INFLUENCE OF ADDITIVES ON THE DRAIN DOWN CHARACTERISTICS OF STONE MATRIX ASPHALT MIXTURES

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Abstract

In Kerala highways, where traditional dense graded mixtures are used for the surface courses, major distress is due to moisture induced damages. Development of stabilized Stone Matrix Asphalt (SMA) mixtures for improved pavement performance has been the focus of research all over the world for the past few decades. Many successful attempts are made to stabilize SMA mixtures with synthetic fibres and polymers. India, being an agricultural economy produces fairly huge quantity of natural fibres such as coconut, sisal, banana, sugar cane, jute etc.. Now- a -days the disposal of waste plastics is a major concern for an eco- friendly sustainable environment. This paper focuses on the influence of additives like coir, sisal, banana fibres (natural fibres), waste plastics (waste material) and polypropylene (polymer) on the drain down characteristics of SMA mixtures. A preliminary investigation is conducted to characterize the materials used in this study. Drain down sensitivity tests are conducted to study the bleeding phenomena and drain down of SMA mixtures. Based on the drain down characteristics of the various stabilized mixtures it is inferred that the optimum fibre content is 0.3% by weight of mixture for all fibre mixtures irrespective of the type of fibre. For waste plastics and polypropylene stabilized SMA mixtures, the optimum additive contents are respectively 7% and 5% by weight of mixture. Due to the absorptive nature of fibres, fibre stabilizers are found to be more effective in reducing the drain down of the SMA mixture. The drain values for the waste plastics mix is within the required specification range. The coir fibre additive is the best among the fibres investigated. Sisal and banana fibre mixtures showed almost the same characteristics on stabilization.

Keywords: *Stone Matrix Asphalt, stabilizing additives, fibres, waste plastics, drain down, stabilizing capacity.*

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1. INTRODUCTION

Stone Matrix Asphalt (SMA) has been first introduced in Europe for resisting damage from the studded tires better than other type of HMA [1]. In recognition of its excellent performance, a national standard was set up in Germany in the year 1984. The Indian Roads Congress has adopted a tentative SMA specification [2]. One test road was constructed in Delhi in October 2006, using SMA as a surfacing course [3]. By considering the advantage of the proven field performance of this test track and in other regions of developed countries with climatic conditions reasonably close to that of India, SMA can be considered as the right choice for long lasting pavements.

SMA is a gap graded bituminous mixture containing a high proportion of coarse aggregates and filler with relatively less medium sized aggregates [4]. It has rich mastic comprised of bitumen, fines, and mineral filler. Additives such as fibres or polymers are used as a stabilizer to secure the mastic within the overall structure and prevent the draining off during storage, transportation and placing of SMA.

Drain down is considered to be that portion of the mixture (fines and bitumen) that separates itself from the sample as a whole and flows downward through the mixture [5]. Drain down test is more significant for SMA mixtures than for conventional dense-graded mixtures. It can be used to determine whether the amount of drain down measured for a given bituminous mixture is within the specified levels (should not exceed 0.3% by weight of the mixture [6]). SMA mixtures exhibited a very high bitumen binder film thickness (6-7% by weight of mix). This high binder content and the filler content as compared to that of dense-graded HMA lead to higher susceptibility for the bitumen binder to drain off the aggregate skeleton in SMA mixtures. Irregular distribution of bitumen binder due to its drain down can lead to raveling of zones with low bitumen binder content and reduction of permeability in zones with accumulation of bitumen binder [7, 8].

Potential problems with SMA mixtures are drainage and bleeding. Storage and placement temperatures cannot be lowered to control these problems due to the difficulty in obtaining the required compaction. Therefore, stabilizing additives has been added to stiffen the mastic and thereby reducing the drainage of the mixture at high temperatures and to obtain even higher binder contents for increased durability [9]. Fibres or polymers can be used as the additives. In this study the influence of natural fibres (coir, sisal and banana fibre), a polymer (polypropylene) and a waste material (used plastics in shredded form) on the drain down characteristics of SMA mixtures are studied.

2. MATERIAL CHARACTERISATION

Aggregate of sizes 20mm, 10mm and stone dust procured from a local quarry at Kochi, Kerala is used in the present investigation and the physical properties of aggregates are given in Table-1. Ordinary Portland cement from a local market which makes a better bond with aggregate, bitumen and additive is used as the filler material and the physical properties are shown in Table-2. Bitumen of 60/70 penetration grade obtained from Kochi Refineries Limited, Kochi, is used in the preparation of mix samples and the physical properties of bitumen are given in Table- 3.

