Evaluation of Mixing and Compaction Temperatures of VG-30 neat and SBS-PMB-40 binders with and without WMA additives for Paving Applications.

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Abstract

The exhaustion of gases raises the concerns for increase in rate of global warming increase rate, hot mix asphalt (HMA) alternative is the requirement of asphalt industry. Emerging new technology in warm mix asphalt (WMA) has a potential of revolutionizing a fast production for mixture asphalts. The mixing, lay down and compaction of asphalt mixes using WMA technology made possible at lower temperatures significantly compared to hot mix asphalt (HMA). The production temperatures can be reduced by this technology as much as 30 percent. Now day's bitumen industry has been awake of energy saving and environmental benefits, by using WMA additives like sasobit, evotherm and zycotherm with and dosage rates by the weight of binders. In this study an attempt is made to determine the mixing and compaction temperatures using different approaches for VG-30 and SBS-PMB-40 binders with and without WMA additives, which is produced with WMA additives like sasobit,evotherm and Zycotherm, with an additive dosage rate of 0.3%,0.75% and 0.3% respectively by the weight of binder, mixing and compaction temperatures have been evaluated for Bituminous Concrete (BC) of Grade-2. In the present study, the performance of VG-30 and SBS-PMB-40 With and without WMA additives were compared in terms of mixing and compaction temperature by adopting various methods such as Brook field viscometer, Coating and Marshall stability methods.

Results showed that the addition of WMA additives such as sasobit, evotherm and zycotherm in VG-30 and SBS-PMB-40 reduces both mixing and compaction temperatures of mixes. Compared with VG-30 and SBS-PMB-40 binder without, the addition of Sasobit, evotherm and zycotherm with an additive dosage rate of 0.3%,0.75% and 0.3% respectively by the weight of binder, are more temperature susceptible, which shows that addition of these additives can reduce the mixing and compaction temperatures and also indicates that wma additives make VG-30 and SBS-PMB-40 more temperature susceptible and are in good agreement with the results of the published literature.

Keywords: Mixing and compaction temperature, HMA, WMA additives, VG-30, SBS-PMB-40, Marshall Properties. Viscosity.

1.Introduction

Asphalt concrete mixture produced at lower temperature refers to warm mix asphalt (WMA) the temperatures used typically in hot mix asphalt (HMA) production. At temperatures with typical values of 50-100°F (28-56°C) less than HMA the WMA is produced; this is produced in batch or drum either plant at which are typically discharge temperature in between 280-320°F(138-160°C). It is necessary for HMA, at these elevated temperatures for drying the aggregate, the asphalt binder is coated with it, and the desired workability has to be achieved. WMA used in wide range of technologies such as: chemical, organic, and foaming processes for production that allow placement of asphalt mix, required by traditional HMA technology than those at lower temperatures. Placement temperatures lower are related directly to compaction improvement and densities in-place which are speculated often to raise WMA performances or the life of WMA asphalt pavements make comparable to HMA performances.

In late 1990s WMA technology developed at first in Europe. Around 2004 United States interested in WMA by realizing the success of WMA in Europe. During the 2008-10 timeframe few DOT states begins implementing the WMA. In the present study to attempt has been made to evaluate and investigate viscosity temperature relationship marshall properties and trial mixes for coating neat VG-30, SBS-PMb-40 along with additives of WMA (Sasobit, Evotherm and Zycotherm) to determine mixing and compaction temperatures.

2. Literature review

The asphalt production process main tasks are Mixing and paving/compaction, determine material quality and determine the finding of new methodologies. Adequate mixing and compaction temperatures are determined for production of asphalt with modified bitumen, studies have been carried out by several researchers in past decade on various test conditions of viscosity variation which influences the volumetric and mechanical properties production temperature.

Azari, H., McCuen, R.H., and Stuart, K.D. (1) The effect of temperature on aggregate orientation and the effect of aggregate orientation on shear properties were investigated. Based on these analyses, a narrower range of optimum compaction temperatures was found compared to the range based on volumetric properties alone. The changes in the shear stiffness of the asphalt binder, in the vertical air void distribution, and in the preferred orientation of the aggregates with compaction temperature were the responsible factors for the changes in mixture shear properties.

Awanti, S. S., et al (2) in his studies determined that polymer modified binders show higher softening point and viscosity, when compared to neat binders, and also evaluated that desirable mixing and compaction temperatures for polymer modified binders are 180 and 170^{0}C respectively, for binders' neat bitumen these values were 150 and 138^{0}C respectively.

