder (Nano SiO_2) in suitable dosages. The short-term aging properties of bitumen were investigated using thin film oven test (TFOT). The empirical tests including penetration and softening points were conducted to check for binder consistency.
Keywords: Bitumen, Aging, penetration and softening point, TFOT, SBS, Nano-SiO_2

I. INTRODUCTION

A. Bitumen

Bitumen is a viscous liquid, or a solid, which is soluble in trichloroethylene and is substantially non-volatile and softens gradually when heated. It is black or brown in colour & possesses waterproofing properties.

It is obtained by refinery processes from petroleum, and is also found as a natural deposit or as a component of naturally occurring asphalt. Bitumen is available in different grades such as VG-10, VG-20, VG-30 and VG-40 (IS:73-2013), but its use mainly depends on the type of layer to be constructed of pavement and climatic condition of the place.

Bitumen is not only an important engineering material but also a vital material in pavement engineering whose properties changes with time.

Here, the attempt is made to overcome from this problem by studying scientifically the performance related characteristics of unmodified bitumen (VG-30) with and without modifiers in the laboratory also simulating the effect of short term aging.

B. Modified Bitumen

a) To improve the properties of bitumen.
b) Polymer modified bitumen is used only in wearing course.
c) Better age resistance.
d) Prevention of reflective cracking.
e) Higher resistance to deformation at high pavement temperature.
f) Higher fatigue life.

C. Aging Of Bitumen

The physical properties of bitumen change with time. It may become harder or less elastic. Bitumen properties change over time on exposure to high temperature and atmosphere. This process is referred as Aging.

Based on hardening or stiffening of bitumen material, two types of aging have been derived:

1) Short term aging
2) Long term aging

Short-term aging:

This occurs when bitumen is mixed with hot aggregates i.e. during production and construction.

Long-term aging:

This occurs due to environmental exposure and loading i.e. during the life of the pavement.

a)Factors affecting aging of bitumen

i. Oxidative hardening.
ii. Hardening due to loss of volatiles.

iii. Physical hardening.
iv. Exudative hardening.
v. Hardening of bitumen during storage.
vi. Hardening of bitumen during mixing & transportation of mix.
vii. Hardening of bitumen on road.
viii.

II. MATERIALS

A. Nano SiO_2

Nano-silica with the properties presented in Tables 1, 2, and 3 has been used in this study.

1) Physical properties

Silicon dioxide nanoparticles appear in the form of a white powder. The table below provides the physical properties of these nanoparticles.

Table 1. Physical properties of Nano SiO_2

Properties	Metric
Density	2.4/cm^3
Molar mass	59.96 g/mole

2) Thermal properties

Table 2. Thermal Properties of Nano SiO_2

Properties	**Metric**
Melting Point	1600°C
Boiling Point	2230°C

Table 3. Analysis of Nano SiO_2

SiO_2	Na	Fe	Ti	Ca
>99%	<50 ppm	<20 ppm	<120 ppm	<70 ppm

3) Chemical composition

Table 4 Chemical composition of Nano SiO_2

Element	Content (%)
Silicon	46.83
Oxygen	53.17

4) Uses of Nano SiO_2

Nano silica or silicon dioxide nanoparticles, are a great deal of research due to their:

a) Stability, low toxicity and ability to be functionalised with a range of polymers.
b) Used as an additive in rubber and plastics, strengthening filler for concrete.

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B. Styrene-Butadiene-Styrene (Grade GP-1)

Molecular Structure of SBS: Radial

Table 1 and Table 2 shows the chemical composition and thermal properties of SBS respectively.

Table 5 Chemical composition of SBS

Element	Content (%)
Styrene	30
Butadiene	70

Table 6 Thermal Properties of SBS

Properties	Metric
Melting Point	160°C - 200°C

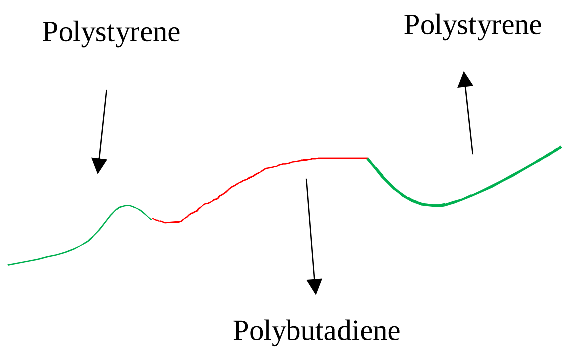


Fig.1 Tri block chain of SBS

1) SBS shows elastic behaviour at room temperature yet behave as plastic at high temperature.
2) Cold weather flexibility, high elasticity, thus SBS modified bitumen can be used at busy intersections, bridge decks and roundabouts for increased life of pavement.

C. *Elementary Analysis of Bitumen*

The elementary analysis of the bitumen binder is presented below in Table 4

Table 7. Analysis of bitumen binder

Component	Percentage %
Carbon	82-88
Hydrogen	8-11
Sulphur	0-6
Oxygen	0-1.5
Nitrogen	0-1

III. OBJECTIVES

A. To evaluate scientifically properties of the bitumen VG – 30 with and without modifier styrene-butadiene-styrene (SBS) and Nano Silica (Nano-SiO_2) in suitable dosages before and after short term aging using Thin Film Oven Test (TFOT).

B. To investigate the effect of SBS and Nano SiO_2, as a modifier replacement.

C. To study the cost effectiveness of modified bitumen as compared to neat bitumen.

D. To compare the properties of modified and unmodified bitumen by conducting conventional and non-conventional tests.

E. The above objectives are as per the below standards:

1) (ASTM D1754) TFOT

IV. LITERATTURE REVIEW

A. Suleiman Arafat Yero and Mohd Rosli Hainin (2012) investigated "the short term aging properties of bitumen".

This paper focuses on the short term aging properties of bitumen using RTFOT to stimulate aging during mixing. Various empirical tests like penetration test and softening point test were conducted. RTFOT was conducted at 163 ºC for 70min, 85min and 100 min. It resulted in physical hardness of binder making it more stiff, thus decreasing penetration and increasing softening points. Thus, aging depends on time and binder source.

B. Ms. Chinkal Patel, Prof. Rupande Desai and Dr. P.J. Gundaliya (2017) did work on "Bitumen Modified with Styrene-Butadiene-Styrene Thermoplastic for roofing applications".

