**Marshall mix design and Performance evaluation, of VG-30 neat and PMB-SBS-40 binders with and without WMA additivesfor Paving Applications.**

Anilkumar L[1] ,S.S Awanti [2]

[1] Assistant Professor, of Civil Engineering, Government Engineering College, Raichur, Karnataka India,Email:

[2] Professor of Civil Engineering, Sharanabasava University, Kalaburgi, Karnataka India,Email:

*Generally, in India, the important highways are made up by Bituminous Concrete (BC). Bitumen mix design can be done by Marshall Mix Design Method, is a balancing method to adjust the proportions of various aggregate sizes and bitumen content. The present research focused on the use of harder grade bitumen VG-30 neat and PMB-SBS-40neat and with WMA additives such as sasobit,Evotherm and Zycotherm, for better performance under heavy traffic load and hot climatic conditions. In this paper laboratory investigations were carried out on neat bitumen of VG-30, SBS- Polymer Modified Bitumen -40 grade to study the physical properties, elastic recovery etc. Marshall tests were carried on neat bituminous concrete mix (BC) grade(2) and SBS-polymer modified bituminous concrete mix grade(2) mix to determine the optimum binder content using Marshall mix design method, Temperature susceptibility of BC and SBS-polymer modified bitumen were determined from static indirect tensile test at different temperatures, Moisture susceptibility of ,BC grade 2 prepared with VG-30 neat, PMB- SBS 40,VG-30+WMA additives and PMB- SBS 40+WMA additive were determined from tensile strength ratio test from test results it is observed that the temperature susceptibility of VG-30 with WMA additives and PMB-SBS-40 With WMA additives is lower than VG-30 neat and PMB- SBS-40. It is also observed that Marshall stability and flow values of PMB-SBS-40 are higher when compared to VG-30 mix at optimum binder content. The static indirect tensile strength values for PMB-SBS-40with and without WMA mixes were higher when compared to VG-30 neat with and without WMA additives mixes at different temperatures. Moisture susceptibility of PMB- SBS-40 with and without additives mixes is low when compared to VG-30 neat with and without WMA additives.*

.

***Key Words** : Hot Mix Asphalt(HMA),Warm Mix Asphalt (WMA),Viscosity Grade(VG), Bituminous Concrete(BC),VG-30, Styrene Butadiene Styrene Polymer Modified Bitumen SBS-PMB-40,Optimim Bitumen Content(OBC),ITS,*

## 1. Introduction

Flexible pavements with bituminous concrete surfacing are widely used in India. The high traffic intensity in terms of commercial vehicles, overloading of trucks and significant variations in daily and seasonal temperature of the pavement have been responsible for early development of distress symptoms like raveling, undulations, rutting, cracking, bleeding, shoving, potholing of bituminous surfacing. Increased incidence of premature rutting of heavy-duty asphalt pavements has been experienced in recent years.

Cracking and permanent deformation are the main forms of distress mechanisms of asphaltic layers in pavements. Thermal and fatigue cracking are the main types of cracks in asphaltic mixtures. In addition to the reduction of structural performance, cracking is the beginning of disintegration and results in water infiltration and acceleration of pavement failure. Therefore, cracking has always been a main concern of pavement engineers. The tensile strength of asphaltic mixtures is commonly related to their resistance against cracking [Ziaee et al. (13]. The higher the tensile strength, the higher is the resistance of the mixture against fatigue and thermal cracking [Huang et al. [3]. Moreover, the mixtures sustaining higher strains before failure in indirect tensile strength (ITS) test are more resistant to fatigue cracking [Tayfur et al. [5]. The tensile strength of asphaltic mixtures can be measured by direct or indirect tension. However, due to the presence of undesirable secondary stresses caused by the requirement to clamp the ends of test specimens, direct measurement of tensile strength is not very popular and the method of applying indirect tensile stress is more common. Therefore, measuring the ITS of asphaltic mixtures is an important and popular test configuration. ITS of asphaltic mixtures in dry and wet conditions is also measured to be used as an indicator for resistance against moisture damage.

In the present study an attempt has been made to evaluate mix design and performance of bituminous concrete mixes of grade -2 prepared with VG-30 neat, PMB-SBS-40 binders with and without WMA additives such as Sasobit,Evotherm and Zycotherm. Marshall mix design is carried out as per MoRT&H-2010 and IRC-SP-53-2010 performance evaluation above mixes have been carried out by conducting Static Indirect tensile tests (ITS) at various temperatures and moisture susceptibility tests.

## 2.Literature review

Bituminous Concrete is one of the most widely used construction materials as a binder layer in roads. It is generally used as a binder layer or called as a binder course of flexible pavement. Some improvements are made in the BC mix by adding different filler materials or additives for enhancing performances and characteristics of mixture to enhance durability of pavement.

Leng, Al-Qadi, & Cao, [2]. The first development of WMA technology was in the 1990s. By WAM-Foam technology in Germany and Norway, the ingredients were investigated. WMA technologies were developed not only by the foam system but also by using wax cores and chemical additives. (Dubravský & Mandula, [5]. The production temperature of WMA is in between 100 °C – 140 °C while the temperature range of Hot mix asphalt (HMA) is about 140 – 190 °C. Kim et al.[9] studied the performance properties of SMA–WMA mixture using a wax-based WMA additive and compared with the conventional SMA mixture without an additive. Authors determined viscoelastic properties, moisture susceptibility, fatigue resistance, rutting resistance at high temperature, and crack resistance at a low temperature of both samples. They reported that WMA variants demonstrated better performance in these performance parameters in comparison to conventional SMA variants (Kim et al., [10]. In addition, SMA-WMA is more environmentally friendly than conventional SMA in terms of economic competition.

Awanti SS (2008) (1) In his paper presents the laboratory investigations carried out to determine the various engineering properties such as physical properties of asphalt cement and (polymer modified asphalt binder) PMAB with (styrene-butadiene-styrene triblock copolymer)SBS, Marshall properties using modified Marshall method, static indirect tensile strength at different temperatures, tensile strength ratio. The temperature susceptibility of PMAB-SBS is lower than asphalt cement. Marshall stability and flow values of PMAC mix are higher when compared to AC mix at optimum binder content. The static indirect tensile strength values for PMAC mixes were higher when compared to AC mixes at different temperatures. Moisture susceptibility of PMAC mixes is low when compared to AC mixes.

Ali Topala , Baha Vural Kökb (2018) (2) Has Investigated the Demand for sustainable pavements increases day by day in asphalt paving industry. Within the scope of this study, the effect of an organic WMA additive was evaluated in terms of mixture characteristics and performance. Mixtures modified with organic WMA additives were produced according to Marshall mix design method and the optimum bitumen content of the samples were determined. Following the determination of optimum bitumen content, the effect of the organic WMA additive was investigated in terms of indirect tensile stiffness modulus, fatigue and creep behaviour. The results appraised the effect of the organic WMA additive on rheological and performance characteristics of bituminous mixtures.

The use of warm mix asphalt (WMA) has been widely becoming more popular in the asphalt industry. WMA technology has many benefits such as global warming, air quality, and fuel needs. The most significant benefits of WMA are less pollution and lower energy consumption. Both the production and laying temperatures of the WMA process are lower than those of the HMA. This shows that the amount of emission they emit to the environment is lower. Therefore, WMA has little effect on the health of employees compared to HMA. In literature, it is identified as many as fifteen different 410

WMA technologies currently available. The foaming or some chemical or organic additives are most commonly used for WMA technologies Chowdhury & Button, [3].

Asphalt_Innovations, [1] A3, a warm asphalt admixture produced by MWV Co., is an additive type with an amine compound. It is introduced as a warm mix asphalt technology to improve the coating, increase adhesion between aggregate and binder, improve workability and compaction. It is also said that the HMA can also be used to increase the properties of the mixture in the production of asphalt. The use of this additive in HMA results in a temperature reduction by 15 to 30 °C compared to the conventional HMA. A3 additive requires a recommended ratio of 0.25-0.75% by bitumen weight in order to make sure the results that the producers of asphalt are trying to accomplish. In this study, A3 added to the bituminous binder at a ratio of 0.4% of the bitumen by weight and mixed for 30 minutes

Supriya Mahida and Chandravadan B. Mishra (2017) (4) : This paper concentrates on the research centre examination of the attributes and performance of warm mix asphalt containing compound added substance. Viscosity grade 30 bitumen was utilized for this study and the WMA added substances utilized as a part of this review were Evotherm and Sasobit. Consistency tests demonstrated the utilized warm mix additives are within permissible limit. Information got from indirect tensile test, tensile strength ratio test, static and dynamic creep test demonstrated that the blends containing warm mix asphalt added substances performed better in contrast with hot mix asphalt. Warm mix asphalt samples indicated lesser aggregate lasting strain gathering in contrast with HMA specimens, Sasobit altered warm blend black-top specimens demonstrated the minimum deformation.

