Experimental Investigation of Stone Mastic Asphalt with Sisal Fiber

Naveen Kumar R
Department of Civil Engineering
TRP Engineering College
Tiruchirappalli, India

V Sunitha
Department of Civil Engineering
National Institute of Technology
Tiruchirappalli, India

Abstract **- In the present study, an attempt has been made to study the engineering properties of mixtures of stone matrix asphalt made with conventional bitumen 60/70 with a non-conventional natural fibre, namely sisal fibre. The binders in different proportions are used for preparation of mixes with a selected aggregate grading to find OBC. The optimum binder content is determined by keeping the suggested air voids content in the mix. The fibre is added to OBC and two other bitumen concentrations closest to it. For this, various Marshall samples of SMA mixtures with and without fibres with varying binder concentration are prepared. Marshall properties such as stability, flow value, density, air voids are used to review the optimum binder content and optimum fibre content for modified SMA mixes. Thereafter, the drain down characteristics for modified and unmodified SMA Mix have been studied. It is observed that only 0.28% addition of sisal fibre significantly improves the Marshall properties of SMA mixes. Addition of nominal 0.28% fibre considerably improves the drain down characteristics of the SMA mixes with conventional bitumen, which would otherwise have not been able to meet the prescribed criteria.**

Keywords - Stone matrix asphalt, bitumen, sisal fibre, modified mix, Marshall Properties, draindown test

I. INTRODUCTION

Researchers are in continuous working for the bituminous pavement improvement in different ways. Stone Matrix Asphalt (SMA) is a gap graded mix, characterized by high coarse aggregates, high asphalt contents. High concentration of coarse aggregate maximizes stone-to-contact and interlocking in the mix which provides strength and the rich mortar binder provides durability. It provides a higher resistant to rutting and provides sufficient friction to pavement surface even it is exposed to repeated loads. In comparison to dense graded mixtures, SMA has higher proportion of coarse aggregate, lower proportion of middle size aggregate and higher proportion of mineral filler. It is used at a very large scale in some countries particularly in Europe, which were used as alternate solution to overcome various problems such as environmental pollution being caused due to mixing and application of other hot mixes. As SMA is constituent of rich binder, it may lead to draindown problem which exists in transportation of mix, at that stage additives were used as solution, especially natural fibres such as sisal fibres. Sisal fibre is a hard fibre extracted from the leaves of the sisal plant (Agave sisalana). Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, the West Indies and the Far East. A sisal plant produces about 200-250 leaves and each leaf contains 1000-1200 fibre bundles. Generally, the strength and stiffness of plant fibres depend on the cellulose content. The structure and properties of natural fibres depend on their source, age, etc. (13). The absorbing nature of sisal fibre serves act as an additive for SMA and life of the fibre is higher as compared to other natural fibres.

II. LITERATURE REVIEW

SMA mixture contains 70-80% coarse aggregate of total aggregate mass, 6-7% of binder, 8-12% of filler.SMA resists permanent deformation and has the potential for long term performance and durability. The main disadvantage of SMA is drain down problem as it is using higher amount binder. Stabilizing bituminous mix with natural fibre potentially increases the service life of pavement in application (1)(2). But the problem of fatigue cracking is still persistent, it occurs because the bituminous mix is weak in tension. Therefore tensile strength of bituminous mix has to improve by addition of suitable reinforcement. Fibres are the most suitable substitute with offers good reinforcement to mix (3). After many researches on different fibres with bituminous mix, found that natural fibres are good substitute for synthetic fibres as they are of low cost. Usually stability increases and flow value decreases by development of resistance due to addition of fibres, air voids increases as fibres have tendency to absorb bitumen (4-6). Fibre content plays vital role in marshal properties, but addition of fibre is limited to some extent (15). Depends on availability selection of natural fibre is also equally important which should have the tendency to store bitumen instead of draining down. Sisal fibre is one among natural fibre which has the nature and is composed of 4% fibre, 0.75% cuticle, 8% dry matter and 87.25% water (12). So normally a leaf weighing about 600 g will yield about 3% by weight of fibre with each leaf containing about 1000 fibres. The tensile properties of sisal fibre are not uniform along its length (14). The root or lower part has low tensile strength and modulus but high fracture strain. The fibre becomes stronger and stiffer at mid- span and the tip has moderate properties. The sisal fibres are usually creamy white, average from 80 to 120 cm in length and 0.2 to 0.4 mm in diameter.

