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Laboratory Investigation of Stone Matrix Asphalt Mixes Using Different Fibres

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Abstract- The concept of Stone Matrix asphalt which is also known as Stone Mastic Asphalt is used in Germany for the first time in 1960. The Stone Matrix Asphalt (SMA) is a mixture of gap-graded mix. SMA contain high coarse aggregate, fibre additives (may be natural or artificial) as stabilizers and high binder content. In this research work, the engineering properties of the SMA mix prepared with and without fibre has been studied. Also, the suitability of SMA mix in high temperature has been checked. The fibres used for this project is cellulose fibre. This project work was done for checking the suitability of cellulose fibre as stabilizer in the SMA mixture and to find out the stability and flow parameters of SMA and to find out these properties of SMA, various tests in laboratory was conducted. According to IRC-SP-79:2008 specification, the aggregate gradation is taken for the stone matrix asphalt mix and the binder content is varied as 5.5%, 6%, 6.5%, 7% by weight of aggregates and fibre used is at optimum fibre content i.e. at 0.3% and 0.5% by weight of aggregate. Here binder used is VG 30 grade bitumen and filler used is stone dust.

Keywords: Stone Matrix Asphalt, cellulose fibre, stone dust, VG 30 grade bitumen.

I. INTRODUCTION

Stone Matrix Asphalt was developed in Germany in 1960. Vehicles of carrying heavy load have special tyres of high pressure which causes high stress on pavement. The conventional bitumen mixes are not sufficient to bear this heavy load. SMA is a highly rut resistant, skid resistant, tough and stable. SMA has a high coarse aggregate content that interlocks to form a coarse skeleton that resist permanent deformation. The coarse skeleton is filled with bitumen and filler. The fibres are added to prevent drain-down of binder during transport and placement of SMA and to provide adequate stability of bitumen pavement. SMA is a gap-graded mixture with 70-80% coarse aggregate of the total mass, 8-12%filler, 6-7% binder, and about 0.3-0.5% fibre or stabilizer or additives. Many researchers have used different types of binders such as conventional 60/70 penetration grade bitumen and many modified binders such as Polymer Modified Binder (PMB), Crumb Rubber Modified Binder (CRMB), Natural Rubber Modified Binder (NRMB) etc. in SMA mixes. Use of Viscosity Grade (VG) Bitumen in the bituminous mixes significantly improves fatigue life, temperature susceptibility and resistance to moisture damage characteristics compared to other unmodified mixes. Also, the stabilizing additives, such as mineral fibres and different types of synthetic polymers, which are used to prevent drain down of the binder from the mixture are unable to give good strength. In this study VG-30 binder have been used in Stone Matrix Asphalt (SMA) mixes along with Topcel, Genicel, fibre as stabilizing additive. The Stone Matrix Asphalt mixes are tested by Marshall properties such as Marshall stability.

II. RESEARCH OBJECTIVES

Following are the main objectives of this study:

1) To check the suitability of SMA mixes using some non-conventional fibres such as Topcel, Genicel.
2) To study the various properties of aggregates to be used in the experimental process of the project.
3) To Prepare several Marshall Specimens moulds and to find out optimum binder content by using air voids in the mixture.
4) To compare the various engineering properties of the SMA samples with conventional bituminous samples at conditioned state.
5) To check the suitability of SMA mixes using some non-conventional fibers such as Topcel, Genicel in high temperature atmosphere.

III. MATERIALS

a) Mineral Aggregates

The mineral aggregates is the mixture of coarse and fine aggregates. Aggregate plays very important role in SMA because of high percentage content of coarse aggregate as compare to conventional bituminous mix. The higher proportion of this coarse aggregate provides a better stone-on-stone contact in between the coarse aggregate, which forms coarser skeleton. The coarser skeleton provides good shear strength and a high resistance to rutting. The coarse aggregate shall consist of crushed rocks retained on 4.75 mm sieve size. It shall be clean, hard, durable of cubical shape and free from dust and soft organic and other deleterious substances.

b) *Mineral Filler*

Stone Matrix Asphalt (SMA) is a gap-graded hot mixture that has higher proportion of coarse aggregate, lower proportion of middle-size aggregate and higher proportion of mineral filler than a dense-graded mixture. Because of the high quantity of mineral filler, the type and quantity of this fraction should play a major role in the properties of these mixtures and their mastics. Mineral filler which is used are finely divided mineral matter such as stone dust and Hydrated Lime.