In Performance evaluation of SBS modified asphalt mixtures using warm mix technology, the findings of Hakseo Kim and Amirkanian et al (4) WMA technology demonstrated (Aspha-min and sasobit) used to reduce compaction temperatures for modified asphalt mixtures using SBS-PMB-40 compared to mixtures of HMA to air voids contents satisfy the target. The WMA mixtures facts those, at levels of lower compactions exhibits lower air voids compared to HMA mixtures for lower temperatures signifies WMA technologies helps in the compaction effort reducing in the initial stages of constructions.

Kim, y.r., zhang, j., ban (5) in their studies analyzed that among the laboratory tests, three (two conventional and one newly attempted) were performed to characterize moisture damage potential which is the primary focus of this study. From the laboratory test results, WMA mixtures showed greater susceptibility to moisture conditioning than the HMA mixtures, and this trend was identical from multiple moisture damage parameters including the strength ratio and the critical fracture energy ratio.

Evaluation of potential process for use in Warm Mix asphalt, more studies of WMA probably conducted by National Centre for Asphalt technology (NCAT) compared against any agencies. The aspha-min demonstrated by the US .Hurley and Prowell, (6) at various stages in NCAT. The super pave gyratory compactor observes reduce air voids with an average of 0.65, 0.87 and 1.5, for alpha-min, Sasobit and Evotherm respectively, at temperatures below 190°F control mix improved compaction observed correspondingly. The resilient modulus may not be affected the mixes of aspha-min, Sasobit and Evotherm.

Technologies for warm mix asphalt make compaction easier. Even under unfavorable windy and cold weather circumstances, certain technologies have been referred to as "Flow Improvers" to improve "compact ability" of bituminous mixtures. In order to produce optimal mixing and compaction viscosities at lower temperatures while maintaining adequate viscosity at service temperatures, WMA systems aim to change the temperature/viscosity relationship.

3. Objectives of The Present Investigation

- To establish the relationship between Viscosity -Temperatures for neat VG-30 and SBS-PMB- 40 with and without warm mix asphalt (WMA) additives by conducting Brook Field Viscosity Test.
- To determine the mixing and compaction temperatures for neat bitumen of VG-30 Grade SBS-PMB- 40 with and without warm mix asphalt (WMA) additives by conducting Marshall stability studies.
- To evaluate mixing and compaction temperatures by Coating method for neat VG-30 and SBS-PMB- 40 with and without warm mix asphalt (WMA) additives.

4. Need for Present Investigation

- Mixing and compaction temperatures are the two main tasks of the asphalt production process, which together determines the quality of material and with the objective of finding new methodologies to determine adequate mixing and compaction temperatures for VG-30 and SBS-PMB-40 binders production with WMA additives, research has to be carried out on viscosity and temperature relationship with test conditions which influence the production temperature on volumetric and mechanical properties of binders with and without additives.
- Warm mix asphalt has been evaluated in the past and is often compared with hot mix asphalt. The mechanism of WMA is to use some additives or technologies to modify the rheological behavior of asphalt binders, and thus to improve the workability of the mixture at lower temperature.

5. Laboratory Investigation.

5.1 Materials

- Aggregates and Stone dust -Basalt type
- VG-30 grade Bitumen.
- PMB-SBS-40.
- WMA Additives: Sasobit , Evotherm and Zycotherm,

5.2 Tests on Materials

5..2.1 Tests on aggregates and stone dust

Physical Properties of basalt aggregates and stone dust were determined in laboratory and the results are presented in Table 5.2. Crushed Basalt type aggregates and stone dust were used as the mineral filler such as stone dust used in the investigations had a specific gravity of 2.68, 2.69. 2.71 and 2.72 respectively. Crushing value, impact value and abrasion value are 20.09 percent,12.24 percent and 28.30 percent respectively for Crushed Basalt type aggregates. These fulfills MoRTH-2010 requirements for BC layer.

Table 5.2 . Physical Properties of Basalt Aggregates and Stone Dust.

SL. No	Tests conducted	Test Results	Specifications as per MORTH 5th Revision	IS Codes
1	Aggregate Impact Test	12.24%	Max 27%	IS-2386 Part IV
2	Aggregate Crushing Value	20.09%	-	IS-2386 Part IV
3	Los Angeles Abrasion Value	28.30%	Max 35%	IS-2386 Part IV
4	Combined Flakiness and Elongation Index	17.48%	Max 35%	IS-2386 Part I
5	Water Absorption Test	0.50%	Max 2%	IS-2386 Part III
6	Specific Gravity Test			IS-2386 Part III
(a)	20 mm down	2.68	2.5 to 3.2	
(b)	12 mm down	2.69		
(c)	6 mm down	2.71		
(d)	Stone Dust	2.72		

5.2.2 Tests on binders

Laboratory tests were conducted on VG-30 neat grade bitumen and the results are presented in Table 5.3

