Studies on SMA Mixes with Partial Rap Replacement in Addition with Fiber

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Abstract: ***Stone Mastic/Matrix Asphalt (SMA) is a gap graded mix, consisting of high percentage of coarse aggregate, binder and fiber additives as stabilizers. High concentration of coarse aggregate maximizes the stone-on-stone contact and the interlocking in the mix which provides strength and the rich mortar provides durability. The stabilizing additives are added to the mix to prevent bitumen draindown from the mix. When compared to dense graded mixes, SMA has higher stability against permanent deformation and has the potential for long term performance and durability. In the present study an attempt has been made to study the engineering properties of the SMA Mix with Polymer Modified Bitumen (PMB) – 70 bitumen and how it behaves on replacement of Reclaimed Asphalt Pavement (RAP) aggregates to virgin aggregates with addition of cellulose fiber. Comparative studies on engineering properties have been carried out on the conventional SMA Mix and the Reclaimed Asphalt Pavement (RAP) +Virgin aggregate SMA mixes with fiber. The binders, RAP and fibers are used in different proportions for preparation of mixes with the selected aggregate grading. Marshall specimens are prepared of conventional SMA mix and mixture of normal and RAP aggregates to determine the optimum bitumen content (OBC) for conventional SMA mix and SMA mix with optimized RAP and fiber, optimum RAP replacement and optimum fiber (OFC) addition. OBC, OFC and RAP replacement are determined on the various Marshall properties carried out. After this, the draindown, moisture susceptibility and rutting tests on the specimens are carried out. It was observed that 16% RAP replacement and 0.3% Fiber addition prove to show good results in the mix when compared to other percentages. The results showed that SMA Mix with optimized RAP and fiber, had better resistance to Engineering properties when compared to conventional SMA Mix.***

Keywords: Stone Matrix/Mastic Asphalt, Reclaimed Asphalt Pavement, PMB-70, Marshall Properties, Cellulose Fiber, Draindown, ITS, TSR, Retained Marshall Stability, Rutting.

1. Introduction

Aggregates bound with the bitumen are conventionally used throughout the world in the form of dense, well or coarse graded mixes with normal bitumen in the construction and maintenance of the flexible pavements. But the availability of these mixes at all the sites or work places is not possible. In such cases bituminous mixes known as Stone Mastic/Matrix Asphalt (SMA) can be used, which consist of a gap graded mix.

Stone Mastic Asphalt was developed firstly in the European continent around late 1960s' and early 1970s' to resist the effect of the damage caused by the studded tires. The results of these tests showed excellent resistance against the deformation of the pavement by the heavy wheel load and traffic characteristics. Since then SMA has been tried and tested in various countries throughout the globe, yielding better results. SMA is a gap graded mixture consisting of high percentage coarse aggregates of around 70%-80% of the mix, high bitumen content of around 6%-7%, filler of around 8%-12% and fiber content with a minimum of 0.3%. The high amount of aggregate content in the mix forms a skeleton like structure providing a good stone-on-stone contact in the mix due to gap graded mix, resulting in the better characteristics of rutting. There is a presence of stone-on-stone contact in the dense graded mix as well, but this contact is of the finer particles of the mix. The load transfer in the SMA Mix occurs mainly through the coarse aggregates, unlike in other cases where it takes place through the fine aggregate-bitumen mix. The higher bitumen content in the mix, makes it durable when compared to other layers. The fiber in the mix, hold the bitumen, prevents the draindown of the bitumen during the transportation process.

The SMA Technical working group of Federal Highway Administration (FHWA) defined SMA as "A gap graded aggregate hot mix asphalt (HMA) that maximizes the bitumen content and coarse aggregate fraction and provides a stable stone-on-stone skeleton that is held together by a rich mixture of Bitumen, Filler and Stabilizing Additive".

Reclaimed/Recycled Asphalt Pavement (RAP), is the removed material from the worn out pavement. This material can be recycled and can be used with the virgin aggregates as a partial replacement to the aggregates.

2. Need for Study

Recycling is one of important factors to be considered in the present situation. Dumping of waste materials causes land requirement. By using some amount of RAP percentage in the SMA Mix, there is reduction in amount of virgin material to be used and reduction in cost as well. Considering these facts an attempt has been made to study the behavior of SMA Mix with RAP and addition of fiber to it using PMB-70.

3. Scope and Objectives of Present Study

This work consists of studying the behavior of the SMA Mix with partial replacement of RAP aggregates and addition of fiber to the mix. The 13mm grade SMA as mentioned in Ministry of Road Transport & Highways (MoRTH) is selected for the study purpose on various engineering properties of the mix.

The main objectives of the present study are;
1) To carry out the basic tests on aggregates and bitumen, and to obtain a proper blend of aggregates to use in the study.
2) To estimate the Marshall properties of SMA samples with the bitumen, by varying its concentrations.
3) To determine the optimum RAP replacement in the mix with the help of Marshall Properties.
4) To determine the optimum Fiber content (OFC) and optimum bitumen content (OBC) in the mix with the help of Marshall Properties.
5) To study the draindown characteristics at the optimum and conventional mixes.
6) To study the behavior of the SMA mixes at Optimum Bitumen Content (OBC), with Optimum RAP replacement and Optimum Fiber Content, with regard to the engineering properties such as, Rutting and Indirect Tensile Strength.
7) To study the moisture susceptibility tests of SMA mixes in terms of their tensile strength ratio and retained Marshall Stability.