By adding SBS in bitumen in different dosages (2%, 3% and 4%) , improvements in the physical properties of bitumen were seen with the help of practical assessments. Likewise, conventional and non-conventional tests were performed which showed that by adding 4% of rubber concentration by weight of bitumen, penetration value decreased and softening point increased following higher specific gravity and rapid ductility. Thus, after such outcomes flat roofs were accepted as a reliable and lasting roof construction solution for commercial and residential buildings.

C. Ashutosh Patekar and Dr. M.S. Ranadive (2014) presented a paper on "Quality assurance and control of bitumen viscosity graded approach".

In this paper, a relative study between penetration grading system and viscosity grading system of bitumen was appeared. It was concluded that viscosity grading system is far more beneficial than penetration grading system keeping in mind the climatic changes and increasing traffic load day-to-day. Likewise, it was found that viscosity grading has less tests as compared to penetration grading system sparing time and cost.

D. Sajad Rezaei et al. (2017), Department of Civil Engineering, Tehran, Iran, investigated for "The effect of nano-SiO2 and the styrene butadiene styrene polymer on the high-temperature performance of hot mix asphalt".

In this research work, the impact of Nano-SiO_2 on high temperature performance of asphalt mixture modified with SBS polymer was studied. Marshall stability test for flow value was performed. Also, interaction of Nano-SiO_2 with aggregate surfaces was checked by adding Nano SiO_2 in different dosages. Test results showed increased Marshall stability and decrease in flow value.

E. Xiaohu Lu et al. (2016) presented a paper on "Long term durability of PMB on bridge deck pavements".

In this study, it was found that performance demands for bituminous materials used on bridge decks are normally high than those for road paving. Additionally , field observations showed that regardless of high traffic loading and tough environmental conditions such as wide temperature span and huge temperature fluctuations, limited rutting with no cracks on it were observed even after 15 years when SBS polymer modified bitumen was used. Lab tests have shown that even after long time service of road , PMB was still very much elastic and also held good low temperature and high temperature properties.

F. Farhad Zafari (2014) presented a paper on "Improvement of bitumen properties by adding Nano Silica".

This paper investigated the merit of application of nano-silica in asphalt binder as an anti-aging additive. Different percentages of nano-silica (2%, 4% and 6%) were added to neat bitumen.Thus, from the experimental work, the study concluded that nano-silica can be a promising candidate to be used as an anti-aging additive in asphalt binder in enhancing rutting resistance and thus improved the properties of the same.

G. Saeed Sadeghpour Galooyak et al. (2015) presented a paper on "Performance Evaluation of Nano-silica Modified Bitumen".

In this analysis, different contents of Nano Silica , 2 wt%, 4% and 6 wt % , were added to bitumen to modify the physical and mechanical properties of Warm mix Asphalt. From the investigations, 6% nano silica was chosen as an ideal content. By increasing the nano silica content, the depth of cracking was decreased , thus, the fatigue life of WMA was extended in the presene of nano silica. Also , the outcomes showed that the rutting depth of modified samples were lessened.

H. Prajapati Harshad , Dr. P J Gundaliya (2014) did work on " Review on Effect of Aging on Paving Grade Bitumen using Different Filler Material ".

In this research work, the properties of binder affecting the aging of bitumen were focussed. Mainly, 3 conventional tests (Penetration, Viscosity & Softening point) were discussed for neat bitumen and modified samples.For aging of bitumen, Thin film

Oven test was discussed. Thus, it was concluded that bitumen modified with different materials resist the effect of aging. Likewise, it was discussed that hardening of bitumen due to aging results in decrease in penetration value and increase in softening point.

I. Tanuj Parmar et al. (2017) presented a paper on " Influence of VG 30 grade bitumen With And Without Additive (Eva) on short term aging ".

Here, the laboratory investigations indicates that short-term aging of the bitumen shows the physical hardness of the binder properties changing after simulating the base bitumen to aging using TFOT, reducing binder penetration , increasing softening points, increasing elastic recovery and the loss of volatile fractions contributes to the difference in weights between un-aged and aged sample. Aging increases the binder hardness; this could be attributed to the increase stiffness of the binder after the TFOT. The elastic recovery increases with increase in percentage of EVA and is observed at 4%.

J. J O'connell , Wj Vd M Steyn presented a paper on " An Overview Of The Ageing Of Bituminous Binders ".

This paper reviews the different reaction mechanisms of ageing of bituminous binder as well as the effects of oxidation accelerators such as heat and ultraviolet light. There is also an overview of the physical and chemical properties of bituminous binders that can be used to monitor the rate of ageing.

K. Kinjal Surti , Prof. C.B.Mishra (2017) presented a paper on " Evaluating the Effect of Modified Bitumen after Short-Term Aging using FTIR Spectroscopy & SEM ".

After TFOT test physical characteristics of the bitumen and polymer modified bitumen had changed. It showed that softening point increased while the penetration value decreased after short term aging with decrease in elastic recovery too which indicate that oxidation of modified bitumen had occurred. SEM test gave the conclusion that elastomeric polymer were well dispersed in the bitumen thus leading to structural modification of bitumen.

L. Praveen Kumar, Md. Tanveer Khan , Maninder Singh (2012) did research on " Evaluation of physical properties of SBS modified bitumen and effect of aging ".

The physical properties of bitumen such as penetration and softening point were improved with addition of polymers. SBS modified binder showed lower Penetration value as compared to neat bitumen. SBS modified binder displayed higher Softening point value as compared to neat bitumen. SBS modified binder gave higher Viscosity as compared to neat bitumen. Effect of Aging on SBS modified binder is with in permissible limits as far as Indian conditions are concerned.

M. Jun Yanga, Susan Tighe (2013) did work on " A review of advances of Nanotechnology in asphalt mixtures ".

Adding nano material in asphalts normally increases the viscosity of asphalt binders and improves the rutting and fatigue resistance of asphalt mixtures. Using Nano-particles can improve the storage stability of polymer modified asphalts. The addition of nanosilica into the control asphalt binder did not greatly affect the low-temperature properties of asphalt binders and mixtures. Nano-modified asphalt performed well in cold regions with many benefits. The asphalt mixture modified by 5% SBS plus 2% nano-SiO2 powder can improve the properties of asphalt binder.

N. Sumit K. Singh, Yogesh Kumar, Sham S. Ravindranath (2018) studied "Thermal degradation of SBS in bitumen during storage: Influence of temperature, SBS concentration, polymer type and base bitumen"

Here, study includes the effect of storage temperature, SBS concentration, polymer type and base bitumen on the properties of polymer modified bitumen during storage at elevated temperatures in sealed aluminium tubes. Our results show that storage temperature, SBS concentration and polymer type play a major role in the observed property erosion, while type of base bitumen has a lesser effect. The samples were stored in sealed aluminium tubes at temperatures of 150 °C, 180 °C and 210 °C for up to 21 days. At 150 °C, the properties of PMB's remained intact even after storing for 21 days. But, significant erosion in conventional and rheological properties of SBS modified bitumen took place within the first 3 days of storage at temperatures ≥ 180 °C. At 210 °C, the PMB properties degrade to the base bitumen values within 1 day.

