International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Studies on Stone Matrix Asphalt with Warm Mix Technology using Sasobit and Zychotherm as Additives

Abhishek Mendigeri[1], Dr. H S Jagadeesh[2]

[1] PG Student, BMS College of Engineering, Bengalore-560019

[2] Professor, BMS College of Engineering, Bengalore-560019

Abstract: ***The Stone Matrix Asphalt (SMA) mix is developed in Germany in the mid-1960's. It is a gap graded asphalt mixture which is intended to withstand deformity (rutting) resistance and durability by using the structural premise of stone-on-stone contact. Also, it is characterized by high coarse aggregates and fine particles, high binder content and fibre additives as stabilizers. It has low air voids with good drainage surface. Studies have been carried out on the SMA mixes under HMA conditions, in this study an attempt has been made to study the behaviour of SMA mix under warm mix conditions. The present work focuses on assessing the properties of Stone Matrix Asphalt Mix and also the effect of warm mix additives with addition of fibres. The objectives of the study are to obtain a desired gradation as per specification given by IRC: SP: 79: 2008 by using locally available aggregates and other materials and to determine the optimum binder content for warm mix additives and optimum fibre content. To determine the above said properties the varying percentages of binder content from 5.8%, 6%, 6.2%, 6.4% and 6.6%, fibre content 0.30%, 0.35%,0.40% and 0.45% by total weight of aggregates and the varying percentages of warm mix additives i.e. Sasobit from 1%,2% and 3%, Zychotherm from 0.05%,0.1% and 0.15% have been considered for the research work. In this study, PMB-40 grade is used as the binder and hydrated lime is used as filler and Arbocel as fibre. After confirming that SMA warm mix with fibre showed better results than conventional SMA mix, At 2% addition of sasobit and 0.35% of fibre. Series of other tests are conducted on this mix to evaluate the engineering properties, the tests are: - Draindown test, Indirect tensile strength test and Rutting test. The above tests results shown that the SMA warm mix with fibre showed better performance than conventional SMA mix.***

Keywords: Stone Matrix Asphalt, warm mix technology, stone-on-stone, Marshall Stability, Draindown characteristics, Arbocel fibre, Indirect Tensile Strength, Rutting

1. Introduction

In highways, major distress is due to the rain-induced damages. It is a settled actuality in created nations that the water actuated harms are required to be less in a gap graded mix like stone matrix asphalt than conventional blends. In any case use of SMA in India is extremely restricted because of absence of appropriate determinations. This requires the requirement for careful trial and field experiments in different parts of SMA, in setting of India. Stone Matrix/Mastic Asphalt (SMA) is a hot blend asphalt, developed in Germany in the 1960's. SMA has been referred some time concerns over the years as Stone Mastic, Grit Mastic or Stone Filled black top. It is a gap-graded hot blend black-top which is intended with expand deformity (rutting) resistance and durability by using a structural premise of stone-on-stone contact. The use of warm mix asphalt (WMA) technology as a substitute for hot mix has been widely increased due to the concerns over global warming, air quality and fuel crisis. By lowering the viscosity of asphalt binder and/or increasing the workability of mixture using minimal heat .WMA technology allows the mixing, transporting, and paving process at significantly lower temperature compared to the conventional HMA. Warm mix reduces energy consumption, lowers emissions and odour or greenhouse gases from plants, creating better working conditions at both the plants and the paving sites. The most commonly used technologies are either using foaming or some chemical or organic additives. These technologies facilitate reduced mixing and compacting temperature. Mixing temperatures commonly used for most of WMA production is about 30–50° C below the temperatures used for HMA.

2. Range of Applications

SMA is sufficient and it is suggested for any surface course. It is particularly utilized for all overwhelming movement streets. SMA is a great deal more sparing than black-top cement. Since the details were presented in 1984, the utilization of SMA has essentially expanded. The stone network black-top is fitting for:

- Roadways
- Federal Streets
- Rural Streets
- Urban Streets
- Airports

3. Scope and Objectives of Present Study

The present work deals with studying the behaviour of the SMA mix with warm mix technology with addition of fibre to the mix. The work is carried out for 13mm wearing coarse SMA mix. The objectives of the present dissertation work is given below:

1) To determine the basic properties of aggregates and binder.
2) To determine a proper blend for the selected size ranges using rothfutch's method.
3) To determine the optimum binder content for the conventional SMA mix
4) To determine the optimum binder content by using warm mix additives Zycotherm and Sasobit.
5) To determine the effect of addition of fibres including warm mix additives into SMA mix.
6) To study the draindown characteristics at optimum fibre content.
7) To study the rutting and indirect tensile strength for optimum fibre content including warm mix additives for the SMA mixes