III. LABORATORY INVESTIGATION

A. *Materials*

The materials used in the present study includes 60/70 penetration grade bitumen, graded aggregate of nominal size (20mm, 10mm, 4.75mm), dust and processed sisal fibre. The physical properties of aggregate and bitumen used in mix were presented in table 2 and 3

B. *Marshall Test*

Marshal Test procedure is used in the investigation for study of behaviour of sisal fibre modified bituminous mix. Gradation of aggregate is one of the important factors for mix, but in this study instead of proportioning of aggregate as conventional method, the adopted grading is middle value of suggested grading in specification prepared by Indian Roads Congress (IRC) (Indian Highways, February 2007) presented in table 1.

C. *Method of Addition of sisal fibre*

Distribution of fibre determines the strength of mix. There are two methods of addition of fibres in bituminous mix, they are wet and dry method. Wet method is addition of fibre in bitumen before adding it to heated aggregate. Dry method of addition of fibres results in homogeneity mixture, because the natural fibre has tendency to mix thoroughly with dry heated aggregate. Also this method reduces balling effect as it is not having any medium to clumps (7).

D. *Preparation of Specimen*

The specimen is prepared with Marshall test method. The process includes two step processes. First the aggregate mix of absolute grading and chosen bitumen were heated separately at 170 – 210 ^{0} C and 150 ^{0} C respectively. After attaining the temperature the bitumen is added to heated aggregate and mixed thoroughly, the mix is maintained at 180 ^{0}C. Post addition period of bitumen should not be more than 5 minute otherwise bitumen will lose it consistency. The mix is then transferred to mould used for test and the sample is compacted by 50 no. blows on either side for compaction at that time 150 ^{0}C should be maintained. Bitumen content used in mix was varied from 5.5 to 7.0% with interval of 0.5 %. The bitumen is added by replacing aggregate. Composition of aggregate for each mix is shown in table 4. These samples were kept as control mix.

The SMA mix were prepared with a additive at the rate of 0.1 to 0.5% (by the weight of total mix) with interval of 0.1 %. The length of fibre was kept as 6mm as per specification (8). The aggregate specimen taken was maintained an absolute grading as for control mix, the aggregate gradation was given figure 1. The fibre rate was varied for each bitumen content (Optimum Bitumen Content (OBC) and two other content closest to OBC). Then the sisal fibre was added to heated aggregate in dry method and mixed thoroughly, the mix was maintained at 180^{0}C. The mix was mixed thoroughly so that balling and clumping would be avoided. The bitumen added mix should not kept more than 5 minutes in stove, because continuous heating of mix leads to loss of consistency of bitumen and increasing flow which leads to heterogeneity mix. After compaction the mix was kept in room temperature for 24 hours before unmolding.

E. *Testing of specimen*

The samples were unmolded and weighted in air and water for density, Air voids (AV), Voids in Mineral Aggregate (VMA), Voids filled with Bitumen (VFB). The prepared sample is tested after 24 hours of casting for stability and flow value. Initially the samples prepared without fibre were tested in order to obtain the OBC for control mix. Optimum bitumen content is obtained by taking the average value of bitumen content for stability value, flow value and percentage AV as stated in equation 1. After finding OBC, the sisal fibres modified mix were tested to get reviewed OBC and Optimum Fibre Content (OFC), which was evaluated by equation 2