Table 5.3 Tests Results for Neat Bitumen VG-30 Binders

Sl.no	Properties	Results		
		VG-30 Bitumen	Specifications for VG-30 Binder	IS Codes
1	Penetration Test at 25°C, 0.1mm	64	Min 45	IS-1203
2	Softening Point (°C), min	48	Min 47	IS-1205
3	Ductility Test (cm) at 25°C	90	Min 40	IS-1208
4	Elastic Recovery Test (%) at 15°C	45	Min	IS-1208
5	Flash Point (°C)	245	Min 220	IRC SP 53 2002
6	Fire Point (°C)	310	-	IS-1209

Table 5.3 Tests Results for PMB-SBS-40 Binders as per IRC-53-2010

Sl.no	Tests conducted	Results SBS-PMB-40	Specifications ns for SBS-PMB- 40 Binder As per IRC-SP-53-2010	IS Codes
1	Penetration Test at 25°C, 0.1mm	54	30-50	IS-1203
2	Softening Point (°C), min	55	60	IS-1205
4	Elastic Recovery Test (%) at 15°C	77	60	IS-1208
5	Viscosity at 150^0C, poise	4.2	3-9	IS-1206(Part-1)
6	Flash Point (°C)	290	220	IS-1208
7	Fire Point (°C)	350	-	IS-1209

Bitumen VG-30 grade bitumen was used in the investigation and procured from local Raichur.

Polymer modified binders, readily blended commercial form of SBS-PMB-40. were procured from “Hindustan Colas Pvt Ltd, Mangalore, were used in the investigation.

WMA additives such as Sasobit,Evotherm and Zycotherm were procured from KPl international ltd,New Delhi,Ingevity India,and Zydex,Hyderabad, India respectively.

From physical properties of SBS-PMB-40 it is observed that softening point values are higher and penetration value is lower when compared to neat bitumen. The values obtained from physical tests on SBS-PMB-40 and VG-30 neat bitumen are fulfilling all the requirements as per IRC: SP:53-2010 and IS:15462-2010. VG-30 neat bitumen fulfils all the requirements of IS:73-2013.

5.3 Determination of Mixing and Compaction Temperatures by using various methods

In the last few years, there are several attempts by many researchers to specify a more practical approach to determine mixing and compaction temperatures for modified bitumen and neat binders. Below are the information and procedures regarding the various method of determining mixing and compaction temperatures for neat and polymer modified mixes.

5.3.1 Viscosity temperature relationship using Brookfield Viscometer Method

Bitumen is available in variety of types and grades. To judge the suitability of these grades various tests are specified by the different agencies like ASTM, ISI, and IRC etc. For classifying bitumen and studying the performance of bituminous pavement, penetration and ductility tests are essential. The other tests like softening point, flash and fire point tests are more important to guide the paving technologists during field operations. In recent years it has been recognized that the above tests are not sufficient to define the temperature susceptibility of bituminous materials.

The present investigation envisages laboratory study of different grades of VG-30 neat bitumen and PMB-SBS-40 with and without WMA additives with respect to change in viscosity measured with Brookfield viscometer.

Broke field viscometer is the most common machine that is utilized to measure the bitumen viscosity for this method. The measured viscosity results are then drawn versus the temperature. The lab standard used in labs all over the world is the Broke field Viscometer. The rotational viscometry principle is used by Broke field viscometers; it states that the torque needed to rotate an item, such as a spindle, in a fluid, reveals the fluid's viscosity. The viscous drag of the test fluid against the spindle is measured by applying torque through a calibrated spring to a disc or bob spindle that is submerged in the fluid. Test procedures that are effective will produce a torque reading between 10 and 100. The test fluid's rheological behavior can be studied using the same spindle at various speeds, however correct rhinometry is not possible with this set-up since the fluid's geometry around a revolving bob or disc spindle in a big container prevents the assignment of a single shear rate.

Spindle is chosen, rotational speed is selected, temperature is controlled if required, spindle rotation is specified before measurements, viscosity is recorded in centipoise and sample temperature is also recorded. The prepared asphalt is placed in the Brookfield Viscometer and a proper speed is selected for the spindle according to the expected viscosity of the sample. The Brookfield Viscometer determines viscosity by measuring the force to the spindle in the solution at a given rate.

Table 5.4. Viscosity temperature of VG-30 neat with and without WMA additives using Brookfield Viscometer

Test Temperature ^{0}C	Viscosity in, poise			
	VG-Neat	VG+3% Sasobit	VG+0.75% Evotherm	VG+0.3% Zycotherm
100	5.50	10.0	8.26	8.60
110	5.34	8.60	6.65	7.60
120	5.06	6.50	3.20	5.20
130	6.0	2.40	1.20	2.60
140	5.40	1.80	1.00	1.00

Table 5.5. Viscosity temperature of SBS-PMB-40 with and without WMA additives using Brookfield Viscometer.