O. Helal Ezzat et.al (2016) presented work on "Evaluation of Asphalt Binders Modified with Nanoclay and Nanosilica"

Storing the nanomodified asphalt binder for future usage up to ten days had no significant effect on its properties. A 3% nanoclay by weight of asphalt improved the performance of the asphalt binder. The binder became more suitable for hot climatic conditions. Results showed lower penetration value, increased softening point temperature, and increased viscosity. An enhancement was also achieved in the high temperature performance grade. Nanosilica was recommended for use in hot climates since it decreased the penetration and increased both the softening point temperature and the viscosity of the asphalt.

P. Ruoyu Li et.al (2017) presented a paper on "Developments of nano materials and technologies on asphalt materials – A review".

The addition of nano-SiO2, significantly improved the low-temperature cracking resistance as well as the high temperature performance. The fatigue life could be prolonged and the permanent deformation could be decreased.

V. PRACTICAL EVALUATION

The tests are to be performed on bitumen and modified bitumen using conventional bitumen and modified bitumen. They include conventional and non-conventional tests. The conventional and non-conventional tests were carried out at Highway engineering laboratory of Civil engineering department at Marwadi Education Foundation Group of Institutions.

A. *Conventional test*

1) Penetration test (IS :1203-1978)
2) Softening point test (IS :1205-1978)
3) Viscosity test (IS :1206-1978)

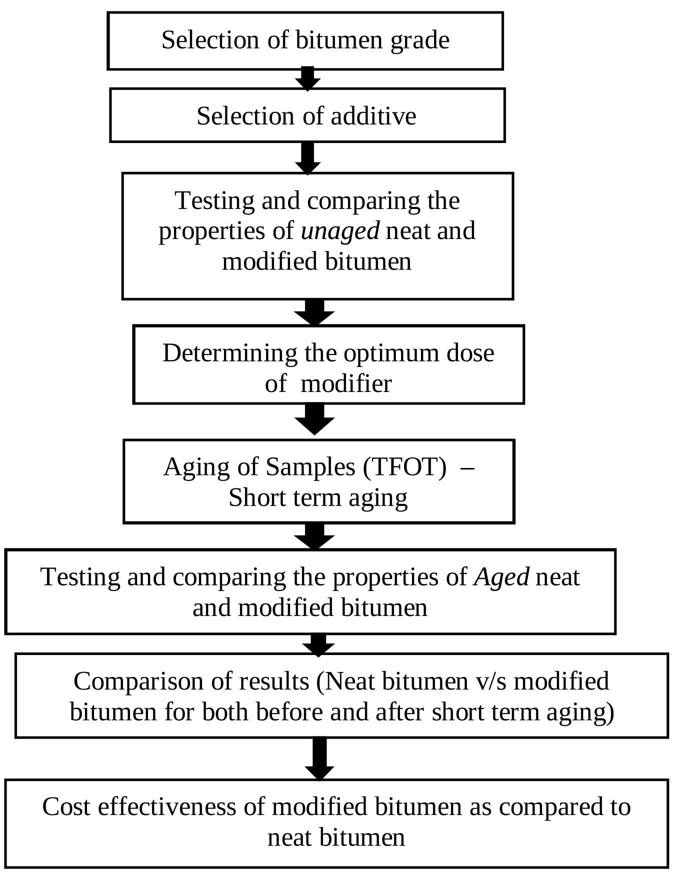
B. *Non-conventional test*

1) Ductility test (IS :1208-1978)
2) Specific gravity test (IS :1202-1978)

Test for short term aging of bitumen:

a) Thin Film Oven Test (TFOT)
(ASTM D 1754, AASTHO T 179)

VI. METHODOLOGY



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A. Modifier concentration

1) SBS: (White colour, powder form)

a) 3%, 5%, 7% by weight of bitumen.

1) Nano SiO_2: (White colour, powder form)

a) 2%, 4%, 6% by weight of bitumen.

VI. RESULT FOR CONVENTIONAL AND NON-CONVENTIONAL TEST

A. Nano SiO_2

Table 8. Result of binder VG-30 with Nano SiO_2: before and after short term aging

Binder Type	Polymer Concentration (%)	Softening Point (°c)	Penetration (mm)	Ductility test (cm)	Specific Gravity	Viscosity (sec)	Loss of Weight (%) (TFOT)
Before Aging							
VG-30	-	47	48	51	0.98	6.65	-
Before aging [VG-30 + Nano SiO_2]	2	48	41	63	1.01	7.36	-
	4	49	47	71	1.01	8.02	-
	6	47	58	82	1.02	8.40	-
After Aging							
VG-30	-	48	47	55	0.99	7.05	0.013
After aging [VG-30 + Nano SiO_2]	2	51	40	70	1.04	8.21	0.002
	4	56	44	76	1.04	8.45	0.013
	6	49	53	85	1.05	9.39	0.024