## 2.1 Need for Present Study

Warm mix asphalt (WMA) is an emerging new technology has a potential of revolutionizing a fast production for mixture asphalt. Bituminous concrete mixes prepared using WMA additives like Sasobit,Evotherm and Zycotherm have reduces production temperatures by as much as 20 to 25% when compared to Hot mix asphalt mixes. It is very much essential to study the performance of these WMA mixes by conducting Marshall mix design, Static indirect tensile tests at different temperatures and moisture susceptibility tests and compare these results with HMA mixes prepared using VG-30 grade neat bitumen, PMB-SBS-40 binders so that WMA mixes can be recommended for practical applications.

## 2.2. Objectives of the Present Investigations

- To carry out Marshall mix design to determine Marshall parameters of bituminous concrete mixes of grade-2 prepared using VG-30 neat and PMB-SBS-40 binders mixes with and without WMA additives like Sasobit,Evotherm and Zycotherm with optimum dosages.
- To conduct static indirect tensile tests at different temperatures on specimens of bituminous concrete mixes of grade-2 prepared using VG-30 neat and PMB-SBS-40 binders mixed with and without WMA additives.
- To evaluate Moisture susceptibility of WMA mixes and compare the results with HMA mixes.

# 3. Laboratory Investigation.

## 3.1 Marshall Mix Design and performance evaluation bituminous concrete mixes prepared with VG-30 grade neat and PMB- SBS-40 with and without WMA additives

## 3.2 Materials used

3.1.1 Aggregates and Stone dust -Basalt type

3.1.2 VG-30 grade Bitumen.

3.1.3 PMB-SBS-40.

3.1.4 WMA Additives: Sasobit , Evotherm and Zycotherm,

## 3.3 Tests on Materials

### 3.3.1 Aggregates

3.3.2 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 3.1. Crushed Basalt type aggregates and stone dust were used as the mineral filler.

Table 3.1. Physical Properties of Basalt Aggregates and Stone Dust.

| SL. No | Tests conducted | Test Results | Requirements as per MORTH 5th Revision | Methods of test. |
|---|---|---|---|---|
| 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 | | |

All the test results fulfill the requirement of MoRTH-2010 for bituminous concrete grade-2 layer.

3.3.3 **Bitumen -**VG-30 grade bitumen used in this investigation is procured from local, Raichur.

Laboratory tests were conducted on VG-30 neat grade bitumen and the results are presented in Table 3.2

Table 3.2 Tests Results for VG-30 grade neat bitumen

| Sl.no | Properties | Test Results | Requirement as per IS.;73-2013 | Method of test |
|---|---|---|---|---|
| 1 | Penetration Test at 25°C, 0.1mm and 100gms, 5 s | 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 |
| 5 | Flash Point by Cleveland open Cup (COC) (°C) | 245 | Min 220 | IS 1209 |
| 6 | Fire Point (°C) | 350 | 315 | |
| 7 | Absolute Viscosity, in Poise at 60°C temperature. | 2950 | IS 1206 Part 22400 – 3600 | IS 1206 |
| 8 | Kinematic Viscosity,in Poise @135°C,cst min | 360 | 350 | IS 1206 part(3) |

### 3.3.4 Polymer Modified Bitumen Styrene betadine styrene (PMB – SBS-40)

Polymer modified binders, readily blended commercial form of PMB - SBS-40. were procured from “Hindustan ColasPvt Ltd, Mangalore, were used in the investigation. Tests Results for PMB-SBS-40 are shown in Table 3.3

Table 3.3 Tests Results for PMB-SBS-40 Binders

| Sl.no | Tests conducted | Test results | Requirements as per IRC-SP-53-2010 | Method of tests |
|---|---|---|---|---|
| 1 | Penetration Test at 25°C, 0.1mm and 100gms, 5 s | 54 | 30-50 | IS-1203 |
| 2 | Softening Point (°C), min | 70 | 60 | IS-1205 |
| 4 | Elastic Recovery Test (%) at 15°C | 77 | 60 | IS-1208 |
| 5 | Viscosity at $150^0$C, poise | 4.2 | 3-9 | IS-1206(Part-1) |
| 6 | Flash Point, COC (°C) | 290 | 220 | IS-1208 |
| 7 | Fire Point (°C) | 350 | - | IS-1209 |

From physical properties of PMB-SBS-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 PMB-SBS-40and 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.

3.3.5 **Warm Mix Asphalt Additives** WMA additives such as Sasobit, Evotherm and Zycotherm were procured from KPl international ltd, New Delhi,Ingevity India, and Zydex,Hyderabad, India respectively.

3.3.6 **Aggregate Gradation** Bituminous Concrete Mix Grade -2 Midpoint aggregate gradation for BC layer as per MoRT&TH 2010 was adopted and is shown in Table 3.4

Table 3.4 Aggregate gradation for BC mix Grade-2

| Sieve Size ,mm | 26.5 | 19.0 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.60 | 0.3 | 0.15 | 0.075 | pan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Desired gradation | 100 | 79-100 | 59-79 | 52-72 | 35-55 | 28-44 | 20-34 | 15-27 | 1-10 | 1-5 | 2-8 | |

To obtain the above aggregate gradation for bituminous concrete mix of grade-2, three types of aggregates and mineral filler viz A,B,C and D were blended by trial and error method by varying the percentages of A,B,C and D to obtain the desired gradation. The blend proportion obtained is shown below: Blend proportion = 0.23A+0.30B+0.16C+0.31D,

By using the above blend proportion gradation is shown in Table 3.5

Table 3.5 Details of Obtained Gradation gor BC-mix grade-2

| **SIEVE SIZE, mm** | **PERCENTAGE PASSING** | | | | **REQUIRED GRADATION** | |
|---|---|---|---|---|---|---|
| | Aggregate (A) (20 mm down) | Aggregates(B) (12.5 mm down) | Aggregate (C) (6 mm down) | Aggregate (D) (stone dust) | **Obtained Gradation** (0.23A+0.30B+0.16C+0.31D) | **Desired gradation** |
| 26.5 | 100 | 100 | 100 | 100 | 100.0 | 100 |
| 19 | 43.78 | 100 | 100 | 100 | 87.1 | 79-100 |
| 13.2 | 2.62 | 98 | 100 | 100 | 77.0 | 59-79 |
| 9.5 | 0.65 | 59.69 | 88.65 | 100 | 63.2 | 52-72 |
| 4.75 | 0.17 | 4.31 | 24.92 | 100 | 36.3 | 35-55 |
| 2.36 | 0.15 | 0.4 | 5.98 | 96.93 | 31.2 | 28-44 |
| 1.18 | 0.14 | 0.3 | 1.6 | 77.8 | 24.5 | 20-34 |
| 0.6 | 0.13 | 0.3 | 0.8 | 60.54 | 19.0 | 15-27 |
| 0.3 | 0.12 | 0.2 | 0.7 | 33.08 | 10.5 | 1-10 |
| 0.15 | 0.1 | 0.2 | 0.5 | 18.34 | 5.9 | 1-5 |
| 0.75 | 0.08 | 0.2 | 0.0 | 6.14 | 2.0 | 2-8 |
| Pan | | | | | | |