4. Literature Review

4.1 Studies on SMA mixes

Bindu C.S and Beena K.S (2015)[1], "Influence of natural fibres on the compressive strength of Stone Matrix Asphalt Mixtures". This paper focuses on the influence of fibres like coir, sisal, banana fibres, on the compressive strength of SMA Mixtures. A preliminary laboratory tests are conducted to characterize the materials. Compressive strength test is conducted to know the resistance to crushing to withstand the stress due to traffic loads. The use all fibres shows the maximum value compressive strength at 0.30% of fibre content. SMA Mix with coir fibre gives more compressive strength shows its higher crushing resistance. The indices of retained strength for all mixtures satisfy the limiting value of 75%. But for control mix, it should be 60%, which indicates the necessity of fibres in SMA Mixtures.

Teja Tallam, Katasani Swetha, Dr A Ramesh (2016)[2] "Assessment of Stone Matrix Asphalt Performance with the inclusion of fibre material on resilient characteristics". The main objective of this study is to compare the addition of polyester fibres in SMA Mix for understanding the behaviour of the resilient characteristics. The performance evaluation of mix is done by using Marshall Stability test, drain down test, and resilient modulus. From Marshall Stability, the optimum binder content was obtained 6.5% for SMA Mix and optimum fibre content was arrived 0.40% when performed by drain down test. The addition of polyester fibre gives good drain down potential and shows better homogeneous mixtures as compared with conventional SMA. From test results, it is observed the resilient modulus is increased by 18% with addition of additives and TSR value increased by 1.2%. This indicates that addition of fibre gives better cracking resistance when it compared with Conventional SMA Mix..

4.2 Studies on Warm mix technology in normal mixes

B. Harish Kumar, et al. (2015)[3], this paper deals with laboratory studies on warm mix asphalt using Zychotherm as an additive. Since by using Zychotherm as an additive the temperature of asphalt pavement can be considerably reduce while comparing with normal asphalt pavements. At lesser temperature, it has given better stability values and also reduces the laying temperature by 20˚C when it is compared to hot mix asphalt, and Zychotherm additive can be fuel efficient since it has reduced fuel cost by 11-14% to conventional fuel cost, aslo after analyses 0.1% Zychotherm is optimum additive content when it is mixed into mixes.

Neha Sharma, B. L. Swami, Divas Sharma (2016)[4], This study focuses on evaluate the performance on SMA Mix using modified bitumen and warm mix technology in comparison with the conventional mix for use as a surface in India. Main objective of this study is to determine the resilient properties of mixtures with addition of modified binders in regards warm mix technology. Here 3 types of binder contents are used for mix namely PMB-40, CRMB-55 and VG-30 and the 13mm SMA gradation will be adopted for this study. And the performance evaluation of SMA mix by Marshall Mix design and resilient modulus. From these tests, it is observed that the performance of mixes with conventional mix is less than the warm mix and modified bitumen. The use of modified binder and warm mix technology improved the performance of SMA Mixes when compared to Conventional binder.

5. Material Characterization

5.1Aggregates

Aggregates used are mainly divided into coarse and fine aggregate based on their size. The aggregates selected for the Stone Matrix Asphalt are subjected to various aggregate tests as specified by IRC: SP: 79: 2008 and MoRTH section 500, confirming to the table 500-36. Good durable quality crushed aggregates of different sizes are obtained from R. N. Shetty Quarry, Jigani Bengalore. The test results on Aggregates as shown in Table 3

5.2 Binder

The proper selection of binder content **is** an important element supporting the stone skeleton performance. In this study Polymer Modified Bitumen (PMB-40) used. To find the physical properties of the binder content the various test are carried out as per IRC: SP: 53: 2010 and MoRTH 500-36 Section. The binder content PMB-40 is obtained Hindustan Colas Pvt. Limited Mangalore. The test results on PMB-40 as shown in Table 4

5.3 Sasobit

Sasobit is a warm mix additive and it is manufactured from coal gasification Sasol wax. It melts with binder at temperatures of 85˚C to 115˚C and It reduces the mixing and handling temperatures by 30˚C to 50˚C. It has high viscosity at lower temperatures and low viscosity at high temperatures.

5.4 Zychotherm

Zychotherm is a warm mix additive manufactured by Zydex industries Gujrat india. It is a odour free additive. It offers lower production and compaction temperatures it is also an antistripping agent. It can be used with all type of modified binders.