Test Temperature ^{0}C	Viscosity, in poise			
	SBS-PMB-40 Neat	SBS-PMB-40 Neat +3% Sasobit	SBS-PMB-40 Neat +0.75% Evotherm	SBS-PMB-40 Neat +0.3% Zycotherm
110	18.80	19.90	18.80	18.90
120	18.60	19.80	8.40	13.40
135	13.90	14.60	4.60	6.10
150	7.30	7.90	3.30	3.60
165	4.60	4.30	1.40	1.20
180	1.10	1.38	1.10	1.00

Figure 5.1Variation of Viscosity with Temperature for VG-30 neat with WMA additives.

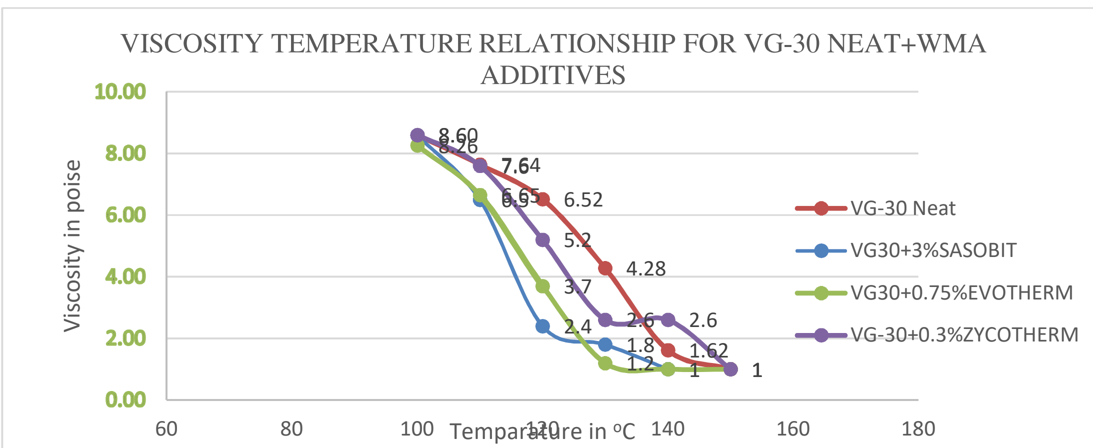
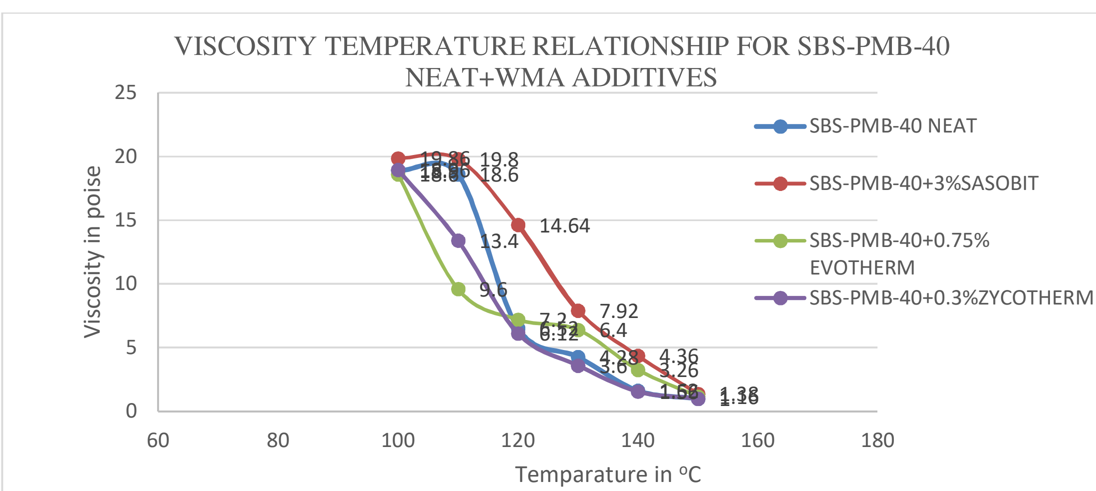


Figure 5.2 Variation of Viscosity with Temperature for SBS-PMB-40 neat with WMA additives.