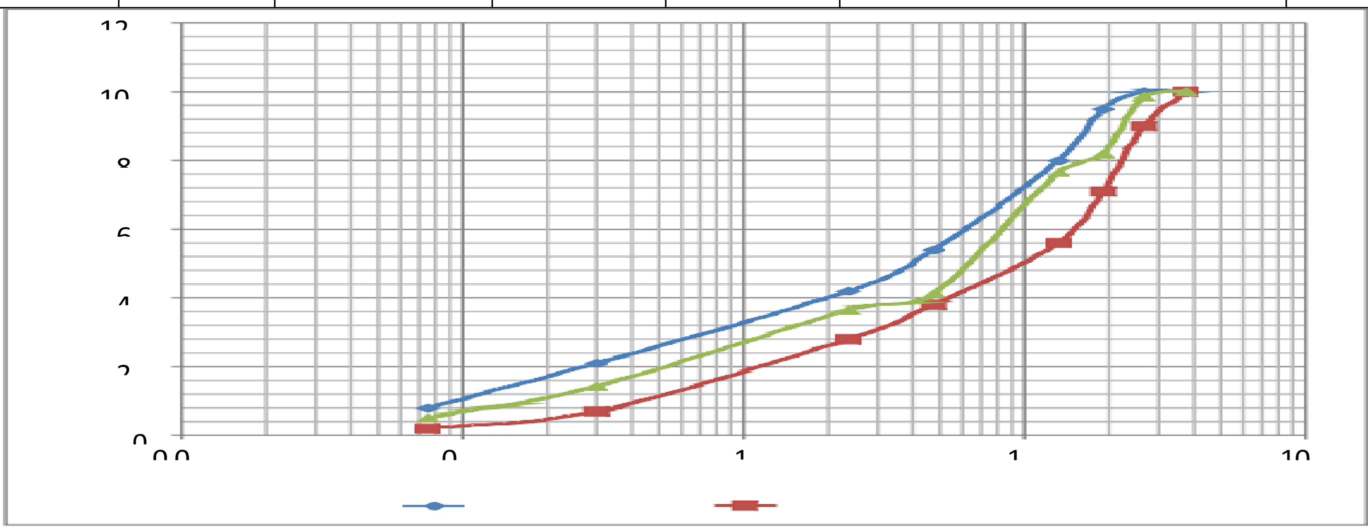

Figure 3.1 Gradation Curve obtained by mixing the aggregates as per blend proportion

### 3.4 Marshall Method of Mix Design

Marshall stability value is defined as the maximum load carried by a compacted specimen at a standard test temperature of $60^0$C. The deformation of the specimen is called flow value which occurs during the loading of the sample up to the maximum. The flow is measured as the deformation in units of 0.25 mm between no-load and maximum load carried by the specimen during the stability test. This test is applicable only for hot mix design using aggregates and bitumen with the máximum aggregate size being 25mm.The test procedure is used in designing and evaluating bituminous paving mixes. The test procedure is extensively used in the design a bituminous mix in the laboratory. Marshall specimens are to be prepared in accordance with ASTM D 6927 stability, flow, density, air voids ,VMA and VFB in the specimen are determined.

Once the gradation is fixed the specimens were prepared for BC grade -2 mix using VG-30 binder with and without WMA additives and PMB-SBS-40 with and without WMA additives binders. The standard procedure given in ASTM D 6927-06 was followed to prepare the mix for each specimens VG-30 neat, VG-30+3% Sasobit,VG-+0.75%Evotherm,and VG-30+0.3% Zycotherm and PMB-SBS-40 neat, PMB-SBS-40 +3% Sasobit , , PMB-SBS-40 +0.75% Evotherm,and , PMB-SBS-40 +0.3% Zycotherm.

The preparation of Marshall Specimens involves the following steps:

Aggregates were heated to 160°C for both the VG-30 and PMB-SBS-40 modified BC grade-2mixes. Both the VG-30 and PMB- SBS-40 modified BC grade-2 mixes begin with heated bitumen, which is heated to a pouring temperature of around 120°C before the aggregates are mixed in. To make VG-30 and PMB- SBS-40 modified BC-grade-2 mixes, the bitumen was heated to a temperature of around 120°C before adding the necessary amount of WMA Additives and mixing well. Mixed material was thereafter placed into Marshall moulds and subjected to 75 blows on each side of the specimen to get the required level of compactness. The above-mentioned BC-grade-2 mixtures were tested after 24 hours after removing the Marshall specimens from their moulds.

**Selection of dosages of WMA additives such 3% Sasobit,0.75% Evotherm and 0.3% Zycotherm**.

In order to find out optimum dosage of WMA additives like sasobit,evotherm and zycotherm marshall stability tests were conducted on various mixes with Vg-30 neat with and without WMA additives, from this investigation it is observed that VG-30+ 3% of Sasobit., BC mix shows the higher stability value of 14.48 kN which is 1.75 times more than Conventional VG-30 grade BC mix. Hence Optimum Sasobit Content was taken as 3%, with the weight of binder.at VG-30+0.75% of Evotherm., BC mix shows the higher stability value of 12.60 kN which is 0.87 times more than Conventional VG-30 grade BC mix. Hence Optimum Evotherm Content was taken as 0.75%, with the weight of binder, at VG-30+0.3% of Zycotherm , BC mix shows the highest stability value of 13.78 kN which is 1.74% times more than Conventional VG-30 grade BC mix. Hence Optimum Zycotherm Content was taken as 0.3% with the weight of binder for the present work.

Similarly Marshall stability tests were conducted on various mixes with PMB- SBS-40 neat with and without WMA additives for PMB- SBS-40+3% of Sasobit, BC mix shows the higher stability value of 14.95 kN which is 1.24% times more than SBS-PMB-neat grade BC mix. Hence Optimum Sasobit Content was taken as 3% with the weight of binder , for PMB-SBS-40+0.75% of Evotherm, BC mix shows the highest stability value of 14.95 kN which is 1.76% times more than PMB-SBS-40 neat grade BC mix. Hence Optimum evotherm Content was taken as 0.75% with the weight of binder for PMB-SBS-40+0.3% of Zycotherm, BC mix shows the highest stability value of 12.72 kN which is 1.74% times more than SBS-PMB-neat grade BC mix. Hence Optimum evotherm Content was taken as 0.3% with the weight of binder for the present work.

### 3.4.1 Determination of optimum binder content

The optimum binder content for the mix design by taking average value of the graphs obtained in the previous step.

1. Binder content corresponding to maximum stability.
2. Binder content corresponding to maximum bulk specific gravity (Gm) .
3. Binder content corresponding to the 4.5% for VG-30 and 3.5% for PMB-SBS-40 Air voids (Vv) in the total mix.
4. Binder content corresponding to the 3mm flow value for VG-30, PMB-SBS-40 in the total mix.

Marshall mix design was conducted to determine Marshall parameters of bituminous concrete of grade-2 prepared using VG-30 neat and PMB-SBS-40 binders mixes with and without WMA additives like Sasobit,,Evotherm and Zycotherm with optimum dosages and optimum bitumen content was obtained for VG-30, PMB-SBS-40 are shown in the Table 3.4 pectively for VG-30+3%Sasobit, VG-30+0.75%Evotherm , VG-30+0.3% Zycotherm , SBS-PMB-40+3%Sasobit, PMB-SBS -40+0.75% Evotherm and PMB-SBS -40+0.3% zycotherm. are shown in 3.5 and 3.6 respectively. Graphical representation of Marshall parameters for VG-30 with and withput WMA additives are also shown in figures 3.1 also for PMB- SBS-40 with and without WMA additives are shown in figure 3.2 respectively.

