STUDY OF EFFECTS OF BINDER QUALITY OF NATURAL FIBER ON STONE ASPHALT MATRIX

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ABSTRACT
Stone Matrix Asphalt (SMA) is a gap graded mix, characterized by high coarse aggregates, high asphalt contents and polymer or fiber additives as stabilizers. High concentration of coarse aggregate maximizes stone-to-contact and interlocking in the mix which provides strength, and the rich mortar binder provides durability. The stabilizing additives composed of cellulose fibers, mineral fibers or polymers are added to SMA mixtures to prevent draindown from the mix. 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 resists 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 mixtures of stone matrix asphalt made with three types of binders namely conventional bitumen 80/100 and 60/70 and modified binder CRMB 60, with a non-conventional natural fiber, namely coconut fiber. The binders and fibers in different proportions are used for preparation of mixes with a selected aggregate grading. The role of a particular binder and fiber with respect to their concentrations in the mix is studied for various engineering properties. For this, various Marshall samples of SMA mixtures with and without fibers with varying binder type and its concentration are prepared. The optimum binder content is determined keeping the suggested air voids content in the mix. Marshall properties such as stability, flow value, unit weight, air voids are used to determine optimum binder content and optimum fiber content for each type of binder for further studies on SMA mixes. Thereafter, the draindown characteristics, both static and repeated indirect tensile strength parameters and moisture susceptibility characteristics in terms of tensile strength ratio and retained stability of different SMA mixtures values have been studied for such mixes. It is observed that only 0.3% addition of coconut fiber significantly improves the Marshall properties of SMA mixes. Addition of nominal 0.3% fiber considerably improves the draindown, indirect tensile strength and fatigue characteristics of the SMA mixes with conventional bitumen, which would otherwise have not been able to meet the prescribed criteria.

***Key Words*:** stone matrix asphalt, coconut fiber, repeated load indirect tensile test, Marshall Properties, indirect tensile strength, draindown test, moisture susceptibility.

I. INTRODUCTION

1.1 General

Aggregates bound with bitumen are conventionally used all over the world in construction and maintenance of flexible pavements. The close, well, uniform, or dense graded aggregates bound with normal bitumen normally perform well in heavily trafficked roads if designed and executed properly and hence very common in paving industry. However, it is not always possible to arrange dense graded aggregates available at the site. In such situations a bituminous mix called stone matrix asphalt (SMA) which basically consists of gap graded aggregates, can be attempted.

SMA was developed in Germany in the 1960s by Zichner of the Straubag-Bau AG central laboratory, to resist the damage caused by studded tires. As SMA showed excellent resistance to deformation by heavy traffic at high temperatures, its use continued even after the ban of studded tires. SMA is a gap graded mixture containing 70-80% coarse aggregate of total aggregate mass, 6-7% of binder, 8-12% of filler, and about 0.3-0.5% of fiber or modifier. The high amount of coarse aggregate in the mixture forms a skeleton-type structure providing a better stone-on-stone contact between the coarse aggregate particles, which offers high resistance to rutting. Aggregate to aggregate contact is also there in dense graded mixtures but it occurs within the fine aggregate particles as the coarse aggregate floats in the fine aggregate matrix, which don't give the same shear resistance as the coarse aggregate skeleton. Brown and Manglorkar (1993) reported that the traffic loads for SMA are carried by the coarse aggregate particles instead of the fine aggregate asphalt-mortar. The higher binder content makes the mix durable. The fibers or modifier hold the binder in the mixture at high temperature; prevent drainage during production, transportation and laying.

SMA has been proved to be more cost effective than dense graded mixes for high volume roads. Brown (1992) observed that a number of factors influence the performance of SMA mixtures, such as changes in binder source and grade, types of aggregate, environmental conditions, production and construction methods etc. Evaluation of these factors would help to determine the long term performance of SMA and provide information to make changes as needed to suit different environmental conditions. The SMA Technical Working Group of

FHWA defined SMA as "A gap graded aggregate hot mix asphalt that maximizes the binder content and coarse aggregate fraction and provides a stable stone-on-stone skeleton that is held together by a rich mixture of binder, filler and stabilizing additives".