The viscosity temperature relationship is used as an index of temperature susceptibility of the binder, to develop viscosity temperature relationship for neat and SBS-PMB binder, viscosity test was conducted at different temperatures such as 100,110,120,130, and 140 ^{0}C by using Broke field viscometer for neat bitumen and 110,120,135,140,150,160,170 and 180^{0}C for SBS-PMB-40 binders with and without WMA additives. The variation of binder viscosity with temperature for VG-30 neat bitumen and SBS-PMB-40 binders are shown in figure 5.1 and 5.2.

As per IRC: SP:53-2010, for PMB mixing and compaction temperatures corresponding to viscosity values of of 4 poise(Max) and 5 poise (Max),respectively. From the Viscosity the viscosity temperature relationship as shown in figure 6.2 .It is observed that, for SBS-PMB-40 mixing and compaction temperatures obtained are 170^{0}C and 160^{0}C, whereas SBS-PMB-40 neat with 3%sasobit 168^{o}C and 162^{o}C, with 0.75%Evotherm 150^o and 135^{o}C and for 0.3% Zycotherm 150^{o}C and 142^{o}C as shown in Table 5.2. The samples strength will have a positive effect by the additives is clearly observed.

As per ASTM D 1559 -96, for neat bitumen mixing and compaction temperatures corresponding to viscosity values of 1.56 ± 018 poise and 2.57±0.28 poise, respectively. From the viscosity temperature relationship (Fig 3.1) it is observed that, for neat bitumen mixing and compaction temperatures obtained are 142 ^{0}C and 132^{0}C whereas VG-30 neat with 3% sasobit 132^{o}C and 118^{o}C, with 0.75%Evotherm 128 and 120^{o}C and for 0.3% Zycotherm 130^{o}C and 125^{o}C as shown in Table 6.1 and 6.2. The samples strength will have a positive effect by the additives is clearly observed respectively

5.3.2 Viscosity Temperatures relationship using Coating method

In this study, the concept of coat ability was used to validate the mixing temperatures of VG-30 neat bitumen and PMB-SBS-40 with and without WMA additives. This approach measures the degree of asphalt coverage around the aggregate particles. IRC: SP 101 [7] has recommended using the test method specified in AASHTO T195 [8] to evaluate coating over the aggregates. This method quantifies the degree of asphalt coating based on visual assessments. The major challenge in this test method is its dependency on manual qualitative visual inspection. Thus, the present study attempted to assess the coating ability of asphalt binder, at a given mixing temperature, by incorporating a complete asphalt-aggregate mixture. This approach is expected to provide a better simulation of in-field condition.

According to Hensley (1998), Mixing can be defined as that temperature, which produces a uniform coating and sufficient coating of the coarse aggregates, which is to be estimated on the basis of experience.in order to determine mixing and compacting temperatures by this approach for VG-30 neat and SBS-PMB-40 BC mixes.

Several trials were tried at different temperatures such as 100,110,120,130,140 and 150 ^{0}C for VG-30 with and without WMA additives and 140,150,160,170, and 180^{0}C for SBS-PMB-40 with and without WMA additives respectively. But at a higher temperature of 140^{0}C the aggregates were coated thoroughly with VG-30 and 170^{0}C for SBS-PMB-40 respectively. Hence from this approach mixing and the compaction temperatures obtained by viscosity temperature relationship was substantiated as 140^{0}C and 170^{0}C and the compaction temperature was taken as 130 and 160^{0}C for VG-30 and SBS-PMB-40 respectively as shown in the Table 6.3.

Table 5.6 Coating temperatures by trial method for VG-30 neat with and without WMA additives

Parameters	VG30-neat	VG30-NEAT+3% Sasobit	VG30-NEAT+0.75% Evotherm	VG30-NEAT+0.3% Zycotherm
Coating temperature ^{0} C	140	110	110	97

Table 5.7 Coating temperatures by trial method for SBS-PMB-40 neat with and without WMA additives.

Parameters	SBS-PMB-40 -neat	SBS-PMB-40 -NEAT+3% Sasobit	SBS-PMB-40 -NEAT+0.75% Evotherm	SBS-PMB-40 -NEAT+0.3% Zycotherm
Coating temperature ^{0} C	158	132	148	140

5.3.3 Determination of mixing and compaction temperature by using Marshall method at arbitrary binder content.

To investigate further the validity of these selections for VG-30 and SBS-PMB-40 with and without WMA additives Marshall specimens were prepared with arbitrary binder content for VG-30 and SBS-PMB-40 at different mixing temperatures of 100,110,120,130 and 140^{0}C and 140,150,160,170, and 180^{0}C for SBS-PMB-40 respectively, Compacting temperatures were taken as 10^{0}C less than the corresponding mixing temperature.