TABLE I. SPECIFICATIONS OF SMA

SMA Designation	**19mm SMA**
Nominal aggregate Size	***19mm***
IS Sieve (mm)	***Cumulative percent by weight of total aggregate passing***
26.5	100
19	90-100
13.2	45-70
9.5	25-60
4.75	20-28
2.36	16-24
1.18	13-21
0.6	12-18
0.3	10-20
0.075	8-12

Source: Indian Roads Congress (IRC) (Indian Highways, February 2007)

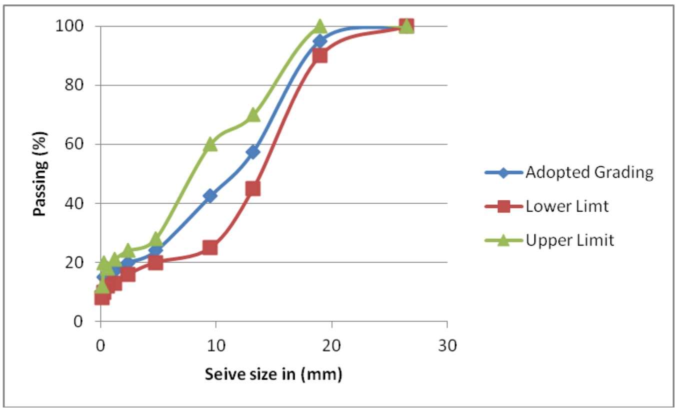

Fig. 1. Gradation of aggregate sample used in mix

TABLE II. PHYSICAL PROPERTIES OF AGGREGATE

Property	**Test**	**Method**	**Value**	**Specification**
Cleanliness	Grain Size Analysis	IS: 2386 (P-1)	–	< 2 % passing 0.075mm
Particle size	Combined Flakiness and Elongation index	IS: 2386 (P-1)	18.21	<30
Strength	Aggregate Impact Value	IS: 2386 (P-4)	15.95%	< 18%
	Crushing Value	IS: 2386 (P-4)	14.74%	< 30%
Water Absorption		IS: 2386 (P-3)	0.3%	< 2%
Specific Gravity		IS: 2386 (P-4)	2.74	2.5 - 3.0

The adopted grading is average value of lower and upper limit for sample preparation of respective Sieve sizes indicated in table 1. With this average value we could achieve the exact grading.

TABLE III. PHYSICAL PROPERTIES OF BINDER

S.No	Property	Test Method	Test Results
1.	Penetration (0.1mm)	IS 73-1961	62
2.	Softening Point, ^{0}C	IS 73-1961	48
3.	Specific gravity	IS 1210	1.01

$$OFC = \frac{\text{Fibre content in (Stability value + Flow value + Air voids)}}{3} \quad (1)$$

$$OBC = \frac{\text{Bitumen content in (Stability value + Flow value + Air voids)}}{3} \quad (2)$$

TABLE IV. COMPOSITION OF AGGREGATE

Sieve Size	Limit	Expected	Bitumen Content				
			5.50%	6%	6.50%	7%	7.50%
26.5	100	100	0	0	0	0	0
19	90 -100	95	57	56	56	56	56
13.2	45-70	57.5	425	423	421	418	416
9.5	25-60	42.5	170	169	168	167	166
4.75	20-28	24	210	209	207	206	205
2.36	16-24	20	45	45	45	45	44
1.18	13-21	17	34	34	33	33	33
0.6	12-18	15	23	22	22	22	22
0.3	10-20	15	0	0	0	0	0
0.075	8-2	10	56	56	55	56	55
Pan		0	113	113	112	111	111
Aggregate in mix			1134 gm	1128 gm	1122 gm	1116 gm	1110 gm
Bitumen in mix			66 gm	72 gm	78 gm	84 gm	90 gm
Wt. of mix	gm		1200	1200	1200	1200	1200

The above table shows the proportion of aggregate in each sieve for varied bitumen content (5.5 % to 7.5 %) with 0.5 % interval. The proportions were calculated with expected percentage of each sieve.