4. Literature Review

In this chapter there is discussion the previous works carried out on SMA mixes, behavior of RAP when used with HMA mixes and the rutting characteristics of the flexible pavement. Flexible pavements constitute the majority in the road network. This consists of bituminous layer on the surface course followed by base sub-base courses over the sub-grade. Hot Mix Asphalt (HMA) is the most common used mix for surfacing of the roads in Indian Scenario, it is a premix bituminous layer consisting of coarse and fine aggregate which are held together with the help of a binder. The main point of using the SMA is to reduce the Rutting or the deformation caused in the surface layer.

4.1 Studies on Stone Matrix Asphalt

Vaishakhi Talati (2014)[(1)] deals with the use of SMA layer as a Surface layer. The study has been carried out in Indian conditions where there is enormous difference in the maximum and minimum loading of the vehicle. The temperature in some parts of the country is very high, this leads to increase in pavement temperature to a greater extent. With this increase in the loading and temperature there is formation of various distress in the pavement. Draindown tests work done to determine the drainage of the bitumen when modified bitumen was used. In this study attempt was made to study the Rutting characteristics of the SMA using CRMB-55 as a binder in the mix. The results indicated the SMA had good stone-on-stone contact, use of modified binder enhanced the rutting resistance and repeated load test indicated higher fatigue life of the mix.

Dr A Ramesh[(2)] carried works on the behavior of the SMA layer in addition with the fibers. The fibers used in the study were cellulose and polyester fibers, the optimum fiber was found out to be 0.4% when performed through the draindown test. Polyester fibers showed good draindown characteristics and provided good homogeneous mixture when compared to the normal conventional mix. The results showed that there is increase in Marshall Properties as well as in the tensile strength ration of the mix.

4.2 Study on Reclaimed Asphalt Pavement

Dr. P K Jain (2014)[(3)], this paper deals with the study of use of RAP in HMA mixes in varying percentages and obtaining the optimum percent of replacement. Various tests were carried, such as Retained Stability, Indirect Tensile Strength and Tensile Strength Ratio, to compare the performance of the RAP modified mix with the normal virgin mix. The laboratory tests indicated that the bituminous mixes containing RAP provided better results when compared to the virgin mixes.

Ahmed Mohamady (2014)[(4)]dealt with the using of RAP material to the virgin mixes in varying percent ranges, the percent ranges used were 0%, 10%, 20%, 25%, 30% and 40%. Marshall test was adopted for the determination of the optimum RAP replacement and to find the optimum bitumen content. Through the results it was obtained that at 30% RAP there were better results when compared to other percent ranges. Further tests like Indirect Tensile Strength, Loss of stability tests were conducted to determine the usage of RAP in virgin mix, which yielded in good results for the mix with RAP when compared to virgin mix.

4.3 Study on Polymer Modified Bitumen

Ravi K Sharma (2012)[(5)]studied the comparison between the use on Polymer Modified Bitumen (PMB-70) and conventional bitumen of 60/70 grade. The bitumen was used on bituminous concrete mixes. Basic tests on the conventional and PMB were conducted. Marshall test was carried out to determine the Optimum Bitumen Content. The results from the Marshall test showed there was around 27% in the stability value of the mix when PMB was used in place of conventional bitumen. The results were PMB found to have high elastic recovery of around 79%. Rutting and Indirect Tensile Strength were carried on both the bitumen, PMB showed significantly higher results when compared to the conventional binder.

4.4 Study on Rutting

Dr. V Tare (2016)[(6)], rutting is the vertical depression observed in road in longitudinal fashion. This occurs due to heavy repeated loads on the path of wheel. In this paper they have used the waste plastic and crumb rubber as binder with the bituminous concrete mix. Marshall mix were carried out to determine the optimum bitumen content. Rutting was carried out for the conventional as well as for the waste plastic and crumb rubber at optimum values at 40°C, 50°C and 60°C by fixing the number of passes at 2500 passes and a tire pressure of 0.7MPa. The results showed that the mix with plastic waste and crumb rubber was less susceptible to deformation as compared to the conventional mix.

4.5 Immersion Wheel Tracking Equipment

Dr. K Ganesh (2013)[(7)], immersion wheel tracking equipment developed and fabricated at BMS College of Engineering. The wheel tracking apparatus measures the effect of rutting by rolling a rubber wheel on the surface of the specimen. The rutting is observed in terms of rut depth. The wheel is fitted in a cantilever position to which the hanging side weights are added which gives the effect of tire pressure, this assembly is then fixed to a movable table which can have a maximum passes of 40 passes per minute, consisting of a water bath in it where temperature can be maintained. The dimensions of the wheel are 200mm×50mm solid rubber wheel. In this equipment there is a provision for various parameters to be varied such as type of wheel (Plain and Treaded), tire pressure, pavement temperature and the thickness of the specimen to be tested. In their study, rutting tests were carried for the bituminous concrete mix using different binder, those are VG-10, CRMB-60 and PMB-70. The results showed that the VG-10 bitumen was more susceptible to changing conditions when compared to PMB or CRMB.