1.2 Advantages over Conventional Bituminous Mixes

Conventional bituminous pavements lack the strength, durability and longevity of SMA. There are several factors for which SMA is better than the conventional mixes. As mentioned by Bose et al. (2006) SMA provides better resistance to rutting due to slow, heavy and high volume traffic, resistance to deformation at high pavement temperatures, improved skid resistance, noise reduction over conventional alternative pavement surfaces, improved resistance to fatigue effects and cracking at low temperatures, increased durability, reduced permeability and sensitivity to moisture. According to Brown and Manglorkar (1993) SMA has also shown good resistance to plastic deformation under heavy traffic loads with high tyre pressures as well as good low temperature properties. Further, SMA has a rough texture which provides good friction properties after surface film of the binder is removed by the traffic. Kamaraj et al. (2004) have reported that SMA has an extended life as compared to conventional dense graded mixes. They have also reported that the cost of SMA has been estimated to be about 20-25 percent more than conventional dense graded mixtures, but this can be justified by the increased life of pavement. In view of these advantages SMA has been proved to be superior over HMA mixes.

1.3 Selection of Binders

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. Superpave performance grade binder such as PG 76 -22 has also been used by some investigators. Reddy et al. (2006) have reported that use of CRMB in the bituminous mixes significantly improves fatigue life, temperature susceptibility and resistance to moisture damage characteristics compared to other unmodified mixes. Considering this fact, an attempt has been made in this investigation to study the SMA mixes made with locally available coarse aggregates, commonly used binders such as 60/70 penetration grade bitumen and CRMB 60. From the review of related literature, it is observed that use of 80/100 bitumen is rare in SMA mixes. An attempt has been made in this investigation to use a commonly used binder, i.e. 80/100 bitumen in SMA mixes, mainly with the objective of exploring the scope of using the same in presence of fibers.

1.4 Selection of Stabilizing Additive

SMA being a gap graded mix has more air void content and higher concentration of binder. Therefore stabilizing additives are added in the mix to prevent draindown of the binder. Many fibers such as cellulose fibers, mineral fibers etc., many polymers, plastics in pellet or powder form, waste materials such as carpet fiber, tires, polyester fiber, natural fiber such as jute fiber have been tried by various investigators in SMA mixes to solve this draindown problem. These fibers and polymers used by various investigators for evaluation of SMA mixes are either costly or not readily available. It has been reported that coconut fiber contains certain amount of cellulose, normally used in SMA mixes to prevent draindown of binder mortar. Hence, an attempt has been made in this study to utilize a naturally and abundantly available low cost material such as coconut fiber, in preparation of SMA mixes.

1.5 Objectives and Scope of the Present Investigation

The concept of stone matrix asphalt is relatively new compared to normal bituminous mixes. The stabilizing additives, such as cellulose fibers, mineral fibers and different types of synthetic polymers, which are used to prevent drain down of the binder from the mixture, are either costly or not easily available in all parts of India.

The main objectives of this investigation are:

 To compare the Marshall properties of SMA samples with binder type and its concentrations
 To compare the Marshall properties of SMA samples with varying fiber
Concentration using different binders

To analyze the results of Marshall tests of SMA mixes for deciding the optimum binder content (OBC) and optimum fiber content (OFC) for further studies
 To study the draindown characteristics of the SMA mixes prepared at OBC and

OFC
To evaluate the SMA mixes with fixed fiber concentration and various binders (at OBC and OFC), in terms of engineering properties such as static indirect tensile test and repeated load indirect tensile test including fatigue characteristics at various temperatures

To study the moisture susceptibility characteristics of SMA mixtures in terms of their tensile strength ratio and retained stability

In this study three types of binders, two unmodified penetration grade binders such as 80/100 and 60/70 bitumen, and one modified binder such as CRMB 60 have been used in SMA mixes along with coconut fiber as stabilizing additive. The SMA mixes are evaluated in terms of Marshall properties such as Marshall stability, flow value, unit weight and air voids, draindown characteristics, static and repeated load indirect tensile strength characteristics, and moisture susceptibility characteristics. The work carried out in this investigation is being described briefly in the following sections.