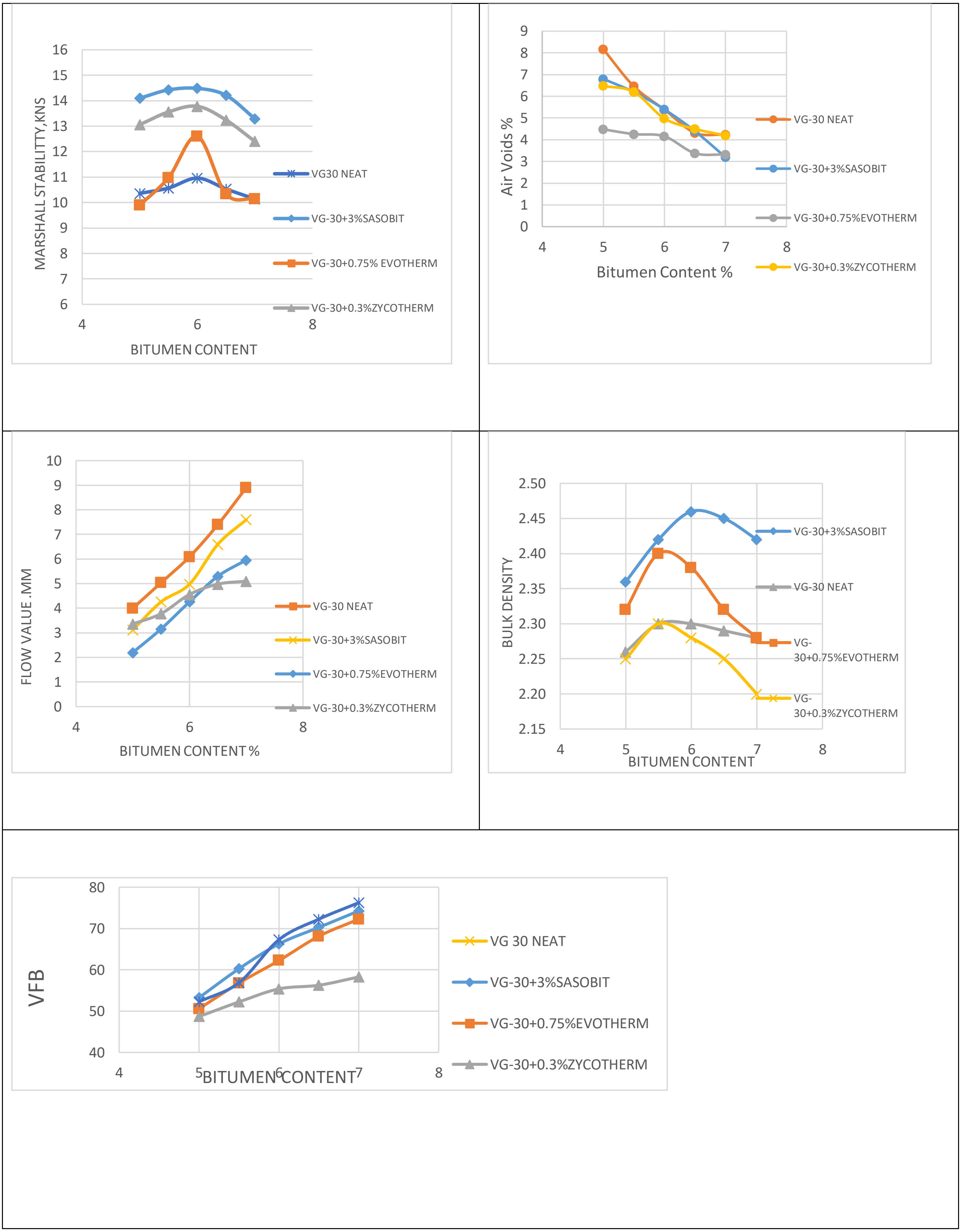


Fig 3.2 Variation of Marshall stability, flow value, air voids, bulk density, with Binder content for VG-30 neat with percentages of WMA additive

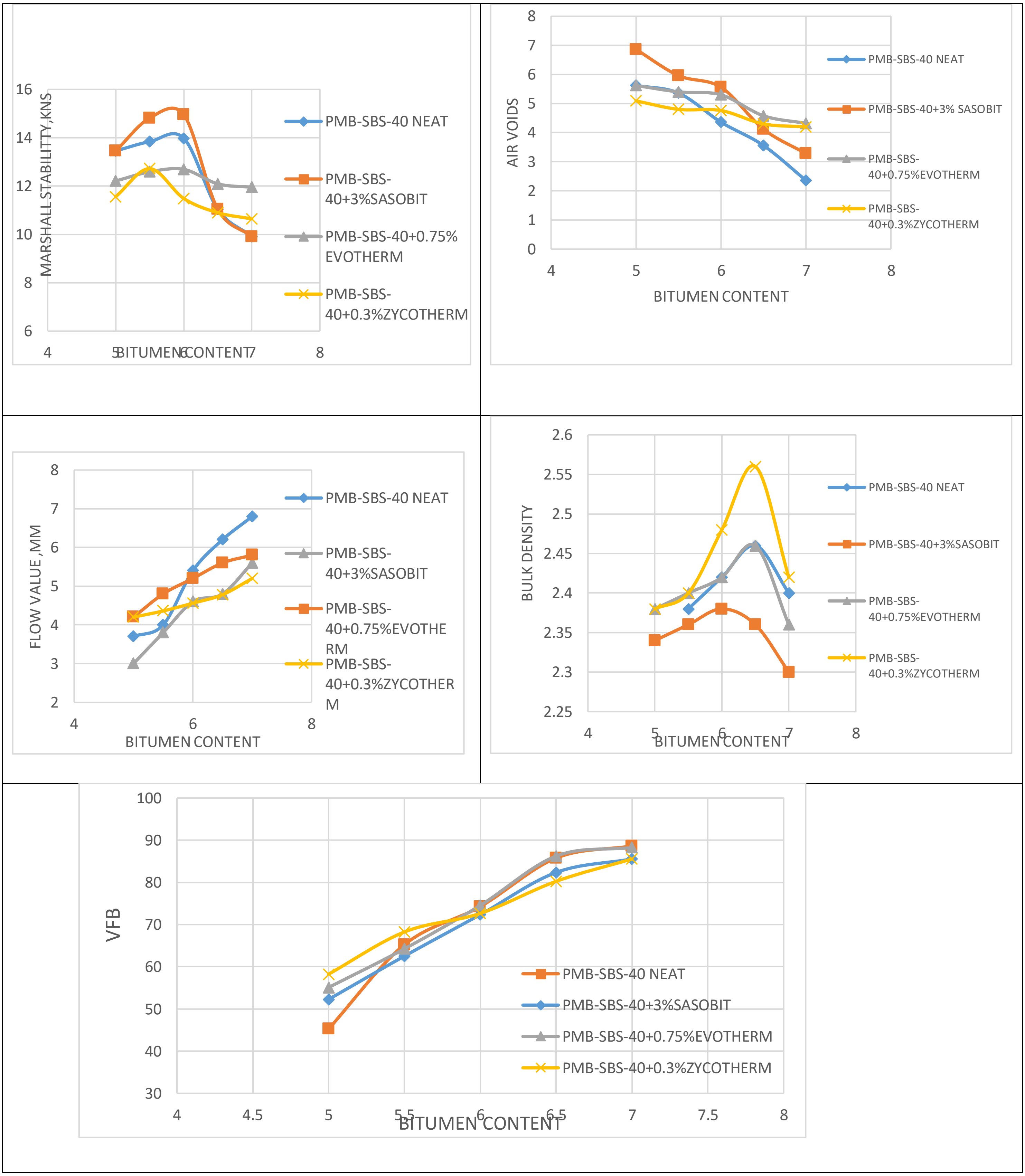


Fig 3.3 Variation of Marshall stability, flow value, air voids, bulk density, with Binder content for PMB-SBS-40 with percentages of WMA additive ,

Table 3.4. Determination of Optimum Binder Content for VG-30 neat with and without WMA additives

| From The Graphs 3.2 for VG-30 with and without WMA additives | | | | |
|---|---|---|---|---|
| Marshall properties | Type of Mix | | | |
| | VG-30 neat | VG-30 +3%Sasobit | VG-30 +0.75%Evotherm | VG-30 +0.3%Zycotherm |
| Max Marshall Stability , Kns (Min 8.86Kns0 | 5.80 | 6.9 | 6.2 | 6.4 |
| Air Voids, % (3-6) | 6.20 | 5.4 | 5.8 | 5.8 |
| Flow Value mm (2-4) | 5.00 | 4.4 | 4.8 | 4.2 |
| Mas Bulk Density | 5.80 | 6.58 | 6.1 | 6.8 |
| VFB (65-75) | 6.10 | 6.40 | 6.10 | 6.6 |
| Optimum Bitumen Content, % | **5.70** | **5.82** | **5.73** | **5.80** |

Table 3.5 Determination of Optimum Binder Content for PMB- SBS-40 with and without WMA additives.

| From The Graphs 3.3 PMB- SBS-40 with and without WMA additives | | | | |
|---|---|---|---|---|
| Marshall properties | Type of Mix | | | |
| | PMB- SBS-40neat | PMB- SBS-40+3%Sasobit | PMB- SBS-40+0.75%Evothermt | PMB- SBS-40+0.3%Zycotherm |
| Max Marshall Stability , Kns (min 12.00) | 6.1 | 6 | 5.8 | 6.80 |
| Air Voids, % (3.-5) | 5.6 | 6.8 | 5.8 | 5.20 |
| Flow Value mm (3-5) | 3.8 | 3.8 | 4.6 | 3.80 |
| Max Bulk Density | 6.8 | 6 | 6.5 | 6.80 |
| VFB (65-75) | 6.10 | 6.40 | 6.10 | 6.6 |
| Optimum Bitumen Content,% | **5.58** | **5.65** | **5.68** | **5.65** |

*Values in bracket indicates requirements as per IRC: SP:53 for PMB-SBS-40 and MoRTH Specifications for VG-30 BC mix.