c) *Binder (VG-30)*

Viscosity Grade Bitumen (Asphalt) is a Bitumen grade mostly used as a Paving Grade and it's suitable for road construction and for the asphalt pavements producing with premier attributes. VG Bitumen is generally used in the production of hot mix asphalt. VG-30 binder is usually used for construction of heavy load Bitumen pavements. Here the VG-30 is used in Stone Matrix Asphalt mix that need to tolerate significant traffic loads and to withstand at high temperature atmosphere.

d) *Stabilizer or Fibre*

SMA is a gap-graded mixture of coarse skeleton with high percentage of voids in the mix. So to prevent drain-down of mix and to provide a good binding between the aggregate or materials of SMA the stabilizing additives are used in the mix. Now-a-days the materials like polypropylene, minerals, polyesters and cellulose are used as a stabilizer or fibre. Cellulose fibre such as Topcel (0.3%) and Genicel (0.5%) is used in this investigation to give good tensile strength in high degree temperature.

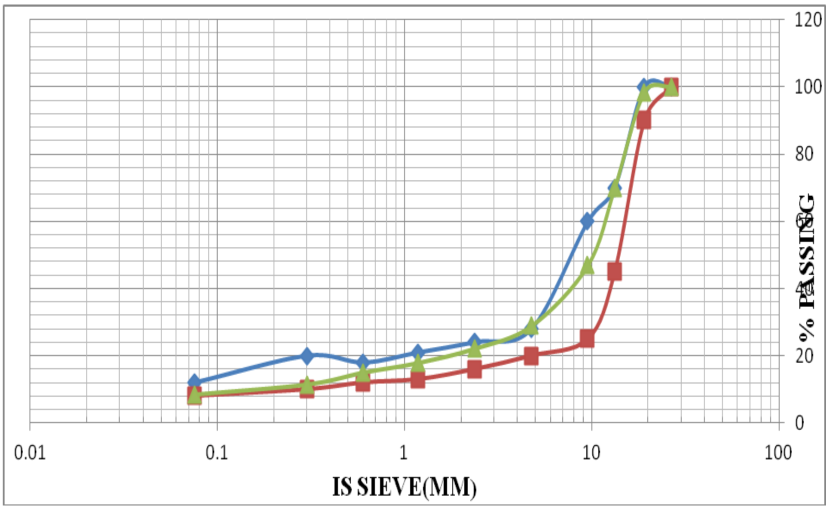
IV. MIX DESIGN

1) *Combined Grading of Coarse Aggregate, Fine Aggregate, Stone Dust, Mineral Filler:*

The avg. % passing of gradation test is used to carry out the combined gradation of Coarse Aggregate, Fine Aggregate, Stone Dust and Mineral Filler. The average of combined grading should be in between the lower limit and upper limit as stated by IRC SP: 79:2008. The following table and graph explains the values of gradation.

Table 1 Gradation of Aggregate

IS Sieve (mm)	20 mm % Passing	10mm % Passing	Stone Dust % Passing	Filler % Passing	20 mm (%)	10 mm (%)	Stone Dust (%)	Lime Filler (%)	Avg (%)	Lower Limit	Upper Limit
					54.0	**19**	**20.0**	**7.0**		**As per IRC SP: 79:2008**	
26.5	100	100	100	100	54.0	19.0	20	7.0	**100**	100	100
19	96.83	100	100	100	52.3	19.0	20	7.0	**98.29**	90	100
13.2	44.07	100	100	100	23.8	19.0	20	7.0	**69.80**	45	70
9.5	4.27	92.46	100	100	2.3	17.6	20	7.0	**46.87**	25	60
4.75	0.21	14.79	94.76	100	0.1	2.8	19.	7.0	**28.88**	20	28
2.36	0	1.53	74.26	100	0.0	0.3	14.9	7.0	**22.14**	16	24
1.18	0	0.83	53.78	100	0.0	0.2	10.8	7.0	**17.91**	13	21
0.6	0	0	40.27	100	0.0	0.0	8.1	7.0	**15.05**	12	18
0.3	0	0	22.97	99	0.0	0.0	4.6	6.9	**11.52**	10	20
0.075	0	0	9.77	93.5	0.0	0.0	2.0	6.5	**8.50**	8	12



Graph 1 Is Sieve Vs % Passing

2) *Preparation of Mixes*

a) Fractioning of material

The sampling of coarse and fine aggregates is carried out for 13mm Stone Matrix Asphalt composition as specified by IRC: SP-79:2008 sampling was done and then the sample is required to heat in oven at 160^O C for 1 hour. Then the sample is taken out from oven and placed at free open area for next 24 hr.

b) Addition of Additives

The cellulose fiber is added in the mix for giving the good Marshall Stability value i.e. tensile strength. Pure cellulose fiber such as Topcel in figure 1 is added in mix with 0.3% and Genicel fibre in figure 2 is added in the mix with 0.5%.