5.5 Hydrated lime

Hydrated lime has been used as the mineral filler in the stone matrix asphalt mixture, with the replacement for stone dust in the percent of 2%. It was procured from Panacea Polychem, Sait industrial town, Bengaluru. The sieve analysis of hydrated lime and test results as shown in Table 1.

Table 1: Sieve Analysis of Hydrated lime and Test results

Sl No	IS Sieve Size (mm)	Weight Retained (gms)	% Weight Retained (gms)	Cumulative % Weight Retained	Cumulative Weight % Passing	Cumulative % passing by weight of total aggregate
1	0.6	2	0.5	0.5	99.5	100
2	0.3	10	4.5	5	95	95-100
3	0.075	13	7	12	88	85-100

5.6 Arbocel fiber

Fibers are used as stabilizer in SMA mixture. It helps to increase the strength and stability also decrease the drain down in SMA Mix. In the present study, the fibre used is ARBOCEL® ZZ 8/1G. It was procured from Strategic Marketing and Research Team, Bangalore. Arbocel is natural cellulose fibre produced from cellulose and it is a powdery to fibrous cellulose additive for use in construction chemicals products. The Characteristics of arbocel fiber as shown in Table 2.

Table 2: Characteristics of Arbocel Fiber

Sl No	Characteristics	Values from Testing Certificate
1	Physical appearance	Long fibre, Grey
2	Cellulose content	80±5 %
3	Average fibre length	1100 µm
4	Average fibre thickness	45 µm
5	Bulk density	200 g/l – 280 g/l
6	Temperature resistance (°C)	Up to 200°C
7	pH value	7.5±1

Table 3: Physical Characteristics of Aggregates- Test Results

Sl No	Aggregate Test	Method	Result	Requirement as per IRC:SP:79:2008
1	Aggregate Impact Value (%)	IS : 2386 (Part-IV)	16.19 %	< 18 %
2	Los Angeles Abrasion Value (%)	IS : 2386 (Part-IV)	13.60 %	< 25 %
3	Combined Flakiness and Elongation Index (%)	IS : 2386 (Part-I)	12.69%	< 30 %
4	Water Absorption	IS : 2386 (Part-III)	0.91 %	< 2 %
5	Specific gravity Coarse Aggregate Fine aggregate	IS : 2386 (Part-III)	2.63 2.68	2.5-2.8

Table 4: Test Results on PMB-40 binder

Sl No	Test	Method	Results	Requirement as per IRC: SP: 53: 2010
1	Penetration at 25°C (mm)	IS – 15462-2004	40	30-50
2	Softening Point (°C)	IS – 15462-2004	64	Min 60
3	Flash Point (°C)	IS – 15462-2004	260	Min 220
4	Specific Gravity	IS – 15462-2004	1.02	>0.99
5	Thin Film Oven Test 1. Loss in mass (%) 2. Increase in softening point (°C) 3. Reduction in penetration (mm)	IS – 15462-2004	0.82 5 32	Max 1 Max 5 Max 35

6. Experimental Programme

6.1 Aggregate Gradation

The different size of aggregates used to obtain proper blend are 19mm down size, 10mm down size, 6mm down size and stone dust. 4000gm of aggregates were taken for sieve analysis. The aggregate gradation is done by using Rothfuch's Method to find the individual percentages of different sized aggregates to be used confirming to the upper and lower limits specified as per MoRTH table 500-37 and IRC: SP: 79: 2008.

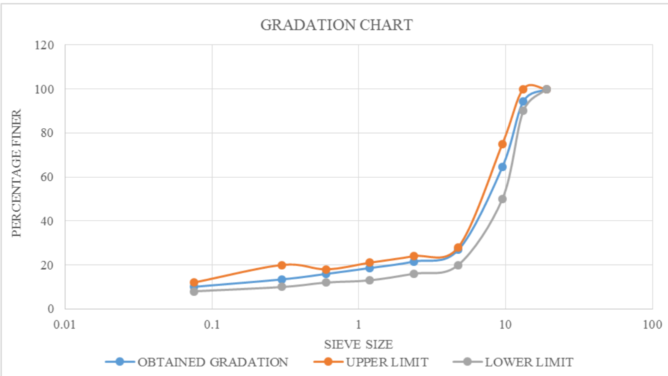


Figure 1: Gradation Chart for SMA Mix

6.2 SMA Mix Design

The mix design is done by using Marshall Stability Test to find the optimum binder content bearing a maximum stability value and also confirming the other Marshall parameters. The design mix shall meet the requirements as per MoRTH table 500-38: SMA Mix requirements.