5. Material Characterization

5.1 Aggregates

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 500-35. Good durable quality crushed aggregates of different sizes were obtained from R. N. Shetty Infra, Jigani Bengaluru. The test results on aggregates are as shown in Table 1. The RAP aggregates were also obtained from the same site, details of it are as shown in Table 2.

Table 1: 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	Crushing Strength Test	IS : 2386 (Part-IV)	14.65%	<30%
4	Soundness ($MgSo_4$)-5 cycles	IS:2386 (Part V)	0%	<12%
5	Combined Flakiness and Elongation Index (%)	IS : 2386 (Part-I)	12.69 %	< 30 %
6	Water Absorption	IS : 2386 (Part-III)	0.91 %	< 2 %
7	Specific gravity Coarse Aggregate Fine aggregate	IS : 2386 (Part-III)	2.72 2.64	2.5-2.8
8	Polished Stone Value	IS:2386 (Part CXIV)	56	>55

Table 2: Physical Characteristics of RAP Aggregates

Sl. No.	Aggregate Test	Method	Result	Requirement as per IRC:SP:79:2008
1	Aggregate Impact Value (%)	IS : 2386 (Part-IV)	8% -14.88% 16%-15.48% 24%-13.10	< 18 %
2	Los Angeles Abrasion Value (%)	IS : 2386 (Part-IV)	15.18 %	< 25 %
3	Crushing Strength Test	IS : 2386 (Part-IV)	18.82%	<30%
4	Combined Flakiness and Elongation Index (%)	IS : 2386 (Part-I)	12.58%	< 30 %
5	Water Absorption	IS : 2386 (Part-III)	1.26%	< 2 %
6	Specific gravity	IS : 2386 (Part-III)	2.62	2.5-2.8
7	Bitumen Content		5%	

5.2 Bitumen

The proper selection of bitumen is an important element supporting the stone skeleton performance. In this study Polymer Modified Bitumen (PMB-70) is used. To find the physical properties of the bitumen the various test are carried out as per IRC:SP:53:2010. The bitumen PMB-70 is obtained Hindustan Colas Pvt. Limited, Mangalore. The test results of PMB-70 are as shown in Table 3.

Table 3: Test Results on PMB – 70 bitumen

S. No.	Test	Method	Results	Requirement as per IRC: SP: 53: 2010
1	Penetration at 25°C (mm)	IS 1203-1978	75	50-80
2	Softening Point (°C)	IS 1205-1978	56	Min 55
3	Flash Point (°C)	IS 1209-1978	222	Min 220
4	Specific Gravity	IS 1202-1978	1.03	>0.99
5	Separation Test, difference in softening point max. °C	IS 1205-1978	3	3
6	Thin Film Oven Test 1. Loss in mass (%) 2. Increase in softening point (°C) 3. Reduction in penetration (mm)	IS 1203-1978 IS 1205-1978	0.67 5.5 31	Max 1 Max 5 Max 35

5.3 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 percentage of 3%. It was procured from PanaceaPolychem, Sait industrial town, Bengaluru. The sieve analysis of hydrated lime and test results as shown in Table 4.

Table 4: Sieve Analysis of Hydrated lime and Test results

IS Sieve Size (mm)	Weight Retained (gm)	Percent Weight Retained	Cumulative Percent Weight Retained	Cumulative Percent Weight Passing	Lower Limit	Upper Limit
0.6	2	1	1	99	100	100
0.3	10	5	6	94	95	100
0.075	13	6.5	12.5	87.5	85	100

5.4 Fiber (Cellulose – 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 fiber used is ARBOCEL® ZZ 8/1G. It was procured from Strategic

Marketing and Research Team, Bangalore. Arbocel is natural cellulose fiber 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 5.

Table 5: Characteristics of Arbocel Fiber

Sl. No.	Characteristics	Values from Testing Certificate
1	Physical appearance	Long fiber, Grey
2	Cellulose content	80±5 %
3	Average fiber length	1100 µm
4	Average fiber 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

6. Experimental Investigations

6.1 Aggregate Gradation

The different size of aggregates used to obtain proper blend are 20mm 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. The gradation charts for conventional SMA and SMA with RAP are shown in Fig. 1 and Fig. 2 respectively.

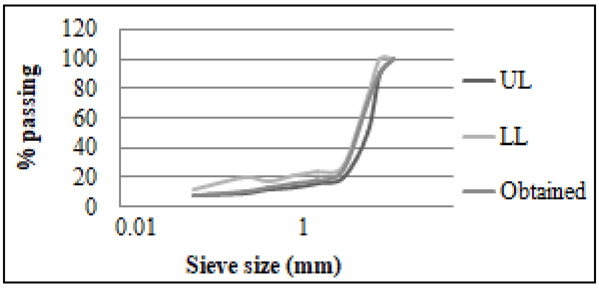


Figure 1: Gradation Chart for Virgin SMA Mix

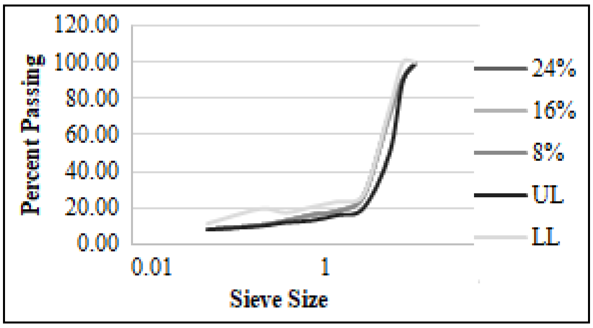


Figure 2: Gradation Chart for Virgin+RAP SMA Mix

6.2 SMA Mix Design

The mix design is done by using Marshall Stability Test to find the optimum binder content, RAP replacement and optimum fiber 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 Specimen Preparation for SMA Mix