TABLE V. SMA REQUIREMENTS

Mix Design Parameters	Requirement
Air void Content	4 %
Bitumen Content	5.8 % min
VMA	17 % min
Drain down	0.3 %

IV. RESULTS AND DISCUSSION

The samples casted were tested and achieved OBC is 6.21% by the weight of total mix. Sisal fibre in varied fibre content was added to OBC, 6.0% and 6.5% to study the characteristics of mix with different fibre content. The characteristics of control mix were presented in fig (2-5).

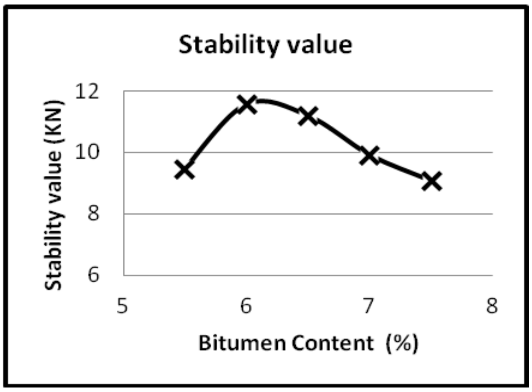

Fig. 2. Stability value vs Bitumen content

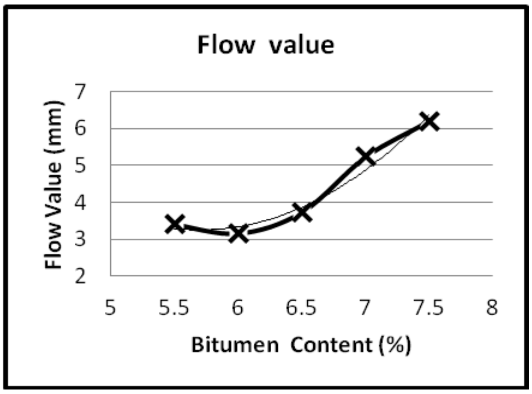

Fig. 3. Flow value vs Bitumen content

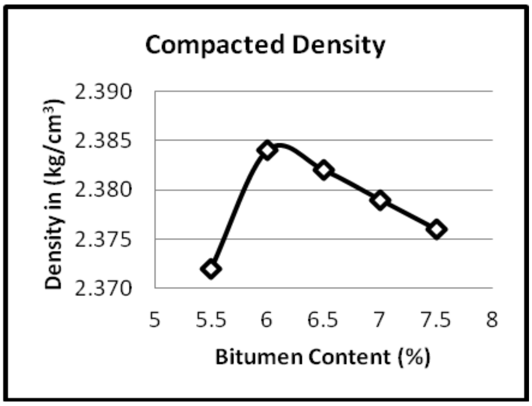

Fig. 4. Density vs Bitumen content

Maximum stability value obtained for control mix is 11.575KN from bitumen content 6.21%, which is fixed as OBC. The flow value for respective bitumen content is 3.09mm. After this bitumen content the stability value decreases.

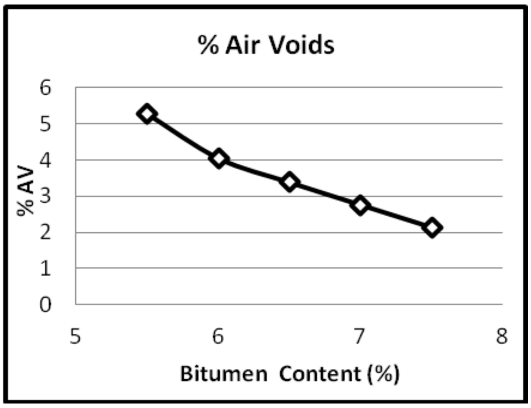

Fig. 5. Percentage air voids vs Bitumen content

As stated above, 5 different fibre content were added to 3 bitumen content. 3 trails were made for each mix. The characteristics of sisal fibre modified mix are presented in fig. (6-8).