6.2.1 Conventional SMA Mix

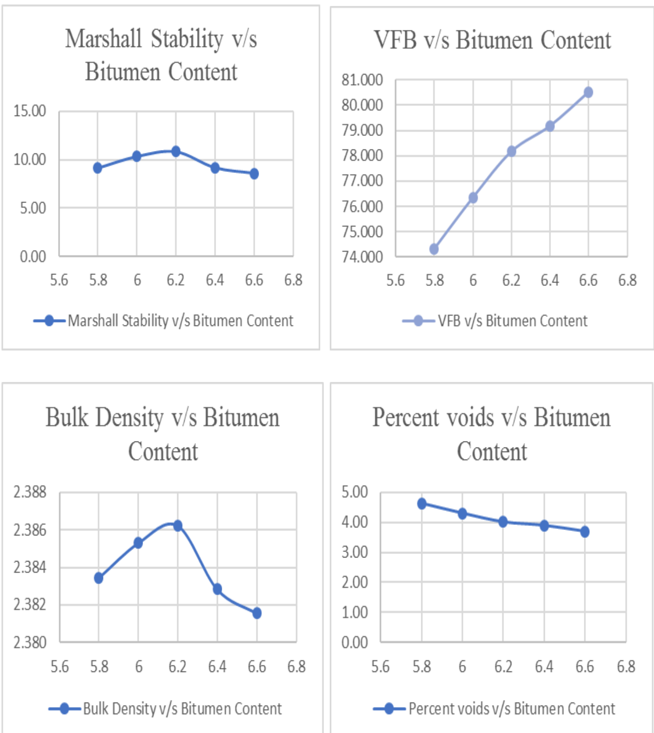
Marshall test has been carried out on the conventional SMA mix. To find out optimum binder content Conventional SMA mix consist of different percentages of aggregates which is obtained from gradation along with 2% hydrated lime and binder content were varied from (5.8%,6%,6.2%,6.4% and 6.6%). Results are tabulated in Table 5.

6.2.2 Marshall stability test on optimized value of warm mix additives with varying percentages of fibre content.

With optimized value of warm mix additives, the fibre content is varied with different percentages form (0.3%,0.35%,0.4% and 0.45%) to find out Marshall properties to satisfy the requirements for SMA mix. Binder content is kept constant for Sasobit additive it is taken as 6%. For Zychotherm additive it is taken as 6.2%. Marshall test is done in two parts first part with optimized value of Sasobit content i.e. 2% and second part is done with optimized value of Zychotherm content i.e. 0.1%. Results are tabulated in Table 6 and Table 7.

Table 5: Marshall Properties for Conventional SMA Mix

% of Bitumen	Gt	Gm	Vv %	VMA %	VFB %	Vb %	Stability Value (KN)	Flow Value (mm)
5.8	2.50	2.383	4.64	18.06	74.32	13.4	9.12	3.81
6	2.49	2.385	4.31	18.20	76.34	13.8	10.34	4.85
6.2	2.49	2.386	4.01	18.38	78.16	14.3	10.84	5.13
6.4	2.48	2.383	3.90	18.70	79.17	14.8	9.17	5.38
6.6	2.47	2.382	3.69	18.95	80.51	15.2	9.09	5.52



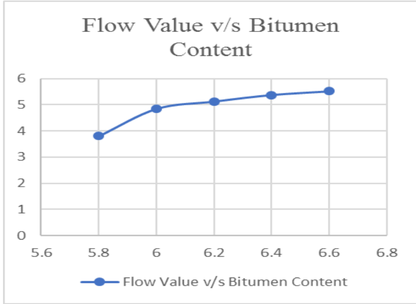


Figure 2: Graphical Representation of Bitumen Content v/s Marshall Parameters

Table 6: Marshall Properties for SMA mix with 1% of Sasobit content and with varying percentages of fibre content

% of Bitumen	Fibre content (%)	Vv %	VMA %	VFB %	Vb %	Flow value (mm)	Stability Value (KN)
6	0.3	4.41	18.33	75.9	13.917	2.12	9.07
6	0.35	3.95	17.90	77.9	13.946	3.22	15.33
6	0.4	3.82	17.75	78.4	13.928	3.78	11.02
6	0.45	3.71	17.62	78.9	13.907	4.1	9.10