Table 3.6 Marshall properties at Optimum Binder Content for BC Grade-02 mix with WMA additives,

| Type of Mix | Optimum binder content | Marshall Stability, kN | Flow,mm | Unit Weight, gm/cc | %, Air Voids | VMA,% | VFB,% |
|---|---|---|---|---|---|---|---|
| VG-30 +3% Sasobit | 5.82 | 12.28 ( Min 8.86 Kns) | 3.26 (2 to 4) | 2.36 (Max) | 4.4 (3--6) | 17.40 | 60.26 (65 -75) |
| VG-30 +%0.75% Evotherm | 5.73 | 12.60 ( Min 8.86 Kns) | 3.16 (2 to 4) | 2.38 (Max) | 4.16 (3-5) | 16.40 | 55.38 (65 -75) |
| VG-30 +0.3% Zycotherm | 5.80 | 12.78 ( Min 8.86 Kns) | 3.26 (2 to 4) | 2.45 (Max) | 4.68 (3-5) | 18.42 | 66.10 (65 -75 |

Table 3.7 Marshall properties at Optimum Binder Content for BC Grade-02,mix with WMA additives

| Type of Mix | Optimum binder content | Marshal Stability, kN | Flow,mm | Unit Weight, gm/cc | %, Air Voids | VMA,% | VFB,% |
|---|---|---|---|---|---|---|---|
| PMB-SBS-40 +3% Sasobit | 5.82 | 14.96 ( Min 12.00 Kns) | 3.10 (2.5 to 4) | 2.50 (Max) | 3.98 (3-5) | 18.40 | 56.66 (65 -75) |
| PMB-SBS-40 +%0.75% Evotherm | 5.73 | 14.68 ( Min 8.86 Kns) | 3.28 (2.5 to 4) | 2.42 (Max) | 4.28 (3-5) | 18.68 | 54.26 (65 -75) |
| PMB-SBS-40 +0.3% zycotherm | 5.80 | 14.50 ( Min 8.86 Kns) | 3.16 (2.5 to 4) | 2.48 (Max) | 4.10 (3-5) | 18.76 | 70.60 (65 -75 |

From analysis of bituminous concrete grade (2) with VG-30 binder the observed OBC is 5.70 %, without the WMA additives and OBC obtained for VG-30+3%sasobit is 5.82%, VG-30+0.75% Evotherm is 5.75 and VG-30+0.3% Zycotherm is 5.80% ,similarly OBC for PMB-SBS-40 obtained is 5.58 % , PMB-SBS-40 +3% sasobit is 5.65%, PMB-SBS-40 +0.75% Evotherm is 5.68 and PMB-SBS-40 +0.3% zycotherm .the same binder content will be considered to analyses the effect of WMA additive like Sasobit, Evotherm and Zycotherm over the mixing and compaction temperature of bituminous mix, for normal mixes usually 140 to 130 $^{0}$c temperature will be adopted. Mixing and compaction temperatures were determined using various methods for VG-30 neat, VG-30+3% Sasobit, VG-30+ 0.75% Evotherm,and VG-30+0.3% Zycotherm and found to be 140,110,120 and 120 $^{o}$C Compacting temperatures as 10$^{0}$C less than the corresponding mixing temperature. Similarly mixing temperatures for PMB-SBS-40neat, PMB-SBS-40+3% Sasobit, PMB-SBS-40+ 0.75% Evotherm, and PMB-SBS-40+0.3% Zycotherm and found to be 170,130,150 and 130$^{o}$C, Compacting temperatures as 10$^{0}$C less than the corresponding mixing temperature and the same respective temperatures were adopted for preparation of Marshall preparation of Marshall specimens. Summary of Marshall Properties of VG-30 without WMA additives at OBC 5.70%.are shown in Table 3.4. and PMB-SBS-40 without WMA additives at OPC 5.58% are shown in Table 3.5. Summary of Marshall Properties of VG-30 with WMA additives at OBC 5.70%.are shown in Table 3.6. and PMB-SBS-40 with WMA additives at OPC 5.58% are shown in Table 3.7

After determination of Optimum binder content for VG-30 and PMB-SBS-40 with and without WMA additives again moulds were casted for the achieved optimum binder content and the results of Marshall parameters are as shown in following Table 3.8 and 3.9

Table 3.8 Marshall properties at obtained Optimum Binder Content for BC Grade-02 Mixes of VG-30 neat with and without WMA additives

| Type of Mix | Optimum binder content | Marshall Stability, in kN | Flow,mm | Unit Weight, gm/cc | %, Air Voids | VMA,% | VFB,% |
|---|---|---|---|---|---|---|---|
| VG-30 | 5.70 | 10.16 ( Min 8.86 Kns) | 3.40 (2 to 4) | 2.32 (Max) | 3.8 (3-5) | 17.25 | 60.48 (65 -75) |
| VG-30 +3% Sasobit | 5.82 | 12.30 ( Min 8.86 Kns) | 3.26 (2 to 4) | 2.36 (Max) | 4.4 (3-5) | 17.40 | 60.26 (65 -75) |
| VG-30 +%0.75% Evotherm | 5.73 | 12.70 ( Min 8.86 Kns) | 3.10 (2 to 4) | 2.38 (Max) | 4.16 (3-5) | 16.40 | 55.38 (65 -75) |
| VG-30 +0.3% zycotherm | 5.80 | 12.78( Min 8.86 Kns) | 3.20 (2 to 4) | 2.45(Max) | 4.68 (3-5) | 16.42 | 66.10 (65 -75 |

Table 3.9 Marshall properties at obtained Optimum Binder Content for BC Grade-02 Mixes of PMB-SBS-40 neat with and without WMA additives

| Type of Mix | Optimum binder content | Marshall Stability, in kN | Flow,mm | Unit Weight , gm/cc | %, Air Voids | VMA, % | VFB,% |
|---|---|---|---|---|---|---|---|
| PMB-SBS-40 | 5.58 | 13.98 ( Min 12.00 Kns) | 3.28 (2.5 - 4) | 2.48 (Max) | 4.2 (3-5) | 18.25 | 68.80 (65 -75) |
| PMB-SBS-40+3% Sasobit | 5.62 | 14.96 ( Min 12.00 Kns) | 3.10 (2.5 -4) | 2.50 (Max) | 3.98 (3-5) | 18.40 | 56.66 (65 -75) |
| PMB-SBS-40+%0.75% Evotherm | 5.64 | 12.70 ( Min 12.00 Kns) | 3.26 (2.5 - 4) | 2.42 (Max) | 4.20 (3-5) | 18.40 | 54.26 (65 -75) |
| PMB-SBS-40+0.3% zycotherm | 5.68 | 12.78 ( Min 12.00 Kns) | 3.16 (2 - 4) | 2.45 (Max) | 4.10 (3-5) | 18.42 | 66.16 (65 -75 |

All the Marshall Parameters results fulfills the requirement of MoRTH-2010 for VG-30 with and without WMA additives and IRC-SP-53for PMB-SBS-40 with and without WMA additives bituminous concrete grade-2 layer with achieved optimum binder content.

## 4.0 Moisture Sensibility Test

### 4.1 Tensile strength ratio test

Resistance to moisture damage for VG-30 with and without WMA additives and PMB-SBS-40 with and without WMA additives of bituminous concrete grade (2) mixes were determined by adopting AASHTO: T-283. Under this method, one set of Marshall Specimens with 6 to 8% average air voids were immersed (conditioned) in a water bath at 60 $^{0}$ for a period of 24 hours. The samples were then removed from the water bath and kept at a temperature of 25$^{0}$ C for a period of 2 hrs. Other set of samples (unconditioned) were kept at a temperature of 24$^{0}$ C hours for a period of 2 hours. These specimens were placed in the indirect tensile strength assembly by loading along the axes of specimens, with two faces being restrained from the movement the entire assembly was then mounted on the conventional Marshall testing apparatus and the load at failure was recorded, the Tensile strength ratio which is a measure of water sensitivity, is calculated by using the equation 4.1

$$TSR = Average\ tensile\ strength\ of\ conditioned\ sampl/Average\ tensile\ strength\ of unconditioned\ sample * 100$$ ….Eqn (4.1

The results of tensile strength ratio (TSR) with respect to VG-30 with and without WMA additives and PMB-SBS-40 with and without WMA additives BC grade-2 mixes, are presented in fig 4.1and 4.2 respectively. It was observed that with addition of WMA additive such as Sasobit, Evotherm and Zycotherm, resistance to moisture induced damage was increased as compared to the conventional VG-30 neat and PMB-SBS-40 mixture. This may due to the lesser amount of air voids in BC mixture than unmodified mixture, when prepared with WMA additives.