1) Graphs

Penetration test results

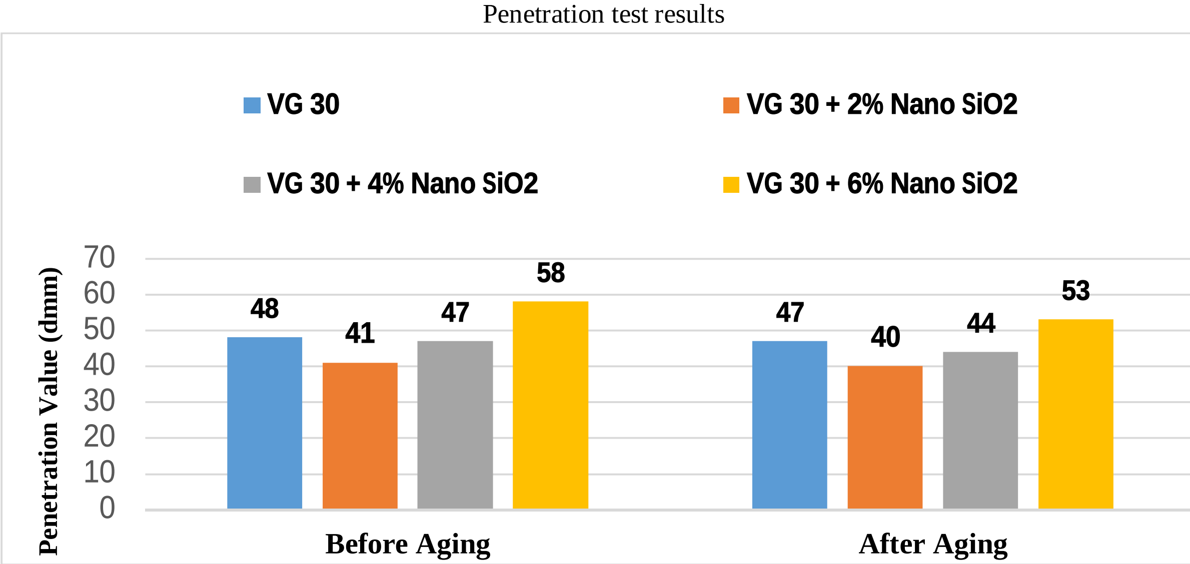

Fig.2 Penetration value v/s % Nano SiO_2

Softening point test results

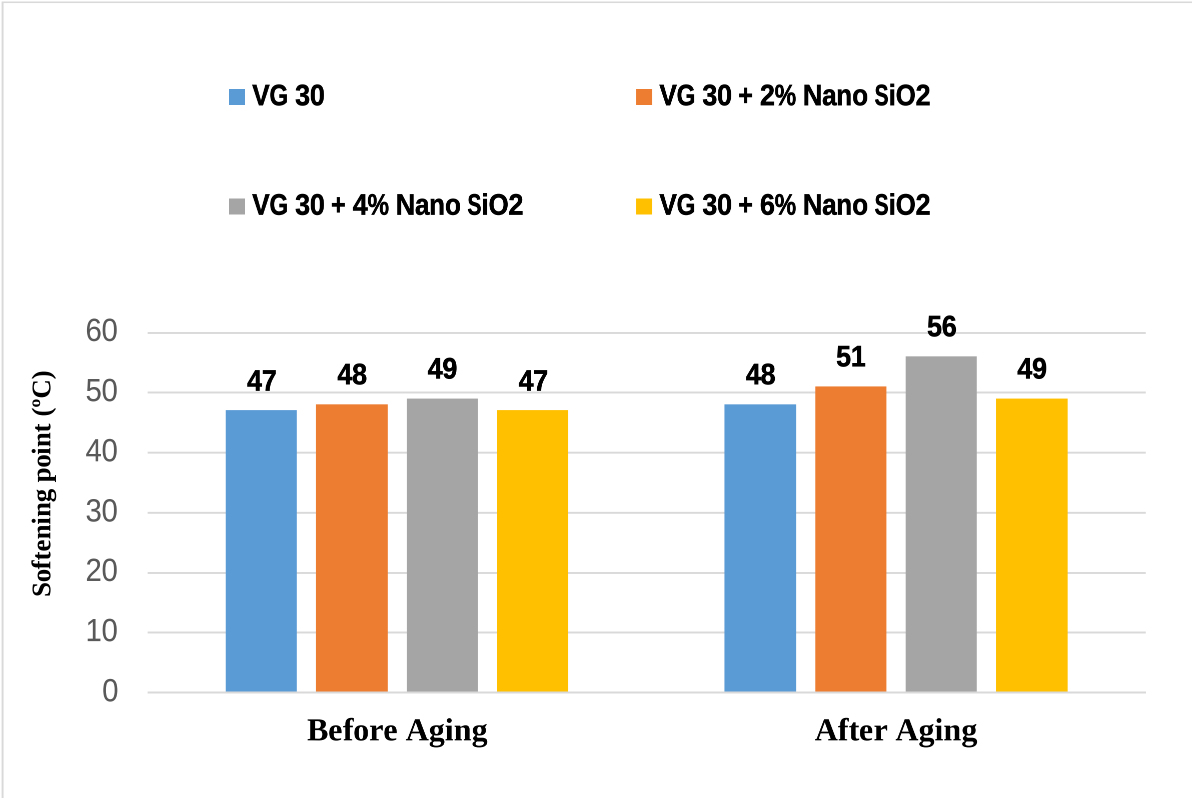

Fig.3 Softening point v/s % Nano SiO_2

Specific gravity test results

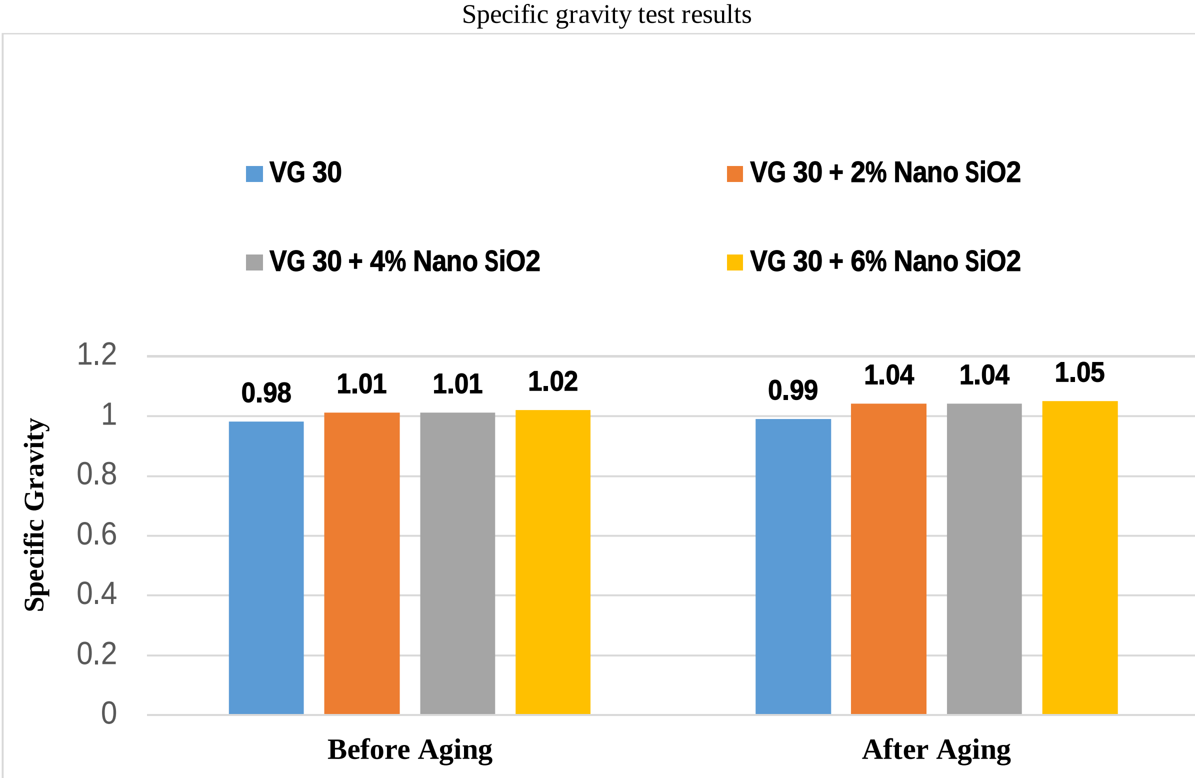

Fig.4 Specific gravity v/s % Nano SiO_2

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Ductility test results

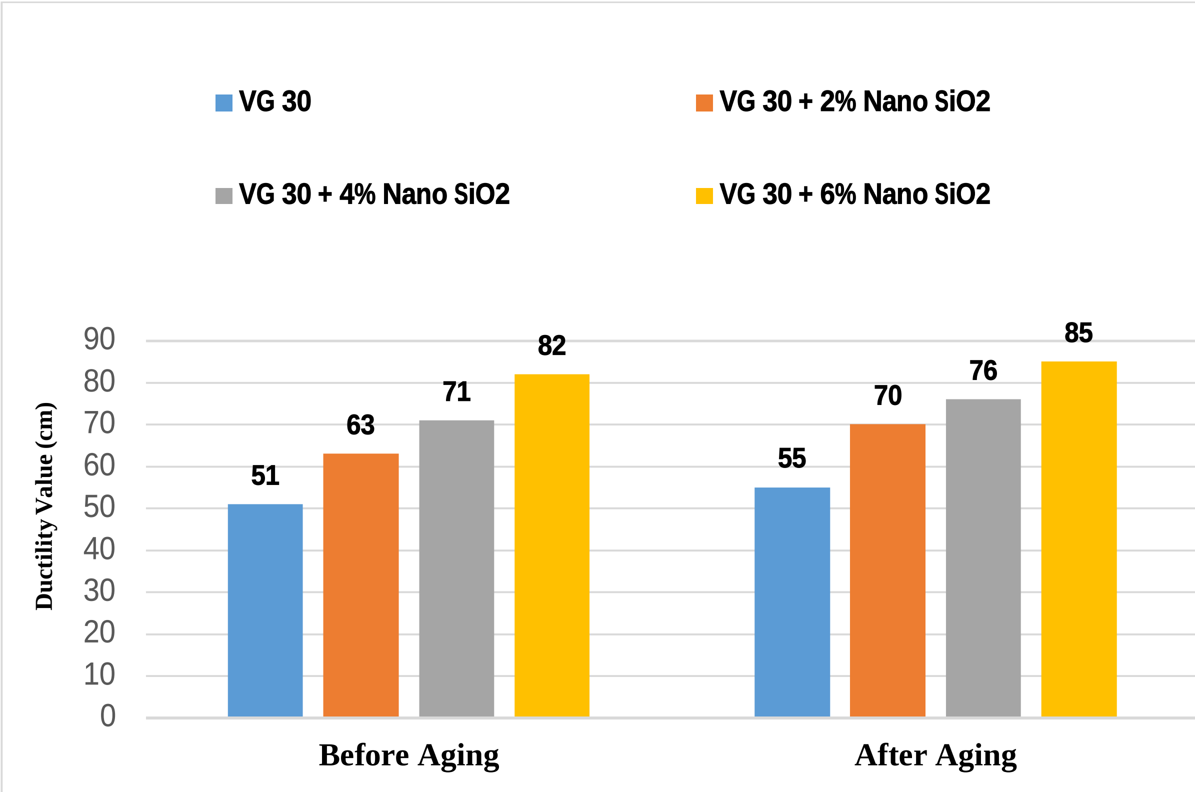

Fig.5 Ductility value v/s % Nano SiO_2

Viscosity test results

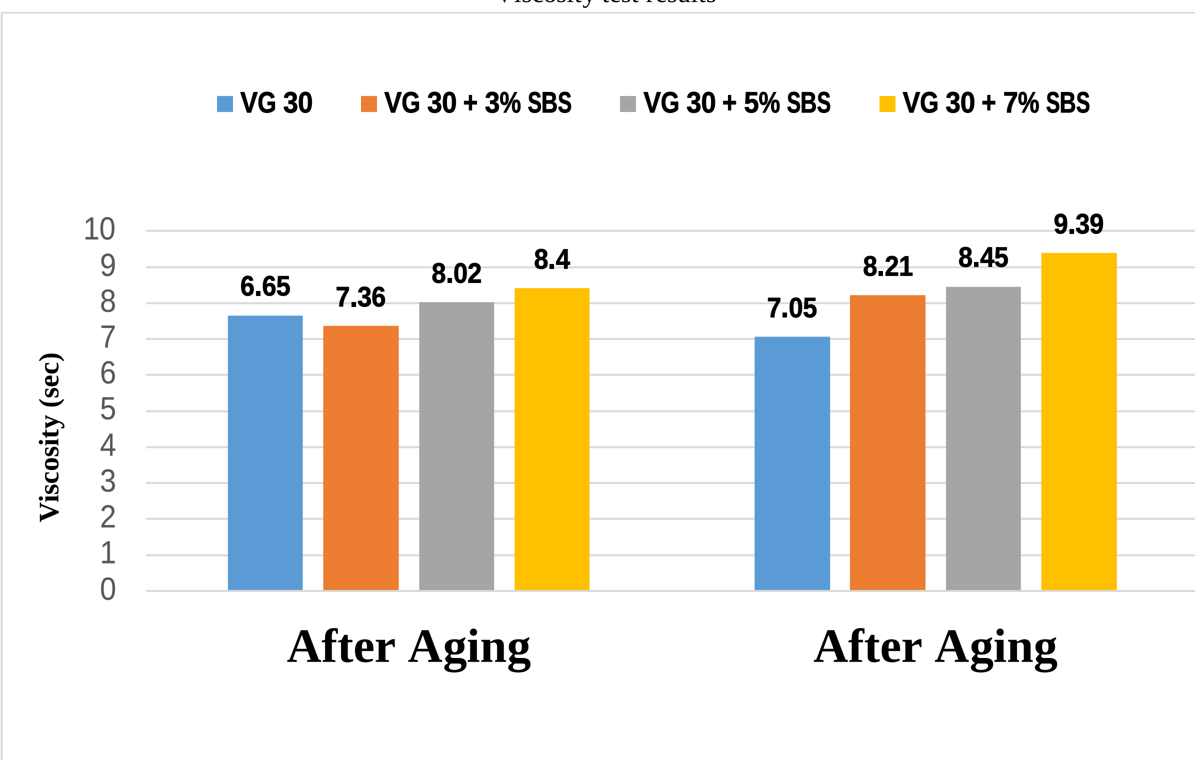

Fig.6 Viscosity v/s % Nano SiO_2

B. SBS

Table 9. Result of binder VG-30 with SBS : before short term aging

Binder Type	Polymer Concentration (%)	Softening Point (°c)	Penetration (dmm)	Ductility test (cm)	Specific Gravity	Viscosity (sec)	Loss of weight (TFOT)
Before Aging							
VG-30	-	47	48	51	0.98	6.65	-
[VG-30 + SBS]	3	57	59	64	1.02	7.43	-
	5	59	54	72	1.04	7.56	-
	7	59.5	47	79	1.05	8.14	-
After Aging							
VG-30	-	48	47	55	0.99	7.05	0.013
[VG-30 + SBS]	3	60	56	68	1.02	9.03	0.002
	5	61	45	74	1.02	9.51	0.005
	7	63	46	80	1.04	9.86	0.007