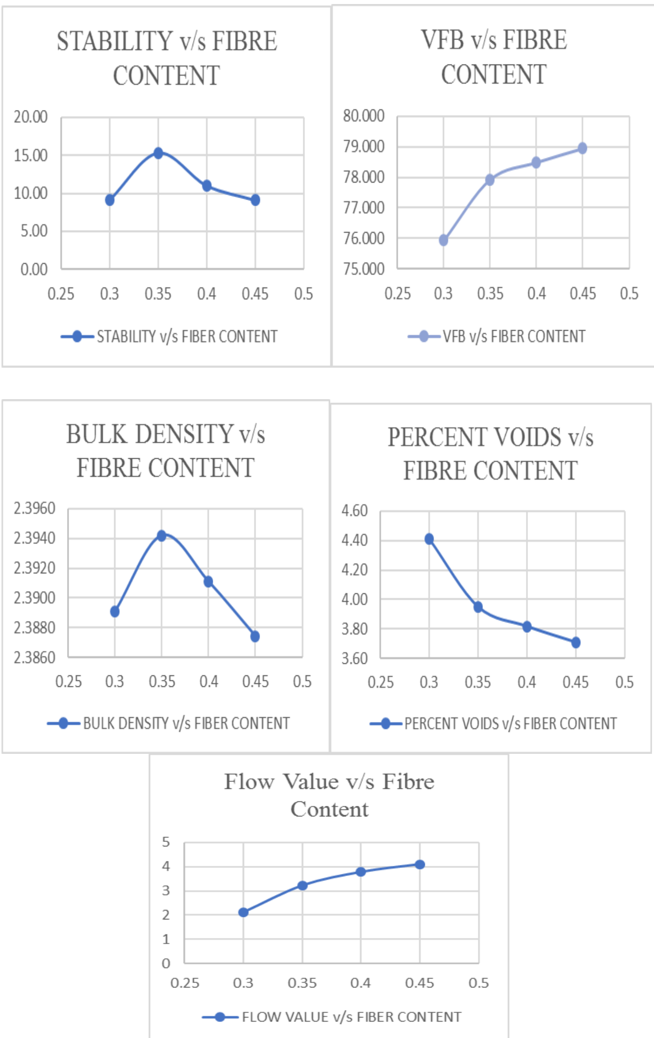


Figure 3: Graphical representation of fibre content v/s Marshall parameters for 2% Sasobit SMA mix

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Table 7: Marshall Properties for SMA warm mix with 0.1% of Zychotherm content and with varying percentages of fibre content

% of Bitumen	Fibre content (%)	Vv %	VMA %	VFB %	Vb %	Flow value (mm)	Stability Value (KN)
6.2	0.3	4.59	18.94	75.7	14.35	2.41	9.27
6.2	0.35	3.97	18.38	78.4	14.40	3.38	14.76
6.2	0.4	3.85	18.24	78.8	14.38	3.68	14.33
6.2	0.45	3.71	18.08	79.4	14.37	3.88	10.39

Figure 4: Graphical representation of fibre content v/s Marshall parameters for 0.1% Zychotherm SMA mix

6.3 Binder Drain down Test

Drain-down of binder is one of the most common features observed in gap-graded bituminous mixes such as Stone Matrix Asphalt and hence the effect of binder content on drain down characteristics of un-compacted fresh mix is an important parameter to address. This test was done in order to assure that binder drain off does not exceed 0.3%.test is conducted on conventional SMA mix, SMA Warm mix with optimized Sasobit, Zychotherm and fibre. Results are tabulated in table no 8

Table 8: Draindown test results

Type of mix	Fibre (%)	Bitumen content (%)	Empty wire basket (A) gm	Wire basket + Sample (B) gm	Empty catch plate (C) gm	Catch plate + Drained Material (D) gm	Drain down results (%) = $\frac{D-C}{B-A} * 100$
Conventional SMA mix	0.35%	6.2	719	1780.78	105.22	107.64	0.22
SMA mix containing optimum Sasobit	0.35%	6	677.28	1724.09	90.79	91.21	0.040
SMA mix containing optimum Zychotherm	0.35%	6.2	718.89	1780.36	105.22	105.63	0.038

The observed values are well within the limits

6.4 Static Indirect Tensile Strength Test

One of the initial concerns regarding the durability of Stone Matrix Asphalt pavement is its resistance to freeze-thaw damage. It is necessary to check the resistance of compacted Stone Matrix Asphalt mixtures to moisture-induced damage and to investigate the effects of saturation and accelerated water conditioning under freezing and thawing cycles. This test includes both indirect tensile strength and tensile strength ratio of SMA Mix. In this test 3 samples were prepared for conventional SMA mix and 6 samples were prepared for optimized SMA warm mix additives and 0.35% fibre. of the specimen. The test results for conventional SMA and optimized SMA Warm mix additives are shown in table 4.6 and 4.7 respectively. Indirect Tensile Strength is calculated using following formula. Results are tabulated in Table 8,9 and 10.