Marshall Test procedure is used in designing, evaluating and optimizing the bituminous paving mixes and has become a normal procedure for the design of paving mixes. This test gives two major features which are stability-flow and density-void analysis. Strength of the specimen is measured in terms of 'Marshall Stability Value', which is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60°C. The loading rate is 50.8mm/min till the specimen fails. Flexibility is measured in terms 'Flow Value', which is change in the diameter of the sample on the application of the load. The density-void analysis is done on the basis of the volumetric properties of the mix.

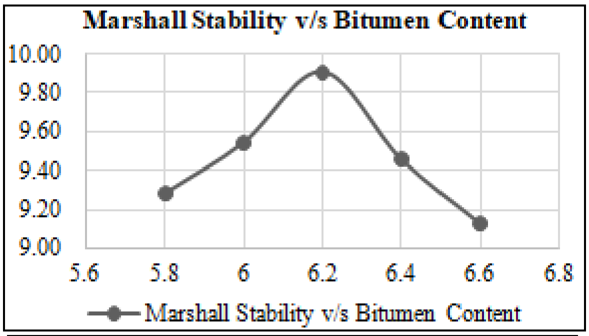
Approximately 1200gm of Aggregates combination and the filler are heated to a temperature of around 170°C-180°C for the preparation of the specimen. The bitumen is heated up to flowing state of around 125°C with the first trial percentage of bitumen. The heated aggregates and the bitumen are mixed in the mixer at a temperature of around 165°C-185°C. The mix is removed and placed in a pre-heated mould and compacted with the help of the rammer weighing 4.5kg with the fall of 45.7cm, giving 50blows on each face of the specimen at a temperature of around 130°C-150°C. Different concentration of the bitumen and various other materials to be used are predetermined and the Marshall Test is carried out on these specimens to obtain the optimized values of the bitumen and the materials used.

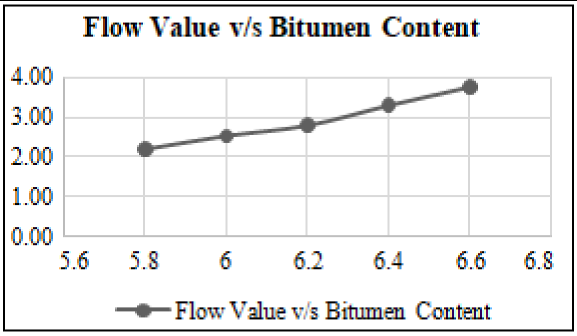
6.2.2 Conventional SMA Mix

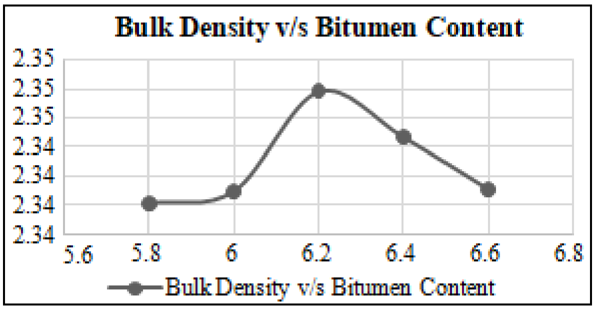
For SMA Conventional mix to know the optimum binder content and stability, the Marshall Stability test was conducted in the laboratory. Varying the percentage of bitumen with an increment of 0.2% starting from a minimum value and progressing further 5.8%, 6%, 6.2%, 6.4% and 6.6%as mentioned. The test results are shown in Table 6 and Marshall Parameters are shown in Figure 3. The volumetric property with binder content (%) for conventional mix are within limits as per IRC: SP: 79: 2008 Specifications for Stone Matrix Asphalt. The optimum bitumen content for conventional SMA Mix was found out to be 6.2%, which is further used in studies on engineering properties.

Table 6: Marshall Properties for Conventional SMA Mix

% of Bitumen	G_t (g/cc)	G_m (g/cc)	V_v (%)	V_b (%)	VMA (%)	VFB (%)	Flow Value (mm)	Stability Value (kN)
5.8	2.34	2.46	4.84	13.17	18.01	73.14	2.2	9.28
6	2.34	2.45	4.55	13.63	18.19	74.96	2.54	9.55
6.2	2.35	2.45	4.03	14.13	18.16	77.82	2.8	9.91
6.4	2.34	2.44	3.91	14.56	18.48	78.85	3.3	9.45
6.6	2.34	2.43	3.81	15.00	18.81	79.75	3.77	9.13