A. Bituminous Mix modified with Sisal Fibre

It can be observed from fig 6, with increase in binder content the stability value increases then decreases as per the normal trend for a conventional bituminous mix. After crossing 6.21% (OBC), it tends to decrease stability value. Increase in fibre content increases the stability value of mix upto 0.3 % of fibre content by the weight of total mix. Then after the value decreases and 0.5% of fibre added mix reaches value even less than the control mix. This is due to the fact that at higher percentage of fiber homogeneous mixing of the fiber materials is not possible and this results conglomeration of fibers (15). Such a heterogeneous mixture affects the aggregate-binder bonding and interlocking between the aggregates resulting in low stability value. Likewise in figure 6 the stability value corresponding to 0.4% fibre content the values get decreased in each bitumen content.

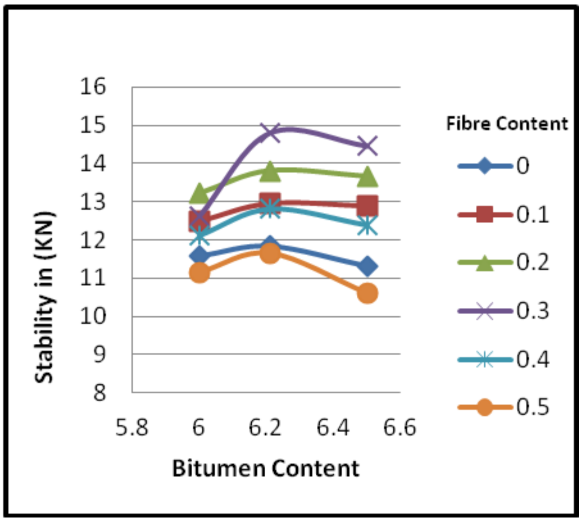

Fig. 6. Stability Value vs Bitumen content

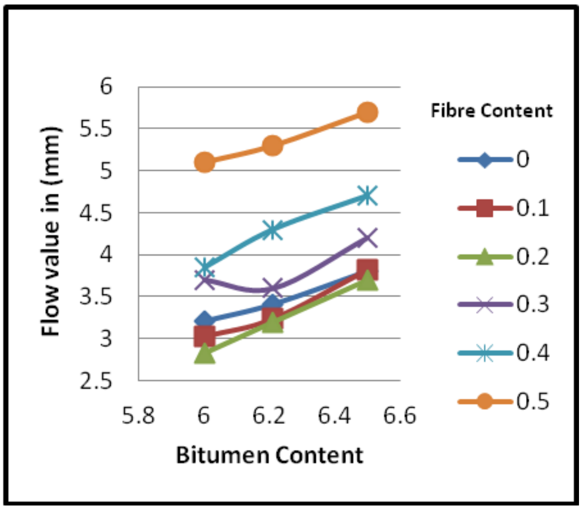

Fig. 7. Flow Value vs Bitumen content

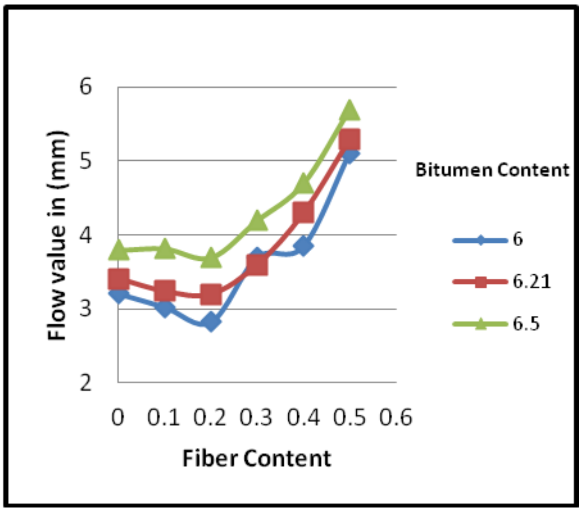

Fig. 8. Flow value vs Fibre content

The flow value increases with increase in binder content. 0.1 and 0.2 % of fibre content achieves flow value less than control mix in each bitumen content. Value corresponding 0.3 % of fibre is slightly higher than control mix and values of 0.5% fibre content is much higher as shown in figure 7. Likewise it is observed in figure 8 that flow values corresponding to 6.5% bitumen content higher value than the other two bitumen content. Thus increase in fibre content increases flow value.