1.6 Organization of Thesis

The whole thesis is divided in to five chapters namely, introduction, review of literature, experimental investigation, analysis and discussion of test results and conclusion. Chapter 2 deals with the review of the investigations carried out previously by various researchers on SMA mixtures using different stabilizing additives.

II. EXPERIMENTAL INVESTIGATIONS

2.1 Introduction

This chapter describes the experimental works carried out in this present investigation. This chapter has been divided into two parts. First part deals with the experiments carried out on the materials (aggregates, bitumen, and fiber), second part deals with the tests carried out on bituminous mixes.

2.2 Tests on Materials Used

2.2.1 Aggregates

For preparation of SMA mixes, aggregates as per NCHRP grading as given in Table 3.1, a particular type of binder and fiber in required quantities were mixes as per Marshall procedure.

Coarse Aggregates

Coarse aggregates consisted of stone chips collected from a local source, up to 4.75 mm

IS sieve size. Standard tests were conducted to determine their physical properties as summarized in Table 3.2.

Fine Aggregates

Fine aggregates, consisting of stone crusher dusts were collected from a local crusher

with fractions passing 4.75 mm and retained on 0.075 mm IS sieve. Its specific gravity was

found to be 2.65.

Filler

Portland slag cement (Grade 43) collected from local market passing 0.075 mm IS sieve

was used as filler material. Its specific gravity was found to be 3.15.

Table 2.1 Adopted aggregate gradation (NCHRP)

Property	Grading
Nominal Size of Aggregate (NSA)	19 mm
Sieve size, mm	Percent Passing
25	100
19	99
12.5	61
9.5	40
4.75	22
2.36	19
1.18	18
0.6	16
0.3	14
0.075	9

Table 2.2 Physical properties of coarse aggregates

Property	Test Method	Test Result
Aggregate Impact Value (%)	IS: 2386 (P IV)	14
Aggregate Crushing Value (%)	IS: 2386 (P IV)	12
Los Angels Abrasion Value (%)	IS: 2386 (P IV)	18
Flakiness Index (%)	IS: 2386 (P I)	17.24
Elongation Index (%)		12.38
Water Absorption (%)	IS: 2386 (P III)	0.09
Specific Gravity	IS: 2386 (P III)	2.64

2.2.2 Binders

Two conventional binders, namely 80/100 and 60/70 bitumen and a polymer modified binder namely CRMB 60 were used in this investigation to study the effects of binder type on SMA mixes. These binders were collected from the local depot. Normal tests were performed to
determine the important physical properties of these binders. The physical properties thus obtained are summarized in Table 3.3.

2.2.3 Fibers

The peelings of ripe coconut were collected locally, dried and neat fibers taken out manually. The lengths of such fibers were normally in the range of 75 to 200 mm and diameter varied from 0.2 to 0.6 mm. The tensile strength of these fibers was tested in a materials testing machine, Tinious Olsen, UK, Model HIOKS. The test was done in tensile mode with 10 KN load cell and the cross head speed was maintained at 0.2 mm/min. The average tensile strength of the fiber thus obtained was found to be 70.58 N/mm^2. The coconut fibers were cleaned and cut in to small pieces of 25-75 mm in length to ensure proper mixing with the aggregates and binder during the process of mixing.