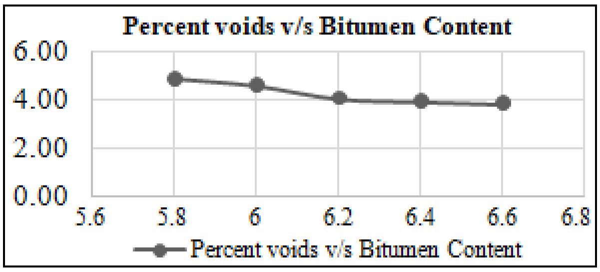


Figure 3: Marshall Properties for the determination of Optimum Bitumen Content for the Conventional SMA Mix

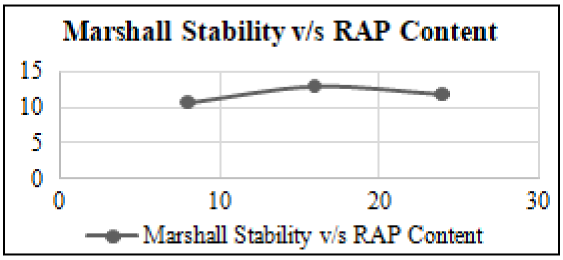
6.2.3 SMA Mix with RAP

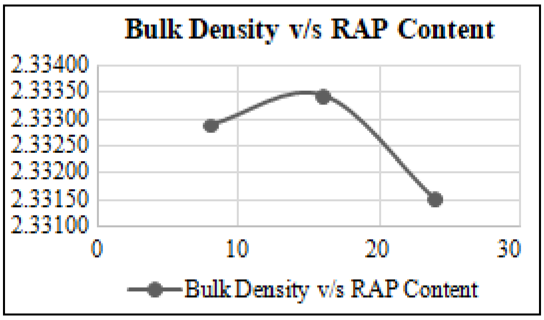
The dosage of RAP to be introduced in the SMA Mix is determined with the help of the Marshall properties. The Dosage of RAP was varied in the percentage ranges of 8%, 16% and 24%. The bitumen content was varied in the same range as observed in the conventional SMA Mix. The gradation for different RAP percentages are discussed earlier.

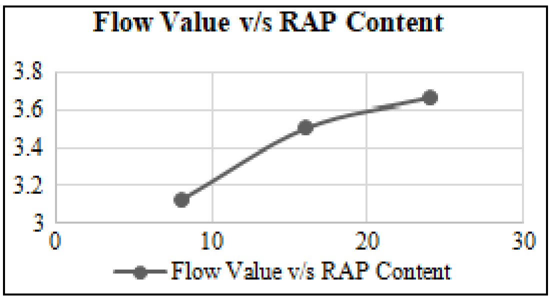
It was observed from the investigations that the optimum dosage of RAP replacement for the mix is 16%. The Marshall properties at this mix were satisfactorily good when compared to 8% and 24% mixes. This optimum percent of 16% is used in the further studies for determination of Fiber content and Optimum Bitumen Content which are to be used for the studies in various engineering properties. The results for this are summarized in table 7 and the graphs are depicted in Fig. 4

Table 7: Marshall Properties for SMA Mix with RAP

Reclaimed Asphalt Pavement (%)	G_b (g/cc)	G_t (g/cc)	V_v (%)	V_b (%)	VMA (%)	VFB (%)	Flow Value (mm)	Marshall Stability (kN)
8	2.33288	2.43	4.05	14.0426	18.09	77.628	3.12	10.7
16	2.33343	2.43	3.91	14.0459	17.96	78.218	3.51	12.9
24	2.33150	2.43	3.88	14.0342	17.91	78.349	3.67	11.83







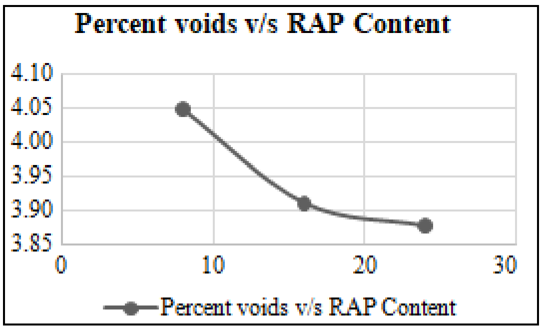


Figure 4: Marshall Properties for the Determination of Optimum RAP Replacement in the SMA Mix

6.2.4 SMA Mix with optimized RAP and fiber

In this section, the attempt is to determine the dosage of Fiber to be used in the SMA Mix, the dosages were varied by 0.3% and 0.35%. The optimum bitumen content (OBC) to be used for the further investigations are also obtained from this section. The bitumen concentrations used in the mix were 5.8%, 6%, 6.2%, 6.4% and 6.6%. The maximum stability and other Marshall parameters were satisfactory at 6.4% of Bitumen content.

The optimum Fiber dosage was observed at 0.3% whereas the Optimum Bitumen Content (OBC) to be used for further investigations of engineering properties was found out to 6.4%. The results for this investigation are summarized in table 8 and the Marshall properties are given in Fig. 5.