Figure 1 Photo of Topcel (0.3%)

Figure 2 Photo of Genicel (0.5%)

c) Preparation of Mould

According to the Marshall procedure given in ASTM D1559 the mixes was prepared. The coarse aggregates, fine aggregates, Stone Dust and mineral filler were mixed according to the adopted gradation. Six samples each of 5.5%, 6%, 6.5% and 7% bitumen were prepared respectively for bituminous course, with an increment of 0.5% of the total mix to obtain the optimum binder requirement and also to determine the effect of binder content and binder type on the mix properties. After obtaining Optimum Binder Content the samples made with and without additives, those are tested in Marshall Stability Test for getting Tensile Strength Ratio.

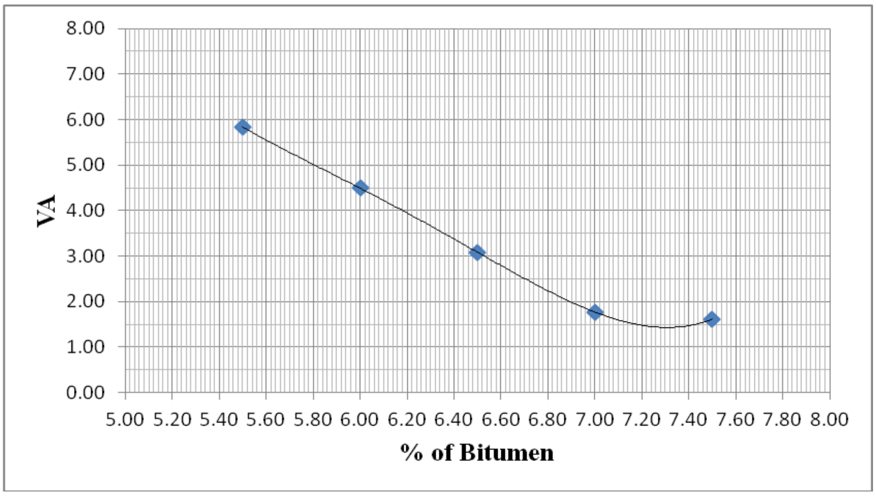
d) Marshall Stability Test (ITS)

Marshall stability test is a standard laboratory test, which is used for calculating the strength and flow characteristics of bituminous pavement mixes. The Indirect load is applied on the Marshall Specimen of unconditioned samples and conditioned (at 60^{o}C, for 24 hours) samples and from that Tensile Strength Ratio(TSR) of the sample is found out. This TSR gives the Tensile Strength of the sample with and without additives.

V. RESULT AND DISCUSSION

1) *Optimum Binder Content*

After taking trials for different binder percentage (Range from 5.5% to 7.0%), Air Voids value was calculated. By plotting graph of air voids Vs Percentage of Bitumen And by referring MORTH it was decided that the value of Percentage of Bitumen should be taken at 4% Air Voids in mixture. Therefore the value of Percentage of Bitumen at 4% air voids is 6.2%.



Graph 2 Va Vs Percentage of Bitumen

2) *Va, VMA, Gsb without additives*

To find value of Voids in Mineral Aggregate and Air Voids of aggregate following procedure was followed:

i) Aggregate content is equal to 100-Percentage of Bitumen.

ii) Measure Specimen weight in water (W_w) and Specimen Weight in air SSD (Saturated Surface Dry) and After that the Specimen weight in air (W_a) was measured.

iii) Calculate Bulk Specific Gravity (G_{sb}) = W_a / (W_{ssd}-W_w). After that Average value of G_{sb} is taken.

iv) Calculate Maximum Specific Gravity (G_{mm})

v) Calculate VMA = 100 – [(G_{sb} x P_s) / G_{sb}]

vi) Calculate V_a = [(G_{mm} – G_{sb}) / G_{mm}] x 100

Voids in Mineral Aggregate or VMA is the intergranular space occupied by asphalt and air in a compacted asphalt mixture. It is the sum of volume of asphalt and volume of air. VMA is kept in a proper range, because too low VMA causes deficiency of binder to properly coat the individual aggregate particle and Excessive VMA will cause unstable of pavement. Generally, 13 percent to 19 percent is the specified range of VMA. Air Voids are the space of air which occur between the coated aggregate particles in the final compacted mix. The stability and durability of bituminous pavement is depending on the Air Voids. Air voids below 3 percent result in an unstable mixture while above 8 percent results in a water-permeable mixture. In this project work, calculated value of VMA and Air voids are in acceptable Range.