2.1. Stabilizing Additives

Three natural fibres namely coir, sisal and banana fibre, a polymer, polypropylene and waste plastics in shredded form are used as stabilizing additives for the present study.

Table -1: Physical properties of aggregates

Property	**Values obtained**	**Method of Test**
Aggregate impact value (%)	16	IS:2386 (IV)
Los Angeles Abrasion Value	27	IS:2386 (IV)
Combined Flakiness and Elongation Index (%)	18	IS:2386 (I)
Stripping Value	Traces	IS 6241:1971 (R2003)
Water Absorption (%)	Nil	IS:2386 (III)
Specific gravity	2.65	IS:2386 (III)

Table -2: Physical properties of cement

Physical property	Values obtained
Specific gravity	3.12
% passing 0.075 mm sieve (ASTM C117)	96

Table -3: Physical properties of bitumen

Property	Result	Test procedure as per specification
Specific Gravity @ 27˚C	1	IS:1202 - 1978
Softening Point (˚C) (R&B Method)	50	IS:1205 - 1978
Penetration @ 25˚C,0.1 mm 100g, 5 sec	64	IS:1203 - 1978
Ductility @ 27˚C (cm)	72	IS:1208 - 1978
Flash Point (˚C) Fire Point (˚C)	240 270	IS:1209 – 1978
Viscosity at 60 ˚C (Poise)	1200	IS:1206 – 1978
Elastic recovery @ 15˚C (%)	11	IRC: SP:53 – 2002

2.1.1 Fibre Stabilizer

Presently, the production of natural fibres in India is more than 400 million tones [10]. In this study, coir, sisal and banana fibre at different percentages by weight of mixture are used as the stabilizing additives. The photographs of these fibres are shown in Fig.-1. The coir fibres and sisal fibre for the present work had locally procured from Alappuzha, and banana fibre from Banana Research station, Thrissur, Kerala and their properties are given in Table- 4.

Fig -1: Coir fibre, Sisal fibre, Banana fibre

2.1.2 Polymer Stabilizer

Polypropylene (Fig-2) manufactured by Reliance Petrochemicals is used for the present study and their physical properties are given in Table-5. The polymer is added at percentages of 1, 3, 5, 7 and 9, by weight of mix to the heated aggregate and thoroughly mixed and heated again so as to have a coating on the aggregate before adding the heated bitumen.

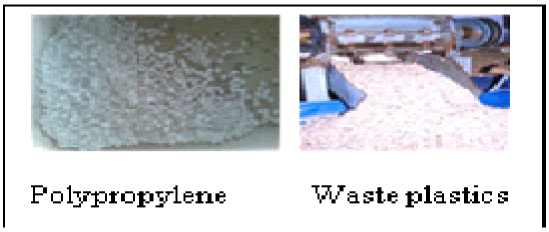

Fig -2: Polypropylene and Waste plastics

Table -4: Physical properties of fibres

Property	**Coir fibre**	**Sisal fibre**	**Banana fibre**
Diameter (μm)	100 - 450	50 - 200	80 - 250
Density (g/cm ^{3})	1.45	1.40	1.35
Cellulose content (%)	43	67	65
Lignin content (%)	45	12	5
Elastic modulus(GN/m^2)	4-6	9 -16	8 -20
Tenacity (MN/m^2)	131 - 175	568 - 640	529 - 754
Elongation at break (%)	15 - 40	3 - 7	1.0 – 1.2

2.1.3 Waste Plastics as a Stabilizer

The plastic used were the disposed carry bags, films, cups etc., with a maximum thickness of 60 microns made out of polyethylene, polypropylene and polystyrene. They are cleaned if needed and shredded to small pieces (particle size 2-3 mm) and is shown in Fig- 2. Waste plastics on heating soften at around 130˚C and thermo gravimetric analysis has shown that there is no gas evolution in the temperature range of 130-180˚C.