Table 8: Marshall Properties for SMA Mix with optimized RAP and fiber

Arbocel Fiber (%)	G_b (g/cc)	G_t (g/cc)	V_v (%)	V_b (%)	VMA (%)	VFB (%)	Flow Value (mm)	Marshall Stability (kN)
0.3	2.32564	2.42	3.9878	14.4506	18.44	78.372	3.97	13.22
0.35	2.32563	2.42	3.9882	14.4505	18.44	78.370	4.48	10.30

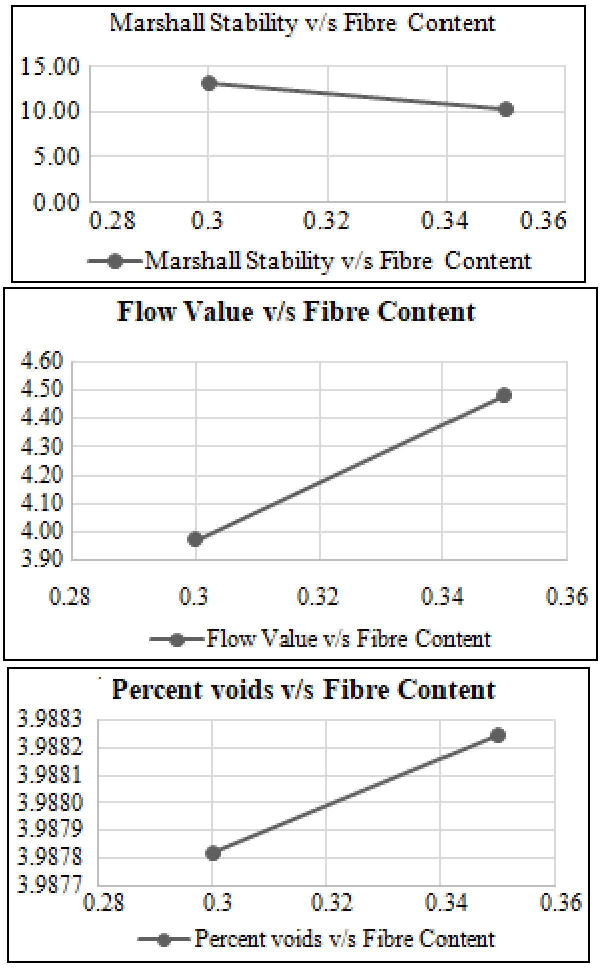


Figure 5: Determination of Optimum Fiber and Optimum Bitumen Content in the SMA mix

6.3 Draindown Test

Draindown 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%. The Draindown characteristics for the SMA mix were conducted for the conventional SMA mixes as well as for the SMA mix with optimized RAP and fiber as obtained above, the results are tabulated in the Table 9 as follows,

Table 9: Drain down Potential Test Results

Mix Type	Draindown (%)
Conventional SMA	0.09
Optimum RAP (16%)	0.1
Optimized RAP + 0.3% Fiber	0.05
Optimized RAP + 0.35% Fiber	0.01

6.4 Moisture Susceptibility Test

The main factor leading to premature failure of the bituminous pavements is due to the presence of moisture in the pavement surface and the inability of aggregates to retain the coating in presence of moisture. Hence, it is important to conduct the tests regarding Moisture Susceptibility. The tests include tensile strength ratio and retained Marshall Stability. For Retained Marshall Stability the tests were carried out for the conventional SMA Mix as well as for the SMA Mix with optimized RAP and fiber and were expressed as a percent value. Tensile strength ratio was done on the basis of the indirect tensile strength procedure, this test was done for the conventional SMA Mix as well as for the SMA Mix with optimized RAP and fiber.

The procedure adopted for ITS test is as per IRC: SP: 79: 2008. The number of blows for ITS is found out at 32 blows on both sides.

The results for ITS and TSR for conventional SMA mix and SMA mix with optimized RAP and fiber are tabulated in Table 10.

Table 10: Moisture Susceptibility

Mix Type	Marshall Stability of Controlled Specimen (kN)	Marshall Stability of Conditioned Specimen (kN)	Retained Marshall Stability (%)	Tensile Strength Ratio (%)
Conventional SMA mix	10.44	9.10	87.20	87.41
SMA mix with Optimized RAP and fiber	13.43	12.51	93.20	92.71

6.5 Immersion Wheel Tracking Test

The rutting tests was conducted on the conventional SMA mixes as well as for the SMA Mix with optimized RAP and fiber. The tests were carried out on the 40mm and 50mm thick (THK) specimens, with two tire pressures for each specimen. The tire pressures used are 5.6kg/cm^2 and

7.2kg/cm^2. The OBC for Conventional SMA mix and SMA Mix with optimized RAP and fiber was found out to be 6.2% and 6.4% respectively.

The results of the rutting of the 40mm THK specimens for different compositions are tabulated as follows in Table 11. Rut depth variation is shown in Fig. 6.

The results of the rutting of the 50mm THK specimens for different compositions are tabulated as follows in Table 12. Rut depth variation is shown in Fig. 7.

The test was conducted at room temperature at 22 passes/min with the help of treaded tire.

Comparison of Rut Depths for different specimens are shown in Fig. 8.