By considering the stability, flow values and percentage air voids for sisal fibre modified mix, the OBC for SMA (modified) is reviewed as 6.18 % by the weight of total mix. OFC is found to be 0.29 % by the weight of total mix. Reviewed OBC and OFC were evaluated from equation 1 and 2. The results of control or unmodified and modified mix were tabulated in tale 6.

TABLE VI. COMPARISIONS OF RESULTS

Mix Design Parameters	Unmodified	Modified	Specification
Marshall Stability value	11.575 KN	14.82 KN	
Flow Value	3.09 mm	3.6 mm	2-4 mm
Air void Content	3.70 %	3.92 %	4%
Bitumen Content	6.21 %	6.18 %	5.8 % min
VMA	18.84 %	18.26 %	17% min
VFB	77.31 %	78.22 %	

REFERENCES

[1] AI-Hadidy AI, Tan Y-q, "Mechanistic analysis of ST and SBS-modified flexible pavements", *Construction Building Material*, 23, 2941–50, 2009.

[2] Ozen, H., A. Aksoy, S. Tayfur, F. Celik, "Laboratory performance comparison of the elastomer-modified asphalt mixtures", *Building Environment*, 43, 1270–77, 2008.

[3] Abdelaziz Mahrez and Mohamed Rehan Karim, "Fatigue characteristics of stone mastic asphalt mix reinforced with fiber glass", *International Journal of the Physical Sciences*, 5(12), 1840-47, 2010.

[4] Amit Goel and Animesh Das, "Emerging road materials and innovative applications", *National conference on materials and their application in Civil Engineering*, 2004.

[5] Aren Cleven, "Investigation of the Properties of Carbon fibre Modified
Asphalt Mixtures", *MichiganTechnological University*, 2000.

[6] Brown E.R., "Experience with Stone Matrix Asphalt in the United States", *NCAT Publication*, Auburn University, Alabama, 1992.

[7] Pawan Kumar, Satish Chandra And Sunil Bose, "Laboratory investigations on SMA mixes with different additives", *International Journal of Pavement Engineering*, 8(1), 11–18, 2007.

[8] Indian Roads Congress, (*Indian Highways, February 2007*), 3, 37-42

[9] Abdelaziz Mahrez and Mohamed Rehan Karim, "Prospect Of Using Glass Fiber Reinforced Bituminous Mixes", *Journal of the Eastern Asia Society for Transportation Studies*, **5**, 794-808, 2003

[10] Ministry of Road Transport and Highways, *Manual for Construction and Supervision of Bituminous Works*, New Delhi, 2000.

[11] Huaxin Chen, Qinwu Xu , Shuanfa Chen, Zhengqi Zhang, "Evaluation nd design of fiber-reinforced asphalt mixtures", *Materials and Design*, 30, 2595–2603, 2009.

[12] Murherjee, P.S.and K.G. Satyanarayana, "Structure and properties of some vegetable fibres, part 1. Sisal fibre", *Journal of Materials Science*, 19, 3925-34, 1984.

[13] Chand, N., K.G. Satyanarayana,.and P.K. Rohatgi, "Mechanical characteristics of sunhemp fibres", *Indian Journal of Textile Research*, 11, 86-89, 1989.

[14] Bisanda ETN and Ansell MP, "Properties of sisal-CNSL composites", Journal *of Materials Science,* 27, 1690-700, 1992.

[15] Thulasirajan, K. and V. L. Narasimha., "Studies on Coir Fibre Reinforced Bituminous Concrete", *International Journal of Earth Sciences and Engineering*, 04(06), 835-838, 2011.