$$ITS = \frac{2000P}{\Pi dt}$$

P = load at which the specimen fails, N
d= diameter of specimen, mm
t= thickness of specimen, mm

$$TSR = \frac{T_{wet}}{T_{dry}} * 100$$

T_{wet} = average ITS of wet specimens
T_{dry} = average ITS of dry specimens

Table 9: ITS test results for conventional SMA mix

Sl. no	Height of Specimen (cm)	Diameter of Specimen (cm)	Maximum Load (N)	Tensile Strength (kPa)	Avg Tensile Strength (kPa)
	Avg h, cm	Avg d, cm			
Unconditioned Specimens					
1	6.95	10.17	3694	33267	32640
2	6.82	10.19	3589	32872	
3	6.97	10.19	3546	31780	
Conditioned Specimens					
1	6.91	10.16	3562	32202	28151
2	7.03	10.15	3256	36254	
3	7.09	10.18	3126	25998	

For conventional mix, TSR value = 86.25 > 85min

Table 10: ITS test results for optimized Sasobit additive and 0.35% fibre content

Sl. no	Height of Specimen (cm)	Diameter of Specimen (cm)	Maximum Load (N)	Tensile Strength (kPa)	Avg Tensile Strength (kPa)
	Avg h, cm	Avg d, cm			
Unconditioned Specimens					
1	7.26	10.16	3418	29509	30127.0
2	6.97	10.16	3240	3240	
3	7.02	10.17	3562	3562	
Conditioned Specimens					
1	6.95	10.16	3087	27841	26697.7
2	6.98	10.15	2892	26254	
3	6.98	10.15	2850	25998	

TSR value = 88.62 > 85min

Table 11: ITS test results for optimized Zychothem additive and 0.35% fibre content

Sl. no	Height of Specimen (cm)	Diameter of Specimen (cm)	Maximum Load (N)	Tensile Strength (kPa)	Avg Tensile Strength (kPa)
	Avg h, cm	Avg d, cm			
Unconditioned Specimens					
1	6.97	10.19	4080	36595	35658
2	6.93	10.16	3978	35968	
3	6.95	10.32	3876	34409	
Conditioned Specimens					
1	6.98	10.18	3876	34727	33109
2	6.95	10.19	3570	32097	
3	6.96	10.18	3621	32504	

TSR value = 92.85 > 85min

6.5 Immersion Wheel Tracking Test

This test will be one of major surface distortion factor is rutting. It is characterized by the longitudinal depression along the wheel path, creating a channel. The rutting behavior of SMA Mixtures prepared in the study was passed by wheel tracking test. The dimension of the mould 6*100*10 cm. the thickness of specimen can be varied based on the specification of different courses.

The total weight of the mix taken for the 40mm and 50mm thickness of rutting specimen is calculated as follows:-

1) For 40mm thickness specimen

a. Mould dimension = 6*100*4 cm
b. V= Volume = 2400 cm^3
c. ρ = Density of mix = 2.32 g/cc (refer
d. M = $V \times \rho$ = 2400 × 2.32 = 5568 gms

2) For 50mm thickness specimen

e. Mould dimension = 6*100*5 cm
f. V= Volume = 3000 cm^3
g. ρ = Density of mix = 2.32 g/cc
h. M = $V \times \rho$ = 3000 × 2.32 = 6960 gms

3) Optimum fiber content = 0.35%

The graph pertaining to 40mm thick specimen for conventional SMA mix and optimized Warm mix additives of Rut depth v/s Number of Passes are shown in figure 6. The graph pertaining to 50mm thick specimen for conventional SMA mix and optimized Warm mix additives of Rut depth v/s Number of Passes are shown in figure 7. Comparision of rut depth of 10000 passes is shown in figure 8.