Table -5: Physical properties of polypropylene

Physical properties	Result obtained
Thermal Expansion Coefficient(˚/C)	14.0×10^{-5}
Melting Temperature(˚C)	140 - 160
Water Absorption	0.03% after 24 hours immersion
Chemical Unit	$-CH_2-CH_2-CH_3-$
Density(g/cm^3)	0.64
Thermal Degradation Temp(˚C)	270 - 300
Ignition Temperature(˚C)	> 700

The aggregate is heated to 170˚C and the shredded plastics waste is added, it gets softened and coated over the aggregate. Immediately the hot Bitumen (160˚C) is added with constant mixing to give a uniform distribution. As the polymer and the bitumen are in the molten state they get mixed and the blend is formed at the surface of aggregate [11]. The physical properties of plastic coated aggregates are given in Table- 6.

Table-6: Physical properties of plastic coated aggregates

Property	Plastic Coated Aggregate			
Impact value (%)	14			
Abrasion value (%)	24			
Stripping value (%)	After(hrs)			
	2	24	72	96
	0	0	0	0
Water Absorption Value (%)	Nil			

From Table-6, it is evident that the plastic coating over the aggregates enhances the toughness and hardness of aggregate. The stripping and water absorption value is found to be nil showing its better adhesion with bitumen.

3. GRADATION OF AGGREGATES

The sieve analysis, blending and the specified limits of the SMA mixture are given in Table 7 as per NCHRP, TRB[12].

Table -7: Gradation of aggregates and their blends for SMA mixture

Sieve size (mm)	Percentage passing				Adopted Grading A: B: C: D 50:30:11:9	Specified Grading NCHRP, TRB
	20 mm (A)	10 mm (B)	Stone dust (C)	Cement (D)		
25.0	100	100	100	100	100	100
19.0	98	100	100	100	99	90 -100
12.5	20	100	100	100	60	50 - 74
9.50	4	58	100	100	39	25 - 60
4.75	0	6	100	100	22	20 - 28
2.36	0	0	92	100	19	16 - 24
1.18	0	0	77	100	17	13 - 21
0.6	0	0	64	100	16	12 - 18
0.3	0	0	45	100	14	12 - 15
0.075	0	0	6	96	9	8 - 10

4. MIX DESIGN

For the proposed design mix gradation, four specimens are prepared for each bitumen content within the range of 5.5 – 7.5% at increments of 0.5 percent, in accordance with ASTM D 1559 using 50 blows/face compaction standards. All bitumen content shall be in percentage by weight of the total mix. As soon as the freshly compacted specimens have cooled to room temperature, the bulk specific gravity of each test specimen shall be determined in accordance with ASTM D 2726[13]. The stability and flow value of each test specimen shall then be determined in accordance with ASTM D 1559. After the completion of the stability and flow test, specific gravity and voids analysis shall be carried out to determine the percentage air voids in mineral aggregate and the percentage air voids in the compacted mix and voids filled with bitumen. Values which are obviously erratic shall be discarded before averaging. Where two or more specimens in any group of four are so rejected, four more specimens are prepared and tested.

The average values of bulk specific gravity, stability, flow, VA, VMA and VFB obtained above are plotted separately against the bitumen content and a smooth curve drawn through the plotted values. Average of the binder content corresponding to VMA of 17 % and an air void of 4% are considered as the optimum binder content [14]. Stability and Flow values at the optimum bitumen content are then found from the plotted smooth curves The optimum bitumen content (OBC) for the SMA mixture is determined and is found to be 6.42 % (by wt. of total mix). The SMA mixture without additives is considered as the control mixture for the drain down test.

5. DRAIN DOWN TEST

The test developed by AASHTO T305 covers the determination of the amount of drain down in an uncompacted bituminous mixture at the optimum binder content when the sample is held at elevated temperatures comparable to those encountered during the production, storage, transport, and placement of the mixture. The samples of the SMA loose mixtures are placed in a wire basket fabricated using standard 6.3mm sieve cloth. Wire basket and its dimensions are given in Fig- 3 and Fig- 4.

A total of twenty two loose SMA samples are tested with triplicate samples for each design mix of SMA, stabilized with each additive and also without additive. The mass of loose SMA mixture sample and the initial mass of the pan is determined to the nearest 0.1g. The loose SMA sample is then transferred and placed into the wire basket without consolidating or disturbing it. The basket is placed on the pan and the assembly is placed in the oven (175˚ C) for 1hour. After the sample has been in the oven for 1 hour, the basket and the pan is removed and the final mass of the pan is determined and recorded to the nearest 0.1 g. The Drain down of the mixture can be calculated as follows,

$$\text{Drain down (\%)} = (C - B)\ 100/A$$

A = Weight of initial total sample (g), B = Weight of initial pan (g) and C = Weight of final pan (g)

The drain down at the optimum bitumen content for each percentage of additive content are determined and reported in Table-8 & 9.