Table 2 Va, VMA, Results (without additives) at OBC

P_b	P_s=100-P_b		W_a	W_w	W_{ssd}	W_{ssd} - W_w	W_a / (W_{ssd}-W_w)	G_{sb}	G_{mm}	VMA	V_a
6.2	93.8	1	1330	791	1334	543	2.449	2.481	2.578	18.51	4.76
		2	1326	789	1328	539	2.460				
		3	1323	801	1334	523	2.534				

3) *Tensile Strength Ratio without additives (Proving Ring Factor=5.805)*

Static indirect tensile test has been used to find the tensile strength ratio of SMA mixes. Six samples are prepared and conducted indirect tensile strength (ITS) of unconditioned and conditioned (at 60^{O}C, for 24 hours) samples have been determined.

Table 3 Tensile Strength Ratio Results (without additives) at OBC

UNCONDITIONED ITS							CONDITIONED ITS				
T cm	D cm	PR (Div)	P (kg)	T (I.T.S.)	Avg T1	Pie	PR	P	T (I.T.S.)	Avg T2	(T2/T1) X 100 (%)
6.7	10	70	406.4	386.1	407.7	3.14	90	522.5	496.4	473.4	116.12
6.8	10	74	429.6	402.2			85	493.4	461.9		
6.8	10	80	464.4	434.8			85	493.4	461.9		

4) *Va, VMA, Gsb with additives*

Below table 3 shows two types of additives i.e. Topcel and Genicel with 0.3% and 0.5% content shows better result for heavy load applications at Optimum Binder Content

Table 4 Va, VMA, Results (with additives) at OBC

Stabilizers	Pb	Ps= 100-Pb		Wa	Ww	Wssd	Wssd - Ww	Wa / (Wssd-Ww)	Gsb	Gm m	VMA	Va
Topcel (0.3%)	6.2	93.8	1	131 7	797	1319	522	2.52	2.52	2.62	17.19	3.87
			2	131 2	794	1314	520	2.52				
			3	131 7	796	1319	523	2.52				
Topcel (0.5%)	6.2	93.8	1	132 4	798	1326	528	2.50	2.50	2.62	17.90	4.58
			2	133 2	804	1337	533	2.49				

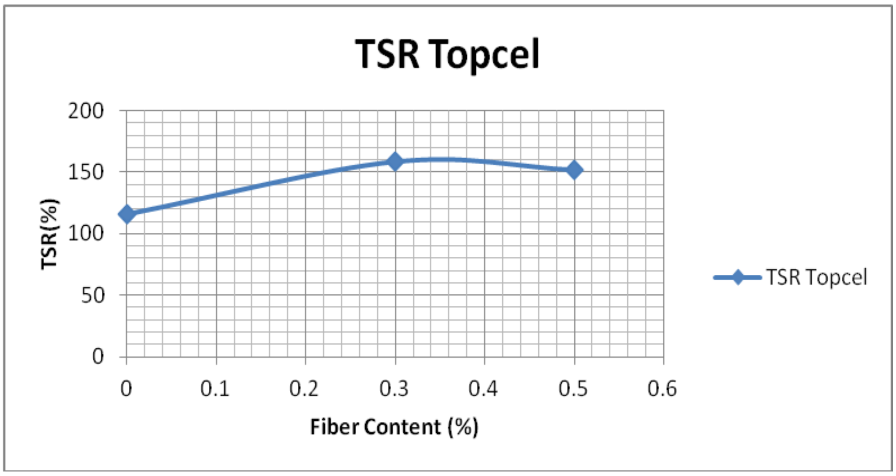
			3	1340	810	1342	532	2.51				
Genicel (0.3%)	6.2	93.8	1	1317	796	1319	523	2.51	2.51	2.62	17.56	4.19
			2	1314	795	1317	522	2.51				
			3	1319	799	1322	523	2.52				
Genicel (0.5%)	6.2	93.8	1	1322	801	1323	522	2.53	2.51	2.62	17.47	4.20
			2	1340	810	1341	531	2.52				
			3	1328	795	1330	535	2.48				