Figure 5: Immersion Wheel Tracking machine

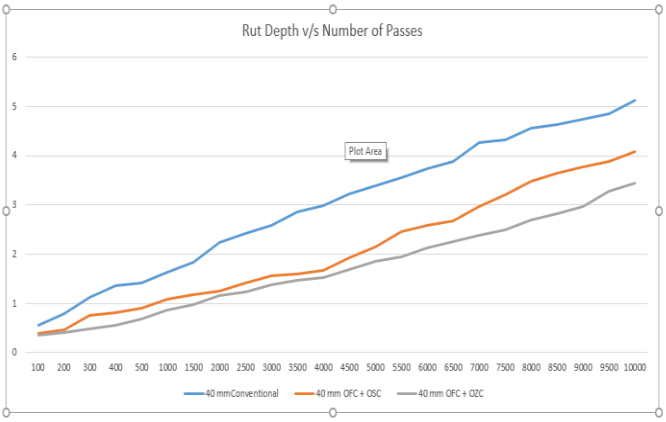


Figure 6: Graphical representation for 40mm rutting characteristics

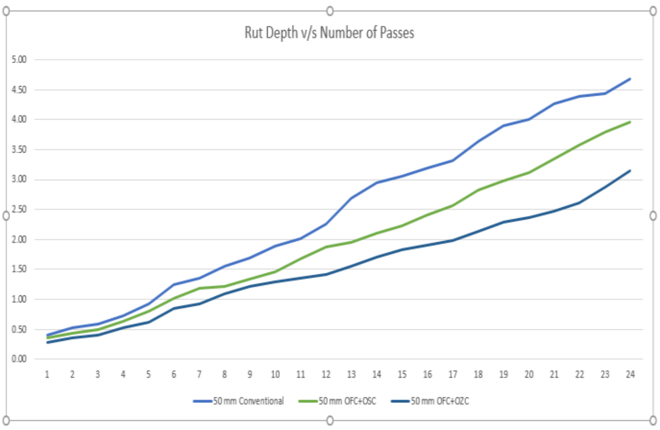


Figure 7: Graphical representation for 50mm rutting characteristics

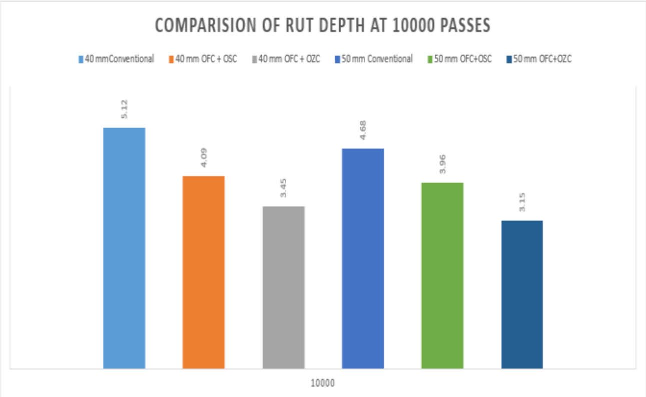


Figure 8: Graphical representation for comparision of rut depth of SMA specimens at 10000 passes

7. Discussions on Test Results

7.1 Discussion on Conventional SMA Mix

Marshall stability test was conducted on conventional SMA mix for the obtained gradation (13mm SMA) as shown in figure 1 and is as per guidelines given in MoRTH. The optimum binder content obtained for conventional SMA Mix was found to 6.2%, with a maximum stability of 10.84 KN. The air void percentage was found to be 4.01%. The voids filled in mineral aggregate percentage was found to be 18.38%. these test results will be used for the further investigations of SMA mixes.

7.2 Discussion on SMA Mix with Addition of warm mix additives

Marshall Stability test conducted on SMA Mix with addition of warm mix additives. Sasobit was added in percentages of (1%,2% and 3%) out of these percentages 2% Sasobit was found to optimum considering the Marshall properties with a maximum stability of 12.33 KN. Zychotherm was added in percentages of (0.05%,0.1% and 0.15%) out of these percentages 0.1% Zychotherm was found to optimum considering Marshall properties with a maximum stability of 13.93 KN. Marshall properties were well within the limits as per specifications given in MoRTH.

7.3 Discussion on SMA Mix with optimized warm mix additives along with addition of fibre

Marshall Stability test conducted on SMA warm mix additives of Sasobit and Zychotherm with addition of fibres varying from 0.30%, 0.35%, 0.40%and 0.45%. The stability value obtained was 9.07KN for 0.30% of fibre, 15.33KN for 0.35% fibre, 11.02 KN for 0.40% and 9.10 KN for 0.45% of fibre. Similarly, for optimised Zychotherm additive the stability value obtained 9.27 KN for 0.30% of fibre, 14.76 KN for 0.35% of fibre, 14.33 KN for 0.40% of fibre and 10.39 KN for 0.45% of fibre. Addition of 0.35% fibre gave the maximum stability for both the warm mix additives and increase in fibre content stability value goes on decreases. Flow value increases with increase in the binder content and the optimum binder content observed for Sasobit SMA mix as 6% and for Zychotherm SMA mix as 6.2%. The air voids percentage decreases with increase in fibre content. As compared to Zychothem SMA Mix the Sasobit SMA mix shows the higher Stability value at 0.35% of fibres.