Grade-2 middle limit aggregate gradation as per MoRT&H-2010 was used and is shown in Table 5.8, From the investigation it has been observed that maximum stability is obtained corresponding to this mixing temperature of 140^{0}C for VG-30 and 170^{0}C for SBS-PMB-40 binders. Other Marshall properties correspondence to this mixing and compaction temperatures also satisfies the requirements as per IRC: SP:53-2010, Hence for further investigation mixing temperatures were taken as 140^{0}C for VG-30 nest bitumen and 170^{0}C for SBS-PMB-40 respectively, and Compacting temperatures were taken as 10^{0}C less than the corresponding mixing temperature.

Marshall properties at different mixing and compaction temperatures for VG-30 and SBS-PMB-40 with and without WMA additives are shown in Table 5.9,5.10,5.11,5.12,5.13,5.14,5.15,5.16, and 5.17 respectively. Requirements of VG-30 mix and SBS-PMB-40 mix as per IRC-53-2010 is shown in Table 5.18.

Gradation of Aggregate: Grade -2 midpoint aggregate gradation for BC layer as MoRT&TH 2010 was adopted and is shown in Table 5.8

Table 5.8 Specification of Aggregates for Gradation for Grade -2 Bituminous Concrete Mix as per MoRT&TH 2010

SIEVE SIZE, mm	**PERCENTAGE PASSING**				**REQUIRED GRADATION**			**ACHIEVED**	**REQUIRED**
	Aggregate (A) (20 mm down)	Aggregates (B) (12.5 mm down)	Aggregate (C) (6 mm down)	Aggregate (D) (stone dust)	upper limit	lower limit	mid limit	blend	gradation
26.5	100	100	100	100	100	100	100	100.0	100
19	43.78	100	100	100	100	79	89.5	87.1	79-100
13.2	2.62	98	100	100	79	59	69	77.0	59-79
9.5	0.65	59.69	88.65	100	72	52	62	63.2	52-72
4.75	0.17	4.31	24.92	100	55	35	45	36.3	35-55
2.36	0.15	0.4	5.98	96.93	44	28	36	31.2	28-44
1.18	0.14	0.3	1.6	77.8	34	20	27	24.5	20-34
0.6	0.13	0.3	0.8	60.54	27	15	21	19.0	15-27
0.3	0.12	0.2	0.7	33.08	10	1	5.5	10.5	1-10
0.15	0.1	0.2	0.5	18.34	5	1	3	5.9	1-5
0.75	0.08	0.2	0.0	6.14	8	2	5	2.0	2-8
Pan									

Each size of aggregate has undergone a different sieve evaluation for the selected aggregate. The resulting gradation is well within the limits and the percent finer of each is calculated as blending proportion 0.23A+0.30B+0.16C+0.31D and reported in the Table 5.9.

Table 5.9 Percentage finer of each aggregate size

Size of Aggregate		Percentage		Wt ,in gms
20 mm (A)	0.23	0.23	23	276
12.5 mm (B)	0.3	0.3	30	360
6mm (C)	0.16	0.16	16	192
Dust (D)	0.31	0.31	31	372
	Total	1	100	1200

Preparation of test specimen

From the above mentioned blend proportion 1200 gms of aggregates are weighed and mixed than heated to a temperature of 160°C than these are mixed with arbitrary mix of VG-30 and SBS-PMB-40 by weight of graded aggregates . Mixed properly and poured in the mold and for compaction after lowering 10-15°C then 75 blows are given on either side. Specification of Aggregate Gradation for Bituminous Concrete mix Grade-2 as per MoRTH Gradation adopted and mixes are investigated.

The coarse aggregate, fine aggregate and the filler material are proportioned and mixed in such a way that final gradation of mixture is within the range specified for desired type of bituminous mix. The volumetric properties of VG-30 neat with WMA Additives (Sasobit Evotherm and Zycotherm) and also for SBS-PMB-40 neat with WMA Additives (Sasobit Evotherm and Zycotherm) were determined using Marshall stability tests after the gradation was established. The tests were carried out in accordance with IS specifications.