## .4.2 Static indirect tensile test

The Static Indirect Tensile Strength Test was carried out a per ASTM: D-4123-82 (1995) to study the behaviour of paving mixes at different temperatures. The split tensile strength of bituminous mixes was determined by applying a compressive load to Marshall specimens along the vertical diametrical plane, through pre-curved steel strips 12.5 mm wide with the same inside curvature as that of Marshall specimen. A nearly uniform tensile stress is developed normal to the direction of applied load and along the same vertical plane causing the specimen to fail by splitting along the vertical diameter (fig 4.1.1). the ultimate load was obtained to calculate maximum indirect tensile strength. Specimens at each test condition were made in triplicate, and the test parameters reported as the numerical average of the test data. Indirect tensile strength of specimen is calculated by using the equation (4.2) as per the ASTM:D-4123-82-1995.

$$Indirect\ Tensile\ Strength\ T = 2P/\pi dt \text{................ Eqn(4.2)}$$

Where, P=Load at failure in N: d=diameter of the specimen in mm: and t=thickness of the specimen in mm

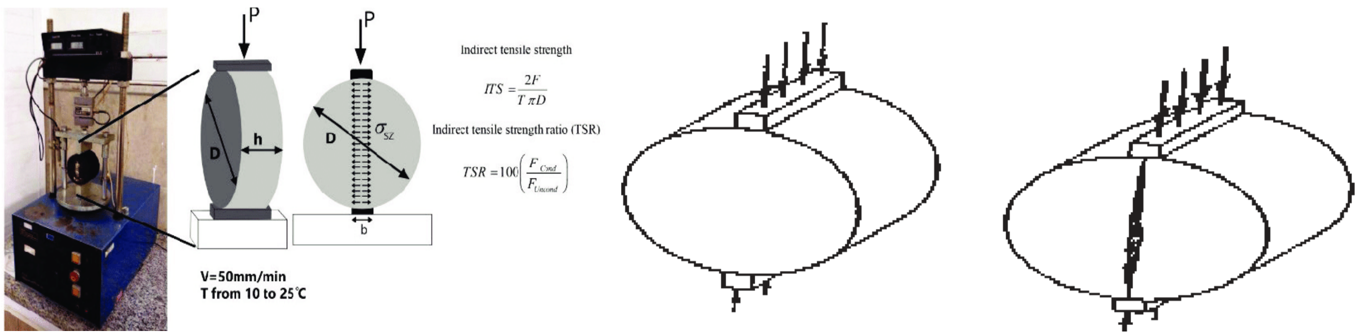


**Fig 4.1.1 Load Configuration and Failure of Specimen in Indirect Tensile Test**.

**4.2.1 Test Procedure**.

This test was conducted by utilizing the loading frame of Marshall test apparatus. A piston of 51mm diameter and 102mm long was attached to the proving ring to provide a compressive load on the vertical diametrical plane of the specimen. The test was conducted at a deformation rate of 51mm/min as in the case of Marshall test. The test assembly was used to hold the specimen properly. The test assembly consist of a horizontal base plate made up of mild steel on which a loading strip was attached in the center so that the concave surface of strip remains at top. Two vertical guide rods consist of a loading strip at the bottom face so that the sample can be loaded diametrically through the two curved surfaces of the strip. The size of the loading strip is 75mmx10mmx12.7mm and diameter of the curvature is 100.2mm, which is same as that of Marshall sample (ASTM D 4123-1995)

Marshall specimens for VG-30 neat with and without WMA additives used in this test were prepared at optimum binder content so as to achieve the required unit weight as obtained by Marshall mix design. The specimens were conditioned at required temperature by placing in temperature-controlled water bath for 2 hours before testing. Conditioned specimens were placed in the indirect tensile test assembly. The loading strips and the specimens were positioned carefully so that the axes of the strips, specimen, and piston were in the same vertical plane. The piston was brought over the test assembly. Test assembly was moved upwards at required deformation rate against the piston to apply the compressive load on the vertical diametrical plane. The failure load was noted from digital gauge. The indirect tensile strength of the specimen was calculated by using equation 4.1. specimens at each test condition were made in triplicate, and the test parameters reported as the numerical average of the test data.

**4.2.2 Test results**

Static indirect tensile strength tests were conducted at different temperatures for PMB-SBS-40 and VG-30 Neat bituminous mixes compacted using Marshall compaction methods. The results are shown in Table 4.2 and variation of static indirect tensile strength with temperature for VG-30 and PMB-SBS-40 ,with and without WMA additives for BC grade-2 mixes are shown in Fig 4.1.

Table 4.2.1 Static Indirect Tensile Strength Test at different temperatures for VG-30 Neat Grade-2 Bituminous mixes.

| Types of Mixes | Indirect tensile strength, Mpa at different temperatures, ℃ | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 25 | 30 | 40 |
| VG-30 Neat | 1.68 | 0.96 | 0.95 | 0.81 | 0.38 | 0.28 |
| PMB-SBS-40Neat | 3.58 | 2.52 | 1.90 | 1.48 | 1.2 | 0.68 |

Static indirect tensile strength tests were conducted at different temperatures for VG-30 and PMB-SBS-40 prepared with WMA additives bituminous mixes compacted using Marshall compaction methods. The results are shown in Table 4.2 and 4.3

Table 4.2.2 Static Indirect Tensile Strength Test at different temperatures for VG-30 with WMA additives of Grade-2 Bituminous mixes

| Types of Mixes | Indirect tensile strength, Mpa at different temperatures, ℃ | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 25 | 30 | 40 |
| VG-30 Neat +3%Sasobit | 1.96 | 1.56 | 1.4 | 1.12 | 0.5 | 0.34 |
| VG-30 Neat +0.75% Evotherm | 1.82 | 1.46 | 1.32 | 1.07 | 0.46 | 0.31 |
| VG-30 Neat +0.3% Zycotherm | 1.92 | 1.36 | 1.30 | 1.01 | 0.43 | 0.3 |

Table 4.2.3 Static Indirect Tensile Strength Test at different temperatures for PMB-SBS-40 with WMA additives of Grade-2 Bituminous mixes

| Types of Mixes | Indirect tensile strength ,Mpa at different temperatures ℃ | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 25 | 30 | 40 |
| PMB-SBS -40+3%Sasobit | 4.26 | 2.68 | 1.96 | 1.62 | 1.36 | 0.8 |
| PMB-SBS -40+0.75% Evotherm | 4.12 | 2.60 | 1.88 | 1.58 | 1.3 | 0.74 |
| PMB-SBS -40+0.3% Zycotherm | 4.20 | 2.54 | 1.80 | 1.44 | 1.24 | 0.71 |