Table 11: Rutting Characteristics for SMA Mix of 40mm Thickness

Mix Type	Conventional		SMA mix with optimized	
Tire Pressure	5.6kg/cm²	7.2kg/cm²	5.6kg/cm²	7.2kg/cm²
Number of	**Rut Depth (mm)**			
100	0.51	0.45	0.52	0.55
200	0.77	0.63	0.58	0.64
300	1.03	0.85	0.66	0.79
400	1.21	1.07	0.79	0.85
500	1.38	1.33	0.85	0.99
1000	1.56	1.58	1.01	1.16
1500	1.79	1.86	1.16	1.28
2000	2.07	2.14	1.28	1.49
2500	2.28	2.33	1.42	1.67
3000	2.47	2.56	1.51	1.81
3500	2.72	2.84	1.63	1.96
4000	2.94	3.09	1.80	2.15
4500	3.16	3.27	1.89	2.31
5000	3.31	3.52	2.03	2.47
5500	3.47	3.86	2.19	2.54
6000	3.63	4.09	2.40	2.68
6500	3.82	4.32	2.53	2.83
7000	4.02	4.49	2.62	2.97
7500	4.13	4.68	2.73	3.11
8000	4.29	4.95	2.81	3.29
8500	4.41	5.19	2.96	3.43
9000	4.63	5.31	3.08	3.58
9500	4.79	5.48	3.16	3.76
10000	4.88	5.63	3.25	3.84

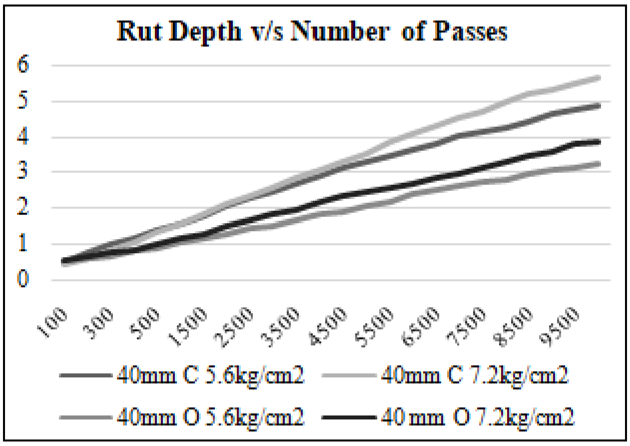


Figure 6: Rutting Characteristics for SMA Mix of 40mm Thickness

Table 12: Rutting Characteristics for SMA Mix of 50mm Thickness

Mix Type	Conventional SMA mix		SMA mix with optimized RAP and fiber	
Tyre Pressure	5.6kg/cm²	7.2kg/cm²	5.6kg/cm²	7.2kg/cm²
Number of Passes	Rut Depth (mm)			
100	0.43	0.50	0.33	0.36
200	0.64	0.76	0.50	0.54
300	0.86	1.02	0.67	0.73
400	1.01	1.20	0.78	0.85
500	1.15	1.37	0.89	0.97
1000	1.30	1.54	1.01	1.10
1500	1.49	1.77	1.16	1.26
2000	1.73	2.05	1.34	1.46
2500	1.90	2.26	1.48	1.61
3000	2.06	2.44	1.60	1.74
3500	2.27	2.69	1.76	1.92
4000	2.45	2.91	1.90	2.07
4500	2.64	3.13	2.05	2.23
5000	2.76	3.27	2.14	2.34
5500	2.90	3.43	2.25	2.45
6000	3.03	3.59	2.35	2.56
6500	3.19	3.78	2.47	2.70
7000	3.35	3.98	2.60	2.84
7500	3.45	4.09	2.67	2.91
8000	3.58	4.24	2.78	3.03
8500	3.68	4.36	2.85	3.11
9000	3.86	4.58	3.00	3.27
9500	4.00	4.74	3.10	3.38
10000	4.07	4.83	3.16	3.44

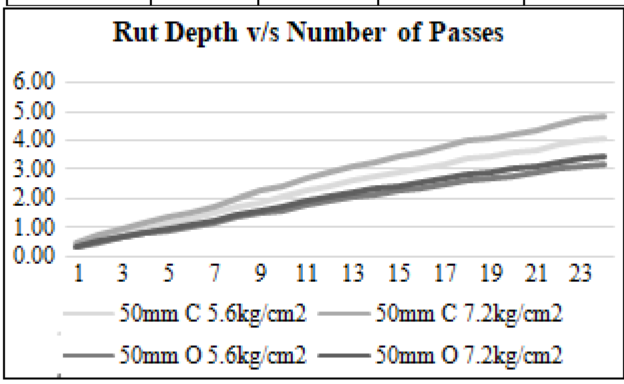


Figure 7: Rutting Characteristics for SMA Mix of 50mm Thickness

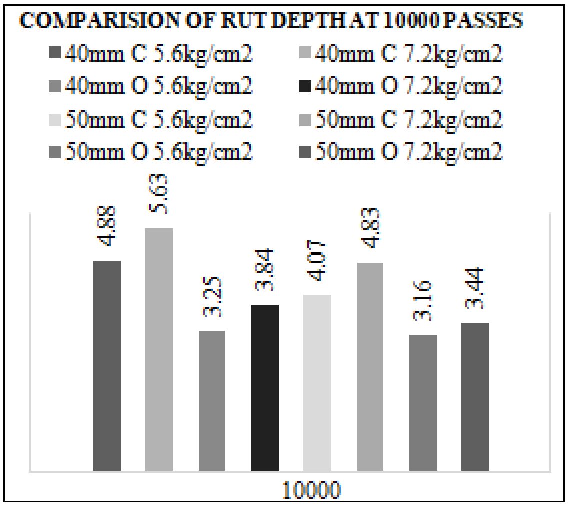


Figure 8: Comparison of Rut Depth of SMA specimens at 10000 Passes

7. Results and Discussion

7.1 Marshall Properties

It is observed that as the bitumen content increase, there is increase in the stability value and density value up to a certain point and then these parameters show decrease in their properties.