Table 5.10. Marshall Properties of VG-30 neat mix at different mixing temperatures

Sl,no	Mixing Temperature, ^{0}C	Marshall Stability,Kgs	Flow,mm	Bulk Density,gm/cm3	Air Voids ,%
1	110	1047	3.20	2.24	11.80
2	120	1306	4.30	2.53	9.56
3	130	1150	4.83	2.56	5.84
4	**140**	**1090**	**4.37**	**2.50**	**3.10**

Table 5.11. Marshall Properties of VG-30 neat + 3% sasobit mix at different mixing temperatures

Sl,no	Mixing Temperature, ^{0}C	Marshall Stability,Kgs	Flow,mm	Bulk Density,gm/cm3	Air Voids ,%
1	90	1090	4.23	2.33	9.52
2	100	1301	4.70	2.33	7.56
3	**110**	**1033**	**4.15**	**2.33**	**3.78**

Table 5.12 Marshall Properties of VG-30 neat + 0.75% Evotherm mix at different mixing temperatures

Sl,no	Mixing Temperature, ^{0}C	Marshall Stability,Kgs	Flow,mm	Bulk Density,gm/cm3	Air Voids ,%
1	100	1054	3.30	2.50	2.97
2	110	1097	3.30	2.53	5.42
3	**120**	**1054**	**4.02**	**2.51**	**2.43**

Table 5.13. Marshall Properties of VG-30 neat +0.3% Zycotherm mix at different mixing temperatures.

Sl,no	Mixing Temperature, ^{0}C	Marshall Stability,Kgs	Flow,mm	Bulk Density,gm/cm3	Air Voids ,%
1	100	1326	4.73	2.45	5.66
2	110	1383	4.01	2.48	2.58
3	**120**	**1343**	**4.01**	**2.48**	**4.10**

Table 5.14 Marshall Properties of SBS-PMB-40 neat Mix at different mixing temperatures .

Sl,no	Mixing Temperature, ^{0}C	Marshall Stability,Kgs	Flow,mm	Bulk Density,gm/cm^3	Air Voids ,%
1	140	1408	3.26	2.48	5.10
2	150	1306	4.76	2.41	5.36
3	160	1302	4.68	2.35	5.50
4	**170**	**1280**	**3.26**	**2.37**	**4.62**
5	180	1160	4.10	2.32	5.62

Table 5.15 Marshall Properties of SBS-PMB-40 +3% Sasobit mix at different mixing temperatures

Sl,no	Mixing Temperature, ^{0}C	Marshall Stability,Kgs	Flow,mm	Bulk Density,gm/cm^3	Air Voids ,%
1	120	1362	4.76	2.34	8.86
2	**130**	**1355**	**4.70**	**2.36**	**5.50**
3	140	1352	4.26	2.34	5.56

Table 5.16 Marshall Properties of SBS-PMB-40+0.75%Evotherm mix at different mixing Temperatures

Sl,no	Mixing Temperature, ^{0}C	Marshall Stability,Kgs	Flow,mm	Bulk Density,gm/cm^3	Air Voids ,%
1	140	1137	4.52	2.46	3.40
2	**150**	**1011**	**3.71**	**2.46**	**3.46**
3	160	1161	3.10	2.43	4.69

Table 5.17 Marshall Properties of SBS-PMB-40 +0.3% Zycotherm mix at different mixing temperatures

Sl,no	Mixing Temperature, ^0C	Marshall Stability,Kgs	Flow,mm	Bulk Density,gm/cm^3	Air Voids ,%
1	120	1132	2.70	2.44	9.40
2	**130**	**1200**	**2.90**	**2.31**	**4.56**
3	140	1088	2.98	2.41	5.35

Table 5.18 Marshall properties required for both neat bituminous and polymer modified bituminous mix prepared with Bituminous Concrete Grade -02 mix as per IRC: SP: 53-2010

Sl,no	Properties	Requirements	
		Neat bituminous mix	Polymer modified bituminous mix
1	Marshall stability in Kgs minimum	900	1200
2	Maximum Bulk Density	Max	Max
3	Air Voids, %	3-6	3-5
4	Marshall Flow Value, mm	2-4	2.5-4
5	Volume filled with bitumen (VFB)	65-75	65-75

7. Results and Discussions

- The viscosity tests conducted by using Brookfield field viscometer on VG-30 neat shows a temperature for mixing of 142ºC and compaction temperature 130ºC whereas VG-30 neat with 3%sasobit 132ºC and 118ºC, with 0.75%Evotherm 128 and 120ºC and for 0.3% Zycotherm 130ºC and 125ºC as shown in table 6.1 The samples strength will have a positive effect by the additives is clearly observed.
- The viscosity tests conducted by using Brookfield field viscometer on SBS-PMB-40 neat shows a mixing temperature of 172ºC and a compaction temperature of 162ºC whereas SBS-PMB-40 neat with 3%sasobit 168ºC and 162ºC, with 0.75%Evotherm 150º and 135ºC and for 0.3% Zycotherm 150ºC and 142ºC as shown in Table 6.2. The samples strength will have a positive effect by the additives is clearly observed.
- Coating method results shows the coating temperature was found to be 140ºC for VG-30 neat 110,110, and 100ºC for 3,0.75 and 0.3 % sasobit,evotherm and zycotherm respectively similarly for SBS-PMB-40 coating temperatures were found to be 158 for neat 132,148 and 140ºC for 3,0.75 and 0.3 % for sasobit,evotherm and zycotherm respectively.