Table 2.3 Physical properties of binders

Binder	Property	Test Method	Test Result
80/100 Bit.	Penetration at 25? C, 100g, 5 sec, 0.1 mm	IS : 1203-1978	92
	Softening Point (R&B), ? C	IS : 1205-1978	44.5
	Viscosity (Brookfield) at 160? C, cP	ASTM D 4402	145
60/70 Bit.	Penetration at 25? C, 100g, 5 sec, 0.1 mm	IS : 1203-1978	68
	Softening Point (R&B), ? C	IS : 1205-1978	48.5
	Viscosity (Brookfield) at 160? C, cP	ASTM D 4402	200
CRMB 60	Penetration at 25? C, 100g, 5 sec, 0.1 mm	IS : 1203-1978	49
	Softening Point (R&B), ? C	IS : 1205-1978	62
	Viscosity (Brookfield) at 160? C, cP	ASTM D 4402	275

2.3 Preparation of Mixes

The mixes were prepared according to the Marshall procedure specified in ASTM D1559. The coarse aggregates, fine aggregates and cement were mixed according to the adopted gradation as given in Table 3.1. Three types of binders as already stated were used in different proportions in the mixes starting from 3% to 7% 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 some initial trials for preparation of SMA samples with coconut fiber, a proper procedure could be developed. The coconut fibers after being cut in to small pieces (25-75 mm) were added directly to the aggregate sample in three different proportions, 0.3%, 0.5%, and 0.7% of the total mix to assess the optimum fiber requirement for the best possible mix. The mineral aggregates with fibers and binders were heated separately to the prescribed mixing temperature. The temperature of the mineral aggregates was maintained at a temperature 10□C higher than the temperature of the binder. Required quantity of binder was added to the pre heated aggregate-fiber mixture and thorough mixing was done manually till the colour and consistency of the mixture appeared to be uniform. The mixing time was maintained within 2-5 minutes. The mixture was then poured in to pre-heated Marshall moulds and the samples were prepared using a compactive effort of 50 blows on each side as 75 blows compaction is reported to result in significant degradation of aggregates as reported by Brown (1992). The specimens were kept over night for cooling to room temperature. Then the samples were extracted and tested at 60□C according to the standard testing procedure.

2.4 Tests on Mixes

Presented below are the different tests conducted on the bituminous mixes with variations of binder type and quantity, and fiber concentration in the mix.

2.4.1 Marshall test

Marshall mix design is a standard laboratory method, which is adopted worldwide for determining and reporting the strength and flow characteristics of bituminous paving mixes. In India, it is a very popular method of characterization of bituminous mixes. This test has also been used by many researchers to test SMA mixes. This test method is widely accepted because of its simplicity and low of cost. Considering various advantages of the Marshall method it was

decided to use this method to determine the Optimum Binder Content (OBC) of the SMA mixes and also study various Marshall characteristics such as Marshall stability, flow value, unit weight, air voids etc.

Figures 3.1 (i) and (ii) show the Marshall apparatus with a loaded Marshall specimen. The Marshall properties such as stability, flow value, unit weight and air voids were studied to obtain the optimum binder contents (OBC) and optimum fiber contents (OFC). The mix volumetrics of the Marshall samples such as unit weight, air voids were calculated by using the procedure reported by Das and Chakroborty (2003). For constraint of time each and every test on all types of mixes can not be completed. Hence it was decided to carry out the next set of experiments such as draindown test, static and repeated load indirect tensile test and moisture susceptibility tests on the SMA mixes prepared at their OBC and OFC.