6. RESULTS AND DISCUSSIONS

Results of drain down at various percentages of additive contents are given in Chart- 1 and Chart- 2. From Table 8 and 9, it can be observed that all additives provide significant stabilization to the mixture as compared to the control mixture. Drain down of the control mixture is 6.5% which is beyond the specified limits (< 0.3%). It is evident that in all stabilized SMA mixtures, the values of drain down decreases considerably with increase in additive content and reaches the acceptable limit at 0.2 % fibre content and 5% WP and PP content. This indicates that in all mixtures, each additive is performing its function as a stabilizing additive. The potential effects of the inclusion of additives in SMA mixtures are therefore beneficial in preventing the bleeding phenomenon and the drain down of this gap graded SMA mix having rich binder content. Either fibre or polymer additive can be effectively utilized as the stabilizing agent. Fibre stabilizers are found to be more effective in reducing the drain down than polymer stabilizers due to the absorptive nature of fibres. Among the fibre stabilized mixtures, SMA mixture with coir fibre shows the 0% drain down at 0.3% fibre content.

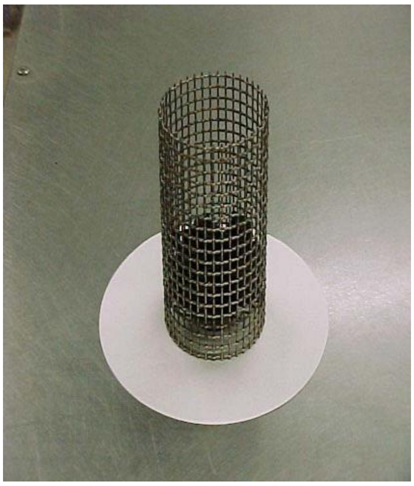

Fig -3: Drain down test apparatus

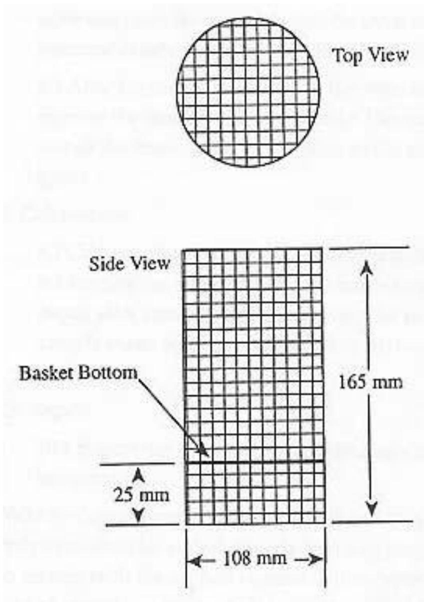

Fig -4: Dimensions of wire basket

Table- 8: Drain down values for different fibre percentages

% Fibre	Drain down (%)		
	Coir	**Sisal**	**Banana**
0	6.497	6.497	6.497
0.1	1.887	2.347	2.584
0.2	0.083	0.114	0.116
0.3	0	0.012	0.014
0.4	0	0	0.003

Table -9: Drain down values for different percentages of PP and WP

% Additive	Drain down (%)	
	Polypropylene	**Waste plastics**
0	6.497	6.497
1	2.402	2.61
3	1.497	1.489
5	**0.146**	0.128
7	0.018	**0.017**
9	0.004	0.002