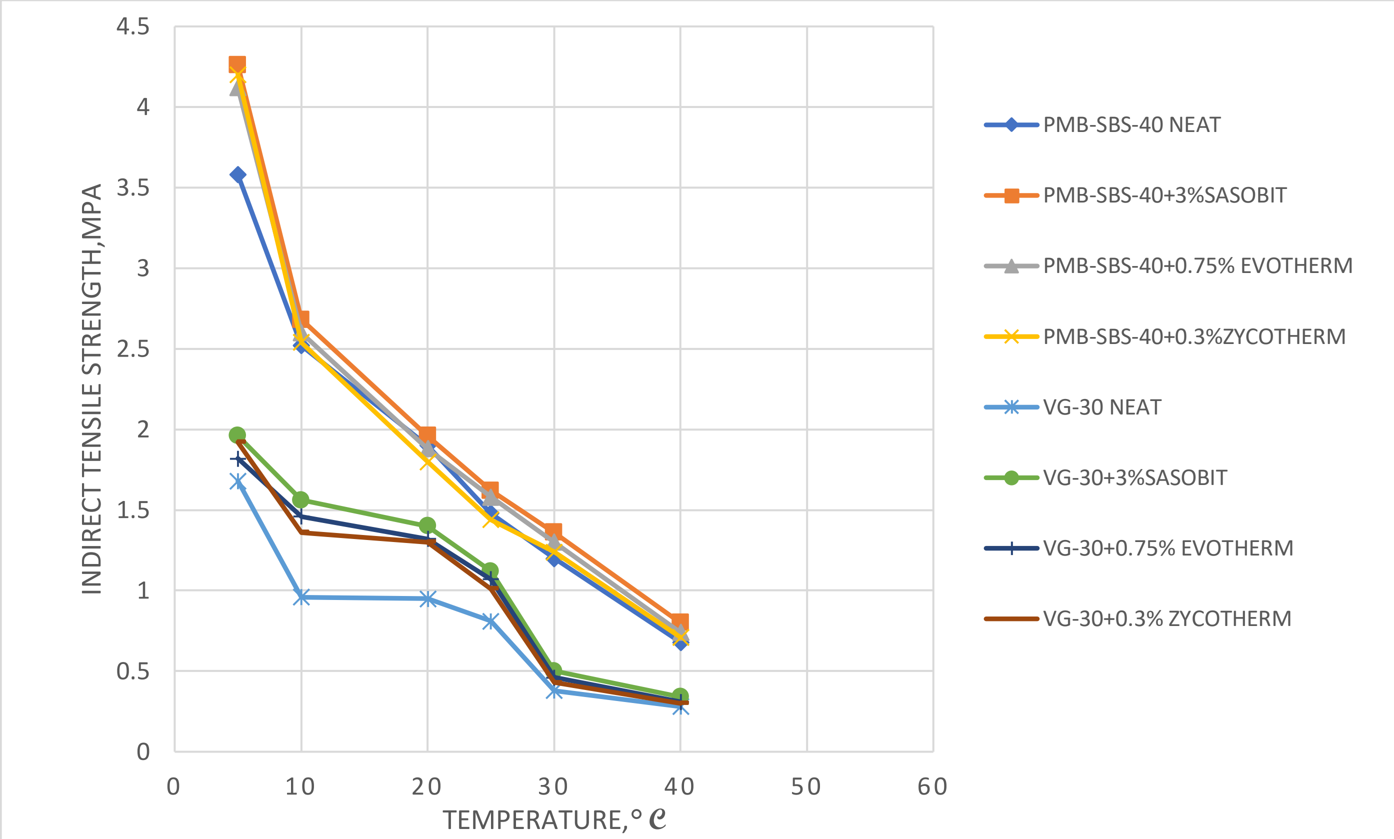


Figure 4.4 Variation of indirect tensile strength with temperature for VG-30 and PMB-SBS-40 with and without WMA additives

## 5.0 Results and discussions

- The optimum bitumen content obtained for bituminous concrete grade-2 mixes using VG-30 neat is 5.70 percent and for PMB-SBS-40 neat at 5.58%.
- The optimum bitumen content values for bituminous concrete grade-2 mixes obtained by using VG-30 +3% \Sasobit, VG-30+0.75 Evotherm and VG-30+0.3% Zycotherm obtained are 5.82%,5.73% and 5.80% respectively
- The optimum bitumen content values for bituminous concrete grade-2 mixes using PMB-SBS-40 +3% sasobit, PMB-SBS-40 +0.75 Evotherm and PMB-SBS-40 +0.3% Zycotherm obtained are 5.65%,5.68% and 5.65% respectively
- According to the Marshall mix design, the maximum stability values for PMB-SBS-40 are 12.55 Kns (min 12.) and for VG-30 neat mix, they are 10.76 kns Kgs (min 9.00). The percentage of air voids in the PMB-SBS-40mix is 4.20% (3-5), while for VG-30 neat mix it is 4.64% (3-6).
- The measured flow values for PMB-SBS-40neat and VG-30 are 3.28 mm (3-5 mm) and 3.18 mm (min 2-4 mm), respectively.
- The Marshall stability values for the VG-30 with and without WMA specimens of BC Grade 2 vary with the variation in temperature as well as the additive dosage rate. The stability value for the VG-30 mixes at 140°C mixing temperature was 10.76 kN. and the stability VG-30+3% Sasobit ,0.75%Evotherm and 0.3% Zycotherm are 12.60,12.60 and 12.78 respectively. due to the addition of ZycoTherm at a dosage rates and reduced mixing temperature of 10,20 and 20°C respectively, the flow values were 4.37,3.26 ,3.16 and 3.26, the percentage air voids were 4.4,4.16, and 4.68 for the respective WMA additives. This show the stability, density, flow value and

percentage air values of the mix was improved at decreased mixing and compaction temperatures withthe addition of the wma additives and are within the MoRTH specifications.

- The Marshall stability values for the PMB-SBS-40 with and without WMA specimens of BC Grade 2 vary with the variation in temperature as well as the additive dosage rate. The stability value for the PMB-SBS-40mix at 170°C mixing temperature was 12.55 kN. and the stability SBS-PMB-40+3% Sasobit ,0.75%Evotherm and 0.3% Zycotherm are 14.96,14.68 and 14.50 respectively. due to the addition of WMA additives at a dosage rate and reduced mixing temperature of 10,20 and 20°C respectively, the flow values were 3.26,3.10,3.28 and 3.10 mm, the percentage air voids were 4.26,3.98,4.28 and 4.10 for the respective WMA additives. This show the stability, density, flow value and percentage air values of the mix was improved at decreased mixing and compaction temperatures with the addition of the wma additives and are within the IRC-SP-53 specifications.
- From Static indirect tensile testing outcomes, it is observed that at test temperatures of 10,20,25,30 and 40$^0$C

  VG-30 with WMA additives such as Sasobit, have shown higher tensile strength in the order of 10.25%, 28.20%, 67.94% and 77.56 for VG-30+3% sasobit, when compared to VG-30 neat 1.04%,15.6%,60.41 and 70.83% from this it is evident that VG-30 with WMA additives perform better than VG 30 neat
- From Static indirect tensile test results, it is observed that at test temperatures of 10,20,25,30 and 40$^0$C SBS-PMB-40 with WMA additives such as Sasobit, have shown higher tensile strength in the order of 26.86%, 39.56%, 67.94%and 70.56 for PMB-SBS-40+3% sasobit, respectively when compared to PMB-SBS-40neat and from this it is evident that PMB-SBS-40with WMA additives perform better than SBS-PMB-40.

## Discussions

- To find the Marshall Properties and Indirect Tensile strength of Paving Application, in this study adopted bituminous concrete mix of Grade-2 mid limit aggregates gradation for bituminous concrete mix according to MoRTH.
- To create bituminous blends, we used the afore mentioned gradation with VG30 neat and PMB-SBS-40 binders with andwithout WMA additions. This study used the Marshall Method to prepare the specimens.
- The Flow Value of the mixes decreased as the percentage of VG-30+3% Sasobit increased. This is because the Sasobit added made the BC mix Stiffer. Also, the obtained flow values follow the MoRT&H specifications.
- The Optimum Bitumen Content for VG-30 Neat mix obtained is 5.70 % and it is increased to 5.80%, 6.60% ,5.82 and 6.11 % for Bituminous concrete mix with 1%, 2% ,3%and 4% Sasobit Content. This increase in OBC is due to the surface area of Sasobit.
- At VG-30+ 3% of Sasobit., BC mix shows the highest stability value of 14.48 kN which is 1.75 times more than Conventional VG-30 grade BC mix. Hence Optimum Sasobit Content was taken as 3% for the present work.
- At VG-30+0.75% of Evotherm., BC mix shows the highest stability value of 12.60 kN which is 0.87 times more than Conventional VG-30 grade BC mix. Hence Optimum Evotherm Content was taken as 0.75% for the present work.
- At VG-30+0.3% of Zycotherm , BC mix shows the highest stability value of 13.78 kN which is 1.74% times more than Conventional VG-30 grade BC mix. Hence Optimum Zycotherm Content was taken as 0.3% for the present work.
- At PMB- SBS-40+3% of Sasobit, BC mix shows the highest stability value of 14.95 kN which is 1.24% times more than SBS-PMB-neat grade BC mix. Hence Optimum Sasobit Content was taken as 3% for the present work.

- At PMB- SBS-40+0.75% of Evotherm, BC mix shows the highest stability value of 14.95 kN which is 1.76% times more than SBS-PMB-neat grade BC mix. Hence Optimum evotherm Content was taken as 0.75% for the present work
- At PMB- SBS-40+0.3% of Zycotherm, BC mix shows the highest stability value of 12.72 kN which is 1.74% times more than SBS-PMB-neat grade BC mix. Hence Optimum evotherm Content was taken as 0.3% for the present work
- From Static indirect tensile testing outcomes, it is observed that at various test temperatures VG-30 with WMA additives such as Sasobit, have shown higher tensile strength for VG-30+3% Sas obit, when compared to

  VG- 30, from this it is evident that VG-30 with WMA additives perform better than VG 30 neat.
- From Static indirect tensile testing outcomes, it is observed that at various test temperatures PMB-SBS-40 with WMA additives such as Sasobit, have shown higher tensile strength for PMB-SBS-40+3% sasobit, when compared to PMB-SBS-40 neat, from this it is evident that PMB-SBS-40 with WMA additives perform better than SBS-PMB-40.
- PMB-SBS-40 neat and with Sasobit mixes prepared by considering the BC-Grade-02 gradation at various temperatures shows higher indirect tensile strength when compared to same mixes considered for VG-30 with and without WMA additives.