Fig. 2.1 Marshall test in progress

2.4.2 Draindown test

There are several methods to evaluate the draindown characteristics of SMA mixtures. The draindown method suggested by MORTH (2001) was adopted in this study. The drainage baskets fabricated locally according to the specifications given by MORTH (2001) is shown in Figure 3.2. The loose uncompacted mixes were then transferred to the drainage baskets and kept in a pre-heated oven maintained at 150□C for three hours. Pre-weighed plates were kept below the drainage baskets to collect the drained out binder drippings. From the draindown test the binder drainage has been calculated from the equation 2.1;

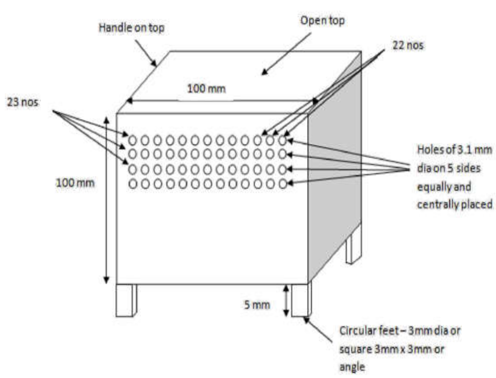


Fig. 2.2 Schematic representation of 100 mm x 100 mm x 100 mm cubical drainage basket

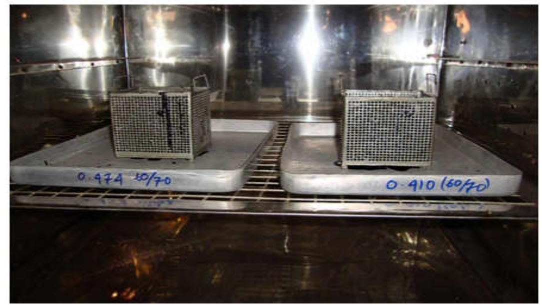


Fig. 2.3 Drainage baskets kept in oven at 150□C

Fig. 2.4 Drainage of 80/100 bitumen sample

Fig. 2.5 Drainage of 60/70 bitumen sample

Fig. 2.6 Drainage of CRMB 60 binder sample

III. ANALYSIS OF TEST RESULTS AND DISCUSSION

3.1 Introduction

It is mentioned earlier that three types of binders, namely 80/100 penetration grade bitumen, 60/70 penetration grade bitumen and CRMB 60 grade binder have been used in the SMA mixes with and without coconut fiber in this investigation. The details of the experiments carried out on these SMA mixes are given in the previous chapter. In this chapter the results and observations of the tests conducted are presented, analyzed and discussed. This chapter is divided into five sections. In first section, the results of the Marshall tests carried out on SMA mixes are presented. In second section, the draindown test results carried out on SMA mixes are discussed. The third and fourth sections deal with the results of the static and repeated load indirect tensile test respectively. The last section presents the moisture susceptibility test results.

3.2 Marshall Properties

Marshall samples were prepared using SMA mixes with different binders, varying the binder and fiber concentrations, as described in Chapter 3. In this chapter, the results of the Marshall tests carried out on these mixes are presented and discussed.

3.2.1 Effect of binder type, binder content and fiber content on Marshall properties

For each type of binder, its concentration and fiber concentration in mixes were varied to study the effects on Marshall properties. Three types of binders, namely 80/100 and 60/70 conventional penetration grade bitumen and CRMB 60 binder as well were used in varying proportions to make a comparative study. The results thus obtained are analyzed below.