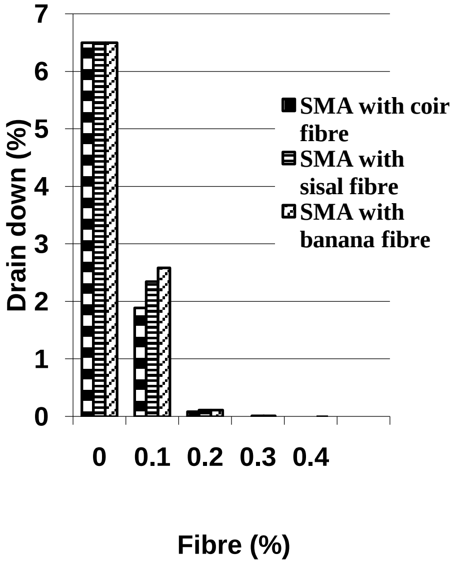

Chart -1: Variation of drain down with different fibre percentages

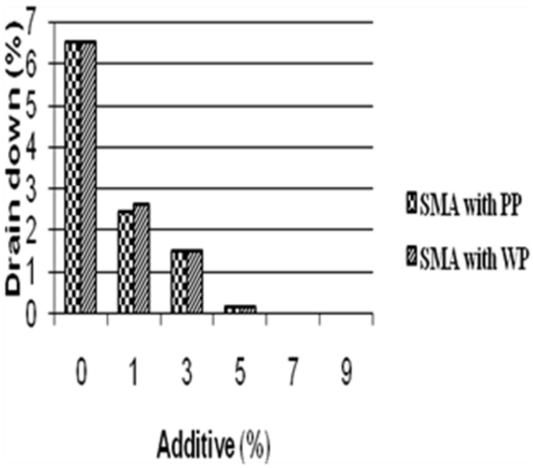

Chart -2: Variation of drain down with different percentages of WP and PP

6.1 Stabilizing Capacities of Different Additives

There are some differences in the performance of each additive at binder contents greater than the optimum binder content. Drain down is also tested at binder contents exceeding the optimum binder content to determine the stabilizing capacity of each additive. Binder contents of each SMA mixes are varied from 6.5% (by weight of mixture) at an increment of 1.0% until a drain down of 0.3% is observed. The stabilizing capacity of each additive is determined as the binder content at which the drain down reached 0.3%. The drain down results at varying binder contents are given in chart-3 and the stabilizing capacities of various additives are given in Table 10. It is evident that the fibre stabilized mixtures have higher stabilizing capacity than the mixes with WP and PP. All the stabilized SMA mixtures have 0.3% drain down above 10% binder content. The coir fibre had the highest stabilizing capacity of 16%. The higher stabilizing effect of fibres can be attributed to the absorptive nature of the fibres compared to the polymers. The fibers firmly bind the aggregate particles inside the matrix and prevent them of movement, which makes the mix stiffer. SMA with waste plastics reached the drain down limit at 11% binder content. The waste plastics and polypropylene have almost similar stabilizing capacities.

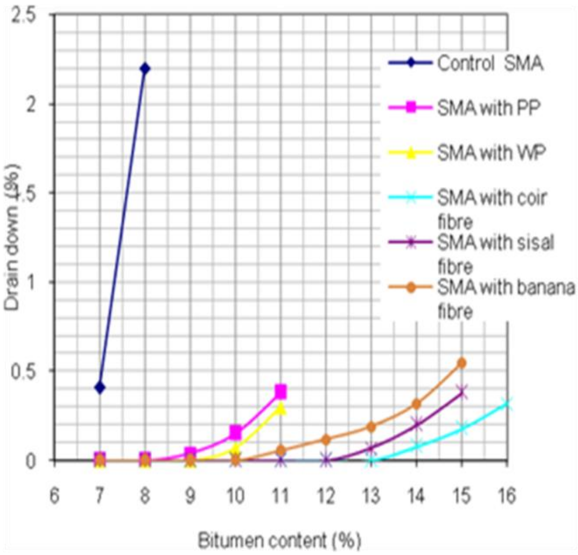

Chart -3: Drain down results at varying binder contents

Table- 10 Stabilizing capacities of various additives

Additive	Stabilizing Capacity (%)
Coir	15.9
Sisal	14.7
Banana	14
Polypropylene	10.8
Waste plastic	11

7. CONCLUSIONS

From the drain down study of the SMA mixtures, it can be concluded that all the five additives used in the stone matrix asphalt for the present investigation act as effective stabilizing agents. The role of additive is to stiffen the mastic and thereby reducing the drainage of the mixture at high temperatures during storage, transportation, placement and compaction of SMA mixtures. Due to the gap graded gradation and rich binder content in SMA, the control mixture is subjected to heavy drain down. This strongly supports the need of the additive in SMA mixtures. The coir fibre which has a higher stabilizing capacity as compared to other additives is found to be more effective than the others. From the studies it can be concluded that the natural fibres and the waste plastics can replace the imported synthetic fibres and the expensive polymers in Stone Matrix Asphalt.

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