5) *Tensile Strength Ratio with additives (Proving Ring Factor=5.805)*

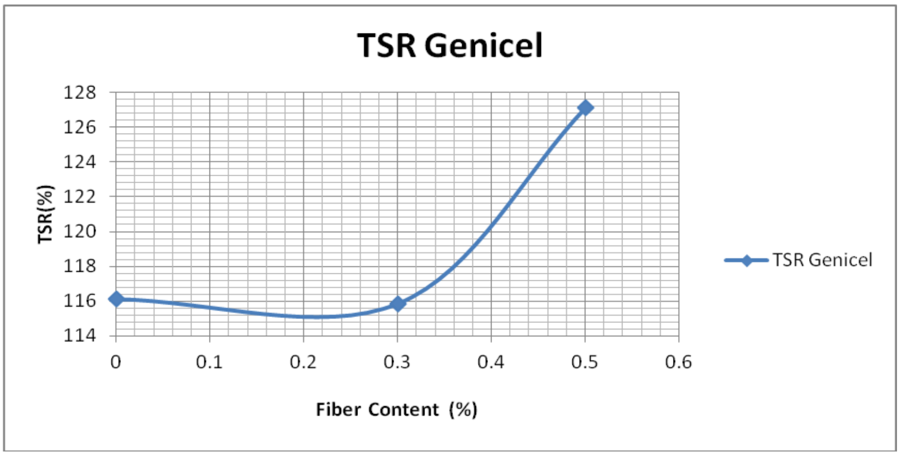
After testing different types of stabilizers with different percentage (0.3% and 0.5% respectively), it was concluded that the Topcel stabilizer gives better strength at 0.3% fibre content than 0.5% fibre content. On the other hand, the Genicel stabilizer gives better strength at 0.5% fibre content than 0.3% fibre content (Result shown in Table 4).

Table 5 Tensile Strength Ratio Results (with additives) at OBC

UNCONDITIONED ITS							**CONDITIONED ITS**				
T cm	**D C m**	**PR (Div)**	**P (kg)**	**T (I.T.S.)**	**Avg T1**	**Pie**	**PR**	**P**	**T (I.T.S.)**	**Avg T2**	**(T2/T1) *100 (%)**
6.5	10	80	464.4	454.8			155	899.7	881.6		
6.5	10	90	522.4	511.6	485.7		100	580.5	568.8	772.3	159.00
6.4	10	85	493.4	490.8			150	870.7	866.5		
6.4	10	75	435.3	433.2			125	725.6	722.2		
6.5	10	80	464.4	455.0	459.8		100	580.5	568.8	699.9	152.21
6.4	10	85	493.4	491.1		3.14	140	812.7	808.8		
6.3	10	70	406.4	410.8			80	464.4	469.5		
6.3	10	75	435.4	440.2	428.1		80	464.4	469.5	496.0	115.86
6.4	10	75	435.4	433.3			95	551.5	548.8		
6.5	10	85	493.4	483.3			130	754.6	739.4		
6.3	10	75	435.3	439.9	459.4		95	551.4	557.4	583.9	127.10
6.5	10	80	464.4	455.1			80	464.4	455.0		



Graph 3 TSR Vs Fibre Content



Graph 4 TSR Vs Fibre Content

6) *Tensile strength ratio (TSR) test*

Static indirect tensile test has been used to compute the tensile strength ratio of SMA mixes. The indirect tensile strength (ITS) of unconditioned and conditioned (at 60^{O}C, for 24 hours) samples have been determined for this purpose. The TSR is expressed as the percentage of ratio of these two values. Table 6 shows the results of tensile strength ratio test of SMA mixes with two types of fibre and with 6.2% binder. It can be seen that for mixes without fibre of VG-30 binder has TSR value less than TSR value of mixes with fibre content and hence it is acceptable in terms of moisture susceptibility characteristics.

Table 6 TSR Results (with additives)

Type of Fibre	Mixes with fibre			Mixes without fibre		
	ITS of unconditioned sample (kPa)	ITS of conditioned sample (kPa)	TSR (%)	ITS of unconditioned sample (kPa)	ITS of conditioned sample (kPa)	TSR (%)
Topcel	485.7	772.3	159.00	407.7	473.42	116.12
Genicel	459.4	583.9	127.10			

VI. CONCLUSION

VG-30 Binder was tried for the preparation of the SMA mixes with and without fibres. Topcel and Genicel cellulose fibre which is easily available fibre are used in the mixes. It has been observed that a marginal fibre concentration of 0.3% Topcel and 0.5% Genicel considerably improves the Marshall properties of SMA mixes. It is found that addition of fibre increases the tensile strength of mixes. Also, mainly it is found that the SMA mixes gives better tensile strength in conditioned samples than unconditioned. From the overall discussion of the test results on SMA mixes with VG-30 binders, it can be concluded that mixes of 0.3% Topcel and 0.5% Genicel perform satisfactorily and can be used in SMA mixes for the pavement construction even at high temperature atmosphere.

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