- Marshall tests results indicates mixing temperatures for VG-30 neat, VG-30+3% Sasobit,VG-30+ 0.75% Evotherm,and VG-30+0.3% Zycotherm as 140,110,120 and 120 ^{o}C Compacting temperatures as 10^{0}C less than the corresponding mixing temperature.

- Marshall tests results indicates mixing temperatures for SBS-PMB-40 neat, SBS-PMB-40 +3% Sasobit, SBS-PMB-40 + 0.75% Evotherm,and SBS-PMB-40 +0.3% Zycotherm as 170,130,150 and 130 ^{o}C ,Compacting temperatures as 10^{0}C less than the corresponding mixing temperature.

- Marshall tests results indicated higher stability, Bulk Density, Lower air voids and reduced mixing and compaction temperatures for 3% sasobit addition in VG-30 neat and SBS-PMB-40.

- Addition of 3% Sasobit reduces the temperatures for compaction and mixing in the range of 15 to 20^{o} C ,for VG-30 and SBS-PMB-40,addition of 0.75%Evotherm reduces the temperatures for mixing and compaction of 16 to 18^{o}C in addition of 0.3% zycotherm reduce the temperatures for compaction and mixing of 12 to 18^{o}C this shows addition of 3% sasobit satisfies the limits.

- The addition of Evotherm and zycotherm shows very less trends but addition of sasobit shows better the temperatures for compaction and mixing for VG-30 and SBS-PMB-40 binders.

8. Conclusions

Based on the experimental results the following conclusions can be drawn.

- Softening points and viscosity values are found to be higher by 16 percent and 98 percent for SBS-PMB40 when compared to VG-30 neat bitumen. The above values for SBS-PMB-40are found to be 14 percent and 101percent higher than neat bitumen, whereas the penetration value of SBS-PMB-40are found to be 36 percent and 37 percent than neat bitumen.

- Elastic recovery of for SBS-PMB-40 and for SBS-PMB-40 and VG-30 neat bitumen is 16 times higher when compared to neat Bitumen. This shows higher flexibility and higher deformation resistance of for SBS-PMB-40 compared to VG-30 neat bitumen.

- SBS-PMB-40 binders have shown higher elastic recovery when compared to neat bitumen. This shows higher flexibility and higher deformation resistance of SBS-PMB-40 compared to Neat Bitumen.

- In the present study, the performance of VG-30 and SBS-PMB-40 With and without additives were compared in terms of mixing and compaction temperature by adopting various methods such as Brookfield field viscometer, Coating and Marshall stability methods.

- Desirable mixing and compacting temperatures for VG-30 neat binder are 140^{0}C and 130^{0}C respectively. Desirable mixing and compacting temperatures for SBS-PMB-40 binder are 172^{0}C and 162^{0}C respectively.

- From the point of Viscosity-temperature relationship susceptibility the addition of WMA additives makes VG30 and SBS-PMB-40 more temperature susceptible which shows that addition of these additives can reduce the temperatures for compaction and mixing.

- The viscosity tests conducted by using Brookfield field viscometer on VG-30 neat shows a temperature for mixing of 142°C and compaction temperature 135°C whereas VG-30 neat with 3%sasobit 132°C and 118°C, with 0.75%Evotherm 128 and 120°C and for 0.3% Zycotherm 130°C and 125°C as shown in Table 6.6. The samples strength will have a positive effect by the additives is clearly observed and hence the same temperatures are adopted for further investigation in this work.

- The viscosity tests conducted by using Brookfield field viscometer on SBS-PMB-40 neat shows a mixing temperature of 172°C and a compaction temperature of 162°C whereas SBS-PMB-40 neat with 3%sasobit 168°C and 162°C, with 0.75%Evotherm 150 and 135°C and for 0.3% Zycotherm 150°C and 142°C as shown in Table 6.1 and 6.2. The samples strength will have a positive effect by the additives is clearly observed and hence the same temperatures will be adopted for further investigation in this work.

- Coating method results shows the coating temperature was found to be 140°C for VG-30 neat 110,110, and 100°C for 3,0.75 and 0.3 % sasobit, evotherm and zycotherm respectively similarly for SBS-PMB-40 coating temperatures were found to be 158 for neat 132,148 and 140°C for 3,0.75 and 0.3% for sasobit, evotherm and zycotherm respectively.

- Marshall tests results indicated higher stability, Bulk Density, Lower air voids and reduced mixing and compaction temperatures for 3% sasobit addition in VG-30 neat and SBS-PMB-40

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