**Conclusions.**

**The following conclusions are drawn from the results of various tests conducted under static load on paving mixes with PMB-SBS-40 and VG-30 BC grade-2 with and without WMA additives mixes.**

- All the Marshall Parameters, viz., Stability, Flow Value, Air Voids, Density, Voids in Mineral Aggregates and Voids Filled with Bitumen in bituminous concrete mix with and without WMA Mix satisfied the MoRT&H requirements. .
- The maximum stability values are 17% higher for PMB-SBS-40 mixes when compared to VG-30 mixes.
- Higher unit weights are achieved for PMB-SBS-40 mixes when compared to VG-30 mixes.
- The optimum binder content is reduced for PMB-SBS-40 mixes when compared to VG-30 mixes
- In PMB-SBS-40 mixes air Voids are Low when compared to VG-30 mixes,
- The maximum stability values are higher for PMB-SBS-40 mixes when compared to VG-30 mixes.
- The maximum stability values are higher for PMB-SBS-40 with WMA additives i.e Saobit, Evotherm and Zycotherm in the mixes when compared to VG-30 with WMA additives,
- The optimum binder content is reduced for PMB-SBS-40 with WMA additives i.e Saobit, Evotherm and Zycotherm mixes when compared to VG-30 mixes with WMA additives.
- From Static indirect tensile test results, it is observed that at test temperatures of 10,20,25,30 and 40$^0$C VG-30 with WMA additives such as Sasobit, have shown higher tensile strength for VG-30+3% sasobit, respectively when compared to VG-30 neat and from this it is evident that VG-30 with WMA additives perform better than VG-30 neat mixes.
- From Static indirect tensile test results, it is observed that at test temperatures of 10,20,25,30 and 40$^0$C

  SBS-PMB-40 with WMA additives such as Sasobit, have shown higher tensile strength for PMB-SBS-40+3%

sasobit, respectively when compared to PMB-SBS-40 neat and from this it is evident that PMB-SBS-40with WMA additives perform better than SBS-PMB-40 Mixes.

- From Static indirect tensile test results, it is observed that at test temperatures of 10,20,25,30 and $40^0$C PMB-SBS-40with WMA additives such as Sasobit, Evotherm and Zycotherm have shown higher tensile strength for PMB-SBS-40with WMA additives, respectively when compared to VG-30 neat with WMA additives and from this it is evident that PMB-SBS-40with WMA additives perform better than VG-30 with WMA at Mixes.
- At test temperatures of 10,20,25,30 and $40^0$C, the indirect tensile strength values for PMB-SBS-40 with and without WMA additives specimens prepared using BC grade -2 Mix are found to be higher when compared to VG-30 with and without WMA additive mixes. From this it can be seen that PMB-SBS-40 with and without WMA additives improved the performance of the mixes when compared to VG-30 with and without WMA additives mixes.

## References


[1] Awanti, S. S., Amarnath, M. S., and Veeraragavan, 2008.A.. "Laboratory evaluation of SBS modified bituminous paving mix." J. Mater. Civ. Eng., 20(4), 327

[2] l-Qadi, I. L., Aurangzeb, Q., Carpenter, S. H., Pine, P. J. and Trepanier, J. 2012 "Impact of high RAP contents on structural and performance properties of asphalt mixtures (Report Number FHWA-ICT-12-002)", Springfield: Illinois Center for Transportation, , Illinois, US.

[3] Behl Ambika, Bose Sunil, Sharma Girish, Kumar Gajendra, and Uma Devi "Warm mix asphalt –2011 The wave of future" published in Journal of The Indian Road Congress, Vol. 72-2, page no. 101-107.

[4] Durability and performance characteristics of warm mix asphalt Journal for Indian Road congress Vol77-1 2016

[5] Dubravský m., mandula j. (2013). Technology of warm mix asphalt based on foaming processes. In: SGEM 2013: 13th International Multidisciplinary Scientific Geoconference : Ecology, Economics, Education and Legislation : conference proceedings : Volume 1, Albena, Bulgaria. - Sofia: STEF92 Technology Ltd., 2013 P. 913- 919.

[6] Ali Topala , Baha Vural Kökb .2018," Iinvestigation of the Properties of Warm Mix Asphalt Involving Organic Additive'

[7] Turkish Journal of Science & Technology Volume 13(1), 45-53, 2018

[8] Huang, B., Zhang, Z., Kingery, W., Zuo, G. (2004) "Fatigue crack characteristics of HMA mixtures containing RAP" in: Proceeding 5th Int. Conf. on Cracking in Pavements, RILEM. pp. 631–638.

[9] Supriya Mahida and Chandravadan B. Mishra (2017) " Evaluating the Efficacy of Warm Mix Asphalt "International Conference on Research and Innovations in Science, Engineering &Technology. Selected papers in Civil Engineering

[10] Kheradmand et al. (2014) Kheradmand, B., Muniandy, R., Hua, L. T., Yunus, R. B., Solouki, A., 2014. An overview of the emerging warm mix asphalt technology. International Journal of Pavement Engineering, 15(1), 79-94.MoRTH 2001 (Ministryof Road Transport and Highways) , "Specifications for road and bridge works, 4th revision, Indian Roads Congress, New Delhi.

[11] Khedmati, M., Khodaii, A., & Haghshenas, H. F. (2017). A study on moisture susceptibility of stone matrix warm mix asphalt.

[12] Construction and Building Materials. https://doi.org/10.1016/j.conbuildmat.2017.03.121

[13] Manjunath K.R, Dheeraj Kumar N, Thippeswamy G.S, "Performance and Evaluation on Marshall Stability Properties of Warm Mix Asphalt Using Evotherm and Cecabase Rt®-A Chemical Additive", International Journal of Engineering Trends and Technology (IJETT) – Volume 12 Number 8 - Jun 2014.

[14] Prowell, B.D., G.C. Hurley, and E.Crews, "Field Performance of Warm-Mix Asphalt at National Center for Asphalt Technology Test Track" Transportation Research Record: Journal of the Transportation Research Board No. 1998, Washington, D.C.,2007, pp. 96-102.

[15] Prithvi Singh Kandhal, V. K. Sinha & A. Veeraragavan, "A Critical Review of Bituminous Paving Mixes Used in India", Indian Highway Journal. Evaluating the Efficacy of Warm Mix Asphalt Supriya Mahida and Chandravadan B. Mishra 183

[16] Prithvi Singh Kandhal, "Warm Mix Asphalt Technologies: An Overview", Journal of the Indian Roads Congress, JulySeptember 2010.

[17] Renugadevi. A, "Evaluation of Marshall Properties of Warm Mix Asphalt using Sasobit", International Journal of Engineering Sciences & Research Technology.

[18] Revansiddappa M, Dr.Kiran Kumar, Manjunath. S, Arvind C, Suraj Pokalwar, "Laboratory Evaluation of HMA and WMA inBC Layer", IJSRD - International Journal for Scientific Research & Development| Vol. 2, Issue 10, 2014 | ISSN (online): 2321-0613.

[19] Roberts, F. L., Kandhal, P. S., Brown, E. R., Lee, D., and Knnedy, T., (1996), "Hot Mix Asphalt Materials, Mixtures, Design,and Construction" NAPA Education Foundation, Lanham, Maryland. Second Edition, pp. 241-250.

[20] Rubio MC, Martinez G, Baena L, Moreno F, "Warm mix asphalt: an overview", Journal of Cleaner Production, 2012, 24:76- 84.

[21] Tayfur, S., Ozen, H. and Aksoy, A. ( 2007) "Investigation of rutting performance of asphalt mixtures containing polymer modifiers", Construction and Building Materials, Vol. 21, pp. 328–337.

[22] Charoentham N and Macharoen P 2017 A Study of moisture damage in warm mix asphalt concrete with reclaimedasphalt pavement Journal of the Eastern Asia Society for Transportation Studies 12 1458-1476

[23] Xiao, F., Amirkhanian, S., and Juang C.H. J. Mater. Civ. Eng., 19(6), 475 (2007). [7] Model Material and ConstructionGuidelines, SMA Technical Working Group, (TWG)

[24] Ziaee, S. A., Kavussi, A., Jalili Qazizadeh, M., and Mohammad Zadeh Moghadam, A. (2015) "Evaluation of long term aging of asphalt mixtures containing EAF and BOF steel slags", International Journal of Transportation Engineering, Vol. 2, No. 3, pp. 245-26