It is also seen that as the bitumen content increases, there is increase in the flow value as well as voids filled with bitumen and there is decrease in the percent voids in the mix respectively.

7.1.1 Discussion on Marshall Properties of Conventional SMA Mix

Marshall Tests were conducted on the Conventional mix of SMA for the obtained gradation as shown in Figure 1, as per MoRTH guidelines. The highest Marshall stability value obtained was 9.91kN, flow values were in between 2-4mm, the maximum percent voids of 4% was observed at OBC of 6.2%. These parameters were used for the further studies pertaining to engineering properties of the SMA Mix.

7.1.2 Discussion on Marshall Properties of RAP Replacement in SMA Mix

To determine the amount of RAP replacement in the mix, Marshall Properties were carried out. The different percentages studied were 8%, 16% and 24%. The maximum stability value for the mix was obtained for the one having 16% RAP content in it, the stability value was 12.9kN. The other Marshall parameters were well within the standard values.

7.1.3 Discussion on Determination Optimum Fiber Addition and Optimum Bitumen Content in the SMA Mix

The optimum fiber addition and optimum bitumen content were found out to be 0.3% and 6.4% respectively. The maximum stability observed at 6.4% bitumen content was 13.22kN.

The optimum RAP percent of 16%, Fiber addition of 0.3% and bitumen content of 6.4% were used in the further investigations of the engineering properties of the SMA Mix.
Comparative studies have been carried out on the conventional SMA mix and for the SMA mix with optimized RAP and fiber on various properties like Retained Marshall Stability, Indirect Tensile Strength and Rutting Characteristics if the SMA mix.

With the addition of the fiber, there is increase in the flow value of the mix when compared to the conventional SMA Mix to that of SMA Mix with optimized RAP and fiber.

7.2 Draindown Characteristics

The draindown test results yielded good results, the draindown of bitumen of the specimens was found out to be well within the limit of 0.3% maximum as prescribed in MoRTH. The results are as shown in Table 9.

7.3 Moisture Susceptibility

To determine the Moisture susceptibility of the SMA Mix, Retained Marshall Stability and Tensile Strength Ratio tests were conducted. The retained Marshall stability for conventional SMA Mix was found out to be 87.2% and that of SMA Mix with optimized RAP and fiber was 93.2%.The results of the test showed that the SMA Mix with optimized RAP and fiber were found to be greater than the conventional SMA Mix. The Tensile Strength Ratio for conventional SMA Mix is 87.41% and for SMA Mix with optimized RAP and fiber it is 92.71%, these are greater than the required standard value of 85% as per MoRTH.

7.4 Rutting Characteristics

Rutting resistance of the mix is determined at 10000 number of passes. The 40mm specimens for tire pressures of 5.6kg/cm^2 and 7.2kg/cm^2 showed a rut depth of 4.88mm and 5.63mm for conventional SMA Mix and 3.25mm and 3.84mm for SMA Mix with optimized RAP and fiber respectively. The 50mm specimens for tire pressures of 5.6kg/cm^2 and 7.2kg/cm^2 showed a rut depth of 4.07mm and 4.83mm for conventional SMA Mix and 3.16mm and 3.44mm for SMA Mix with optimized RAP and fiber respectively. From the values we can say that the conventional SMA Mix had more rut depth when compared to SMA Mix with optimized RAP and fiber. As the load on the specimens was increased there was observation that the specimens with lower weight had less rut depth when compared to specimens tested with higher weights. The specimens having SMA Mix with optimized RAP and fiber were found to be more rut resistance than the ones which were made of conventional SMA mixes.

8. Conclusions

The following conclusions can be made from the test results,

- It is observed that there is around 1.33 times increase in the stability value of the SMA Mix with optimized RAP and fiber when compared to the conventional SMA Mix at the optimum bitumen content.
- With the addition of the fiber, there is increase in the flow value of the SMA Mix with optimized RAP and fiber when compared to the conventional SMA Mix. The flow value observed for conventional was 2.80mm for conventional SMA and 3.97mm for SMA Mix with optimized RAP and fiber, which is within the range of 2-4mm. The other Marshall parameters were well within the standard values.
- The draindown of the specimens observed was 0.09% for conventional SMA Mix and 0.05% for the SMA Mix with optimized RAP and fiber.
- The retained Marshall stability for SMA Mix with optimized RAP and fiber was found out to be 1.06 times greater than the conventional SMA Mix.
- There is increase in the TSR by 1.06 times than the conventional SMA value when compared to SMA Mix with optimized RAP and fiber value.
- From the results it can be observed that the SMA mix with optimized RAP and fiber specimens were more rut

resistance when compared to the conventional SMA specimens.

- From the above results it can be noticed that the SMA Mix with optimized RAP and fiber showed better results when compared to the conventional SMA Mix in all aspects.
- By replacing the virgin aggregates with RAP aggregates in the mix by 16%, there is reduction in the usage of virgin aggregates, problem of RAP dumping can be avoided. This also leads to reduction the material cost of the aggregates and the binder used in the mix.

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