1) Graphs

Penetration test results

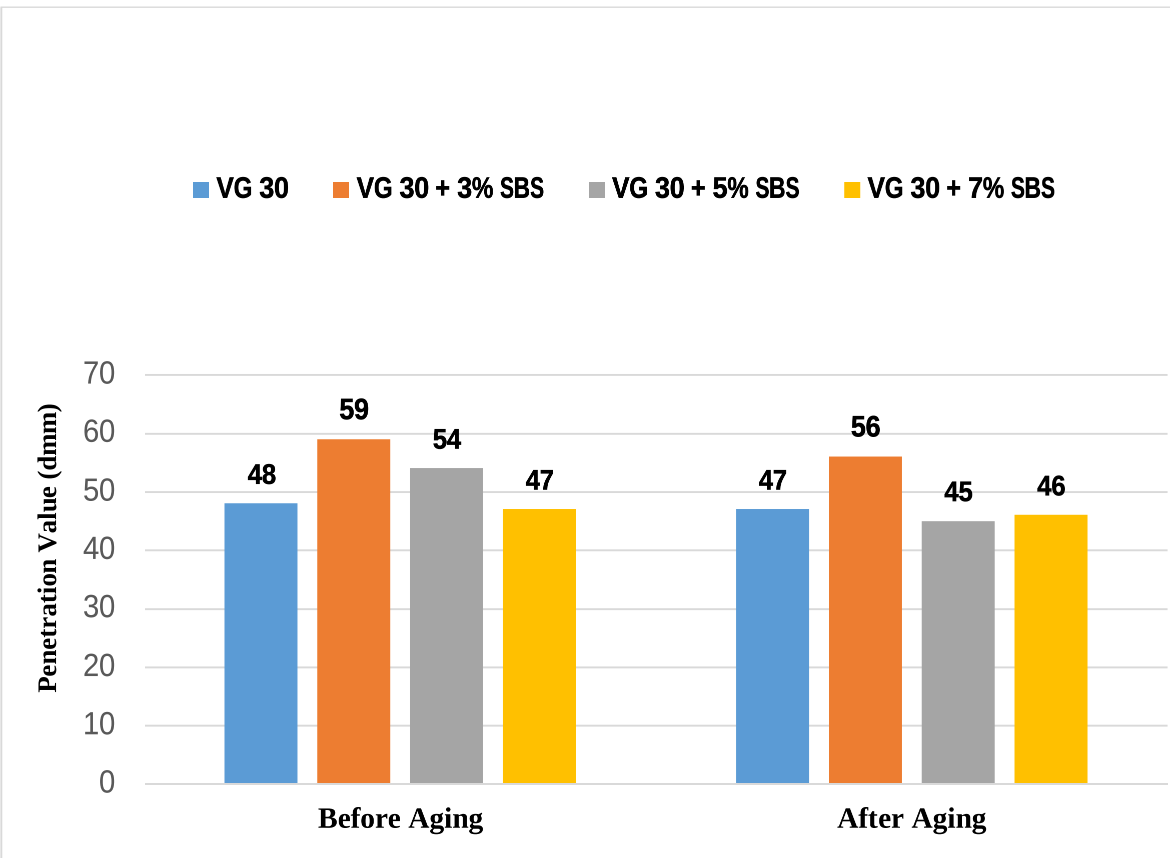

Fig.7 Penetration value v/s % SBS

Softening point test results

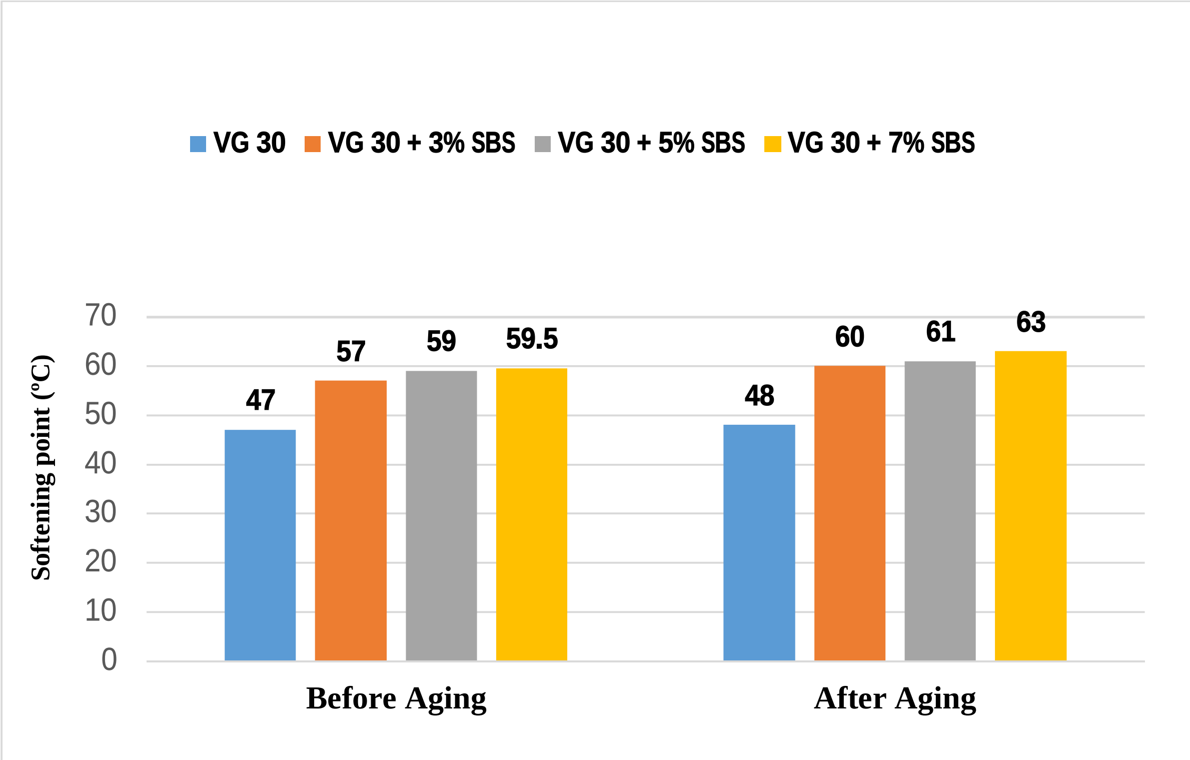

Fig.8 Softening point v/s % SBS

Specific gravity test results

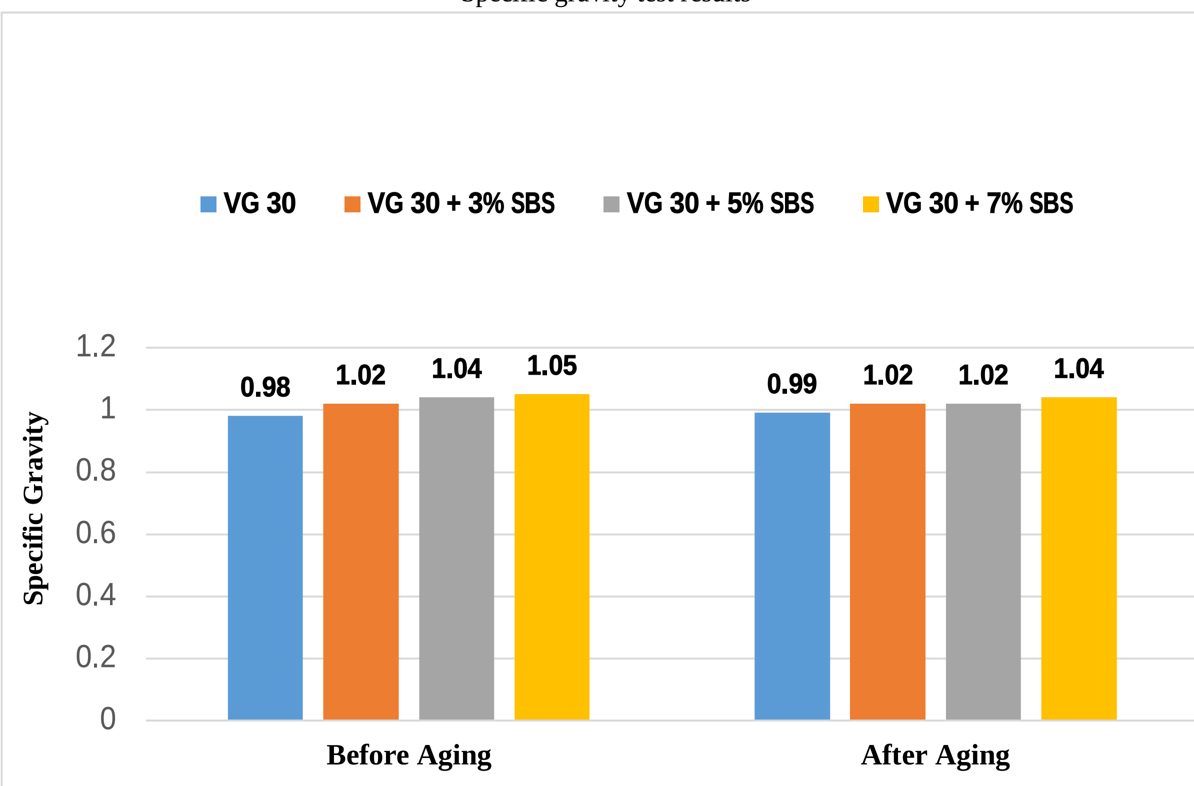

Fig.9 Specific gravity v/s % SBS

Ductility test results

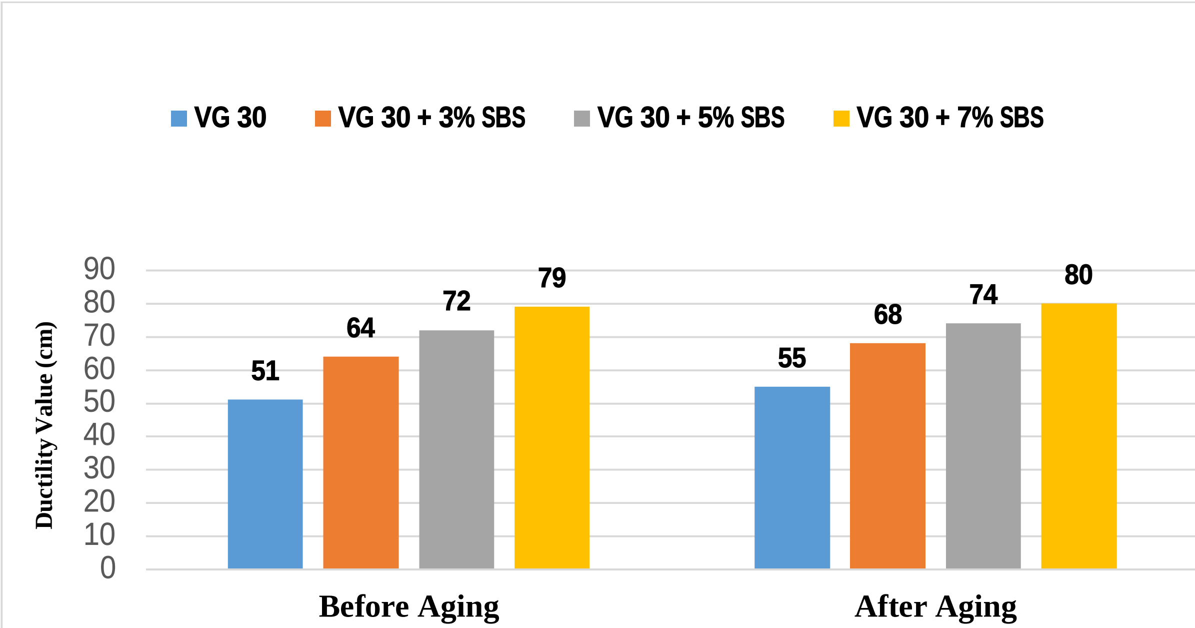

Fig.10 Ductility value v/s % SBS

Viscosity test results

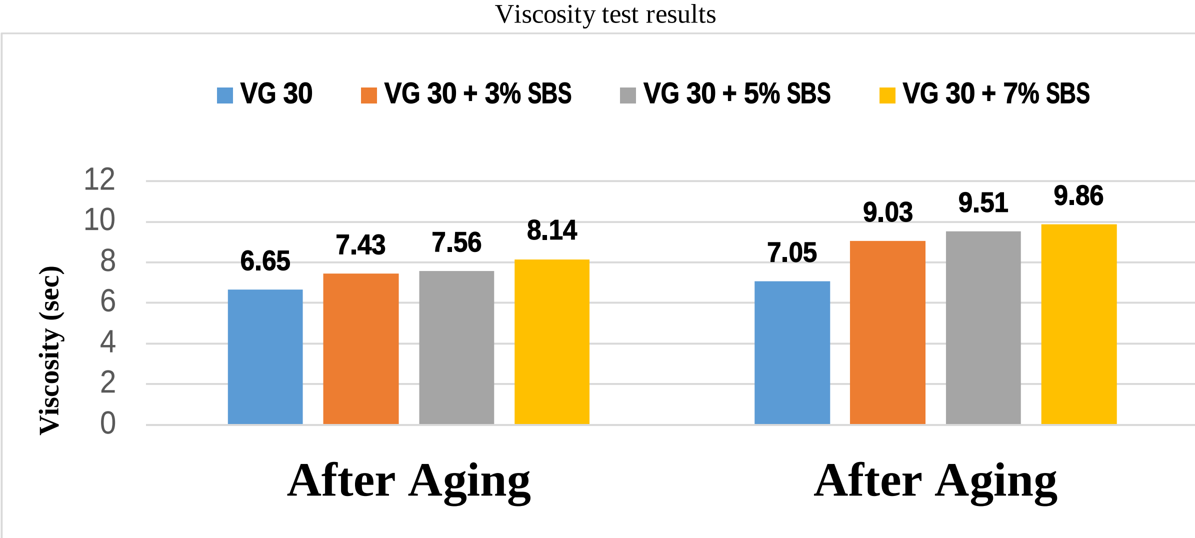

Fig.10 Viscosity v/s % SBS

VII. CONCLUSION

A. VG-30 + Nano SiO_2 (before and after aging):

1) It was difficult to blend Nano SiO_2 with bitumen and heating simultaneously.
2) Softening point increased on increasing the % of Nano SiO_2 and was maximum for 4% content after aging. This enabled bitumen to perform well at high temp and resist deformation for the same.