7.4 Draindown test

Draindown test was conducted for conventional SMA mix and SMA mix containing Warm mix additives of optimum sasobit and zychotherm of 2% and 0.1% respectively including fibre of 0.35%. For conventional SMA mix draindown result was found out to be 0.22%, for Sasobit additive drain down result was found to be 0.040% and for Zychotherm additive was found to be 0.038%. The test results were well within the permisible limits as per IRC:SP:79:2008.

7.5 Indirect tensile strength test

Indirect tensile strength test was conducted for conventional SMA mix and SMA mix containing Warm mix additives of optimum sasobit and zychotherm of 2% and 0.1% respectively including fibre of 0.35%. For conventional SMA mix TSR was found to be 86.25%, for Sasobit additive TSR was found out to be 88.62% and for Zychotherm additive TSR was found out to be 92.85%. Test results are greater than 85% which is the minimum requirement for TSR.

7.6 Rutting characteristics

This test was conducted for both conventional SMA Mix and warm mix SMA with addition of optimum fibre content 0.35%. The test was conducted on 40mm and 50mm thick specimens. From the test results as shown in figure 8 it shows that Rutting resistance of Warm mix SMA is better than conventional SMA mix.

8. Conclusions

The followings are the conclusions based on test results:

1) The aggregates and binder content test results are well in confiruance with specifications as per IRC: SP: 79: 2008.
2) It is observed that there is around 1.13 times increase in the stability value of the SMA mix with optimized Sasobit additive and fibre when compared to the conventional SMA mix and 1.28 times increase in the stability value of the SMA mix with optimized Zychotherm additive and fibre when compared to the conventional SMA mix.
3) The flow value observed for conventional SMA mix was found to be 5.13mm which was crossing the specified limits. After addition of warm mix additives and fibre it was observed that there is decrease in flow values and it was well within the specified limits i.e. 2-4mm. The other Marshall properties were well within the standard values.

4) The draindown of the specimens observed were well within the maximum limit of 0.30% as specified in IRC: SP:79: 2008
5) The tensile strength ratio was found to be greater than 85% as specified in IRC: SP: 79: 2008. The observed TSR value was found to be more for Zychotherm SMA Mix with addition of fibre as compared to Sasobit SMA Mix and conventional SMA mix.
6) Rutting test results observed that the Conventional SMA Mix shows more rut depth as compared to SMA Warm mix with addition of 0.35% fibre in both cases of 40mm and 50mm thick specimens.
7) Hence through the lab studies it was found that SMA warm mix with addition of optimized Zychotherm additive and 0.35% fibre gives better results as compared to conventional SMA mix.
8) Using SMA warm mix decreases the gas emissions and produces a better working environment.

References

[1] **Influence of natural fibres on the compressive strength of Stone Matrix Asphalt Mixtures**, Bindu C.S and Beena K.S**,** 2015 International Journal of Engineering and Technology Voume-2 (6), 2010, 379-3
[2] **Assessment of Stone Matrix Asphalt Performance with the inclusion of fibre material on resilient characteristics**, Teja Tallam, Katasani Swetha, Dr A Ramesh 2016 International Journal of Engineering Development and Research.
[3] **Laboratory studies on warm mix asphalt using Zychotherm as an additive**, B. Harish Kumar, et al., 2015 IJESR, Vol-5, ISSN 2277-2685
[4] **Evaluation of resilient characteristics of stone matrix asphalt (SMA)**, Neha Sharma, B.L. Swami, Divas Sharma, Proceedings of 42nd IRF International Conference, 15th May, 2016, Chennai, india, ISBN: 978-93-86083-17-3
[5] **Experimental investigation of warm mix using Redist as a additive with PMB 40 in mix**, Devendra K. patel , C.B.Mishra and A.A.Amin 2014 IJEDR, Volume 4, ISSN 2347-5161
[6] **Experimental investigation on Warm Mix using Zychotherm as a chemical Additive with PMB 40 in Mix Design,** Prof. Amitkumar A. Patel, Tushar A. Kansagra, 2015 IJSRD Vol. 2, ISSN: 2321-0613
[7] **IS 15462:2004,** Polymer and modified bitumen-Specification
[8] S. K. Khanna, C. E.G. Justo, A. Veeraragavan (2013), "Highway Materials and Pavement Testing (revised 5th edition)". Laboratory Manual.
[9] IRC SP79:2008 "Tentative Specifications for Stone Matrix Asphalt".
[10] MoRTH, Specifications for Road and Bridge Works, up gradation of FIFTH Revision, Ministry of Road Transport and Highways