3) Ductility value of modified bitumen increased rapidly before and after aging.
4) Specific gravity also increased when % of additive was increased.
5) Viscosity also increased for increase in amount of Nano SiO_2.
6) Penetration value decreased considerably. Maximum hardness was achieved for 2%Nano SiO_2.
7) TFOT results showed that loss of weight on heating bitumen added with Nano SiO2 kept on increasing, thus it had noticeable effect of heat.

8) Thus, 4% Nano SiO_2 came out to be optimum out of selected amount i.e 2%, 4% & 6%.

B. VG-30 + SBS (before and after aging):

1) Good reactivity with bitumen and easy blending.
2) Ductility and Specific gravity also showed good results for the same.
3) Penetration value decreased considerably. Maximum hardness was achieved for 7% SBS.
4) Softening point increased on increasing the % of SBS and was maximum for 7% content after aging. This enabled bitumen to perform well at high temp and resist deformation for the same.
5) Viscosity also increased for increase in amount of SBS after aging.
6) TFOT results showed that loss of weight on heating bitumen added with SBS kept on increasing, thus it had noticeable effect of heat.
7) Thus, 7% SBS came out to be optimum out of selected amount i.e 3%, 5% & 7%.
8) Thus, before and after aging results of SBS modified bitumen proved to be a promising waterproofing agent.

C. Laboratory photographs

Fig.11 Penetration test apparatus

Fig.11 Softening point test apparatus

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Fig.12 Ductility test apparatus

Fig.13 Viscosity test apparatus

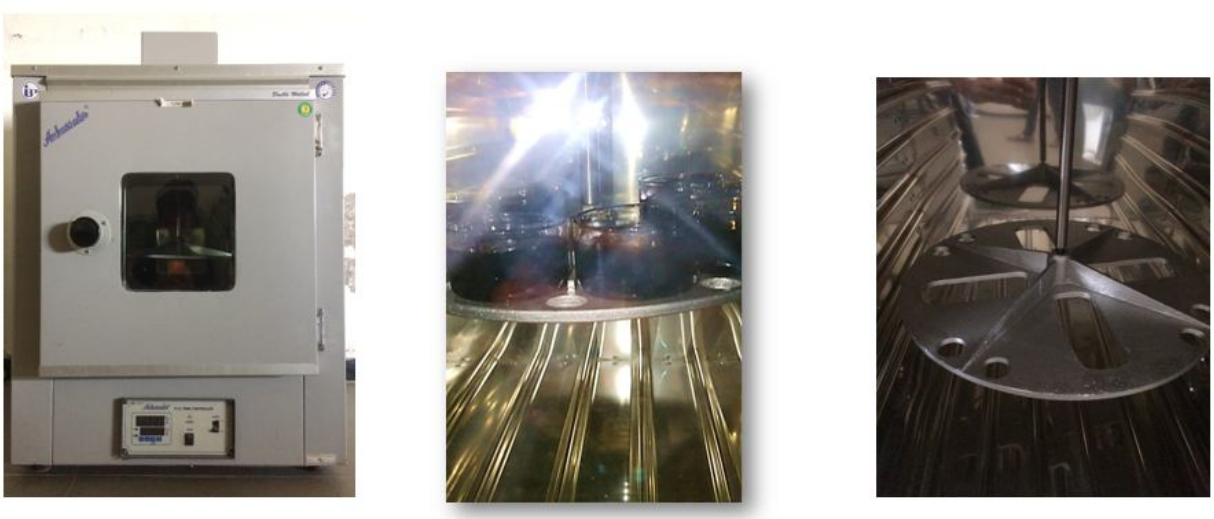

Fig.14 Thin film oven test apparatus

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