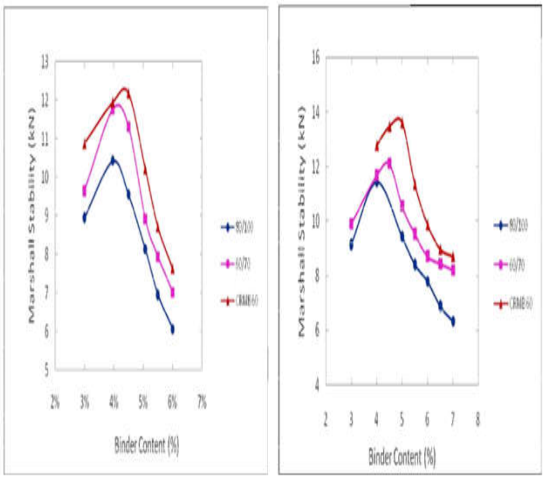
Marshall Stability

Figures 3.1 (i), (ii), (iii) and (iv) show the variation of Marshall stability value with binder content for the three binder types at fiber concentrations of 0%, 0.3%, 0.5% and 0.7% respectively. The binder content in the mix was varied from 3% to 7% by weight. It can be observed from the above figures that, with increase in binder content the stability value increases up-to a certain binder content then decreases as per the normal trend for a bituminous mix. It is observed that the stability value in general increases with the hardness (in terms of penetration value) of the binder. For example at a particular fiber content, the samples prepared with 80/100 bitumen result the least stability values and that with CRMB 60 has the highest stability value. This is because with higher viscous binders the interlocking between aggregates with thicker void packing is better retained. It can also be observed that, when a stiffer binder is used more binder content is required to attain the maximum stability value. This may be due to the fact that the higher viscosity of the binder requires more amount in its voids as its draindown effect is less.

It is observed that with increase in fiber content the stability value increases up to 0.5% fiber, thereafter decreases. 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. Such a heterogeneous mixture affects the aggregate-binder bonding and interlocking between the aggregates resulting in low stability value. It can be observed from these plots that the maximum stability value without fibers in the mix is even more than the stability value with 0.7% fiber in the mix. This trend is followed in case of all the three types of binders.

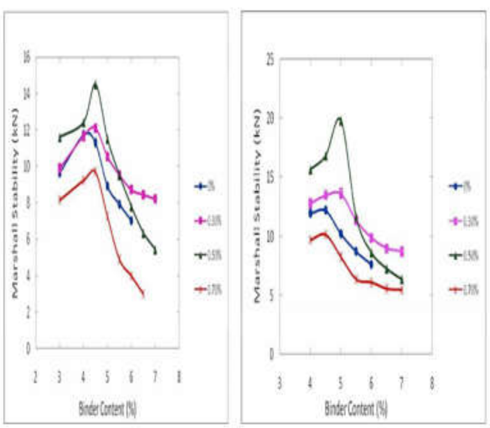
Table 3.1 presents the maximum stability value for different binders at different fiber percentages in the mix and their corresponding binder requirement. For example, for mixes prepared with 80/100 bitumen, without fiber and with 0.3% fiber content the maximum stability value is obtained at 4% binder content and for the mixes with 0.5% fiber and 0.7% fiber the maximum stability value is obtained at 4.5% binder content.

The results of the above Marshall tests have been represented in a different way in Figures 4.2 (i) to (iii).



(i) 0% Fiber (ii) 0.3% Fiber

Fig. 3.1 Variation of Marshall stability value with binder content for different binders



(ii) 60/70 Bitumen (iii) CRMB 60 Binder

Fig. 3.2 Variation of Marshall stability value with binder content for different fiber

concentrations in the mix

Table 3.1 Maximum Marshall stability values and their corresponding binder content

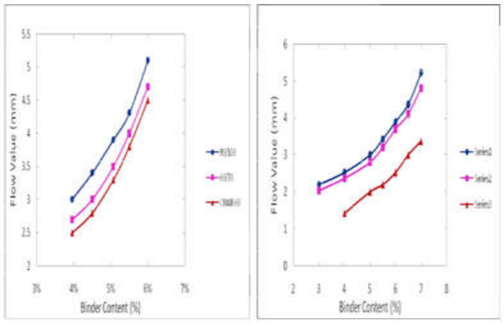
Fiber Content (%) / Binder Type	0%		0.3%		0.5%		0.7%	
	Max. Stability (kN)	Binder Content (%)	Max. Stability (kN)	Binder Content (%)	Max. Stability (kN)	Binder Content (%)	Max. Stability (kN)	Binder Content (%)
80/100 Bit.	10.42	4%	11.43	4%	13.61	4.5%	9.16	4.5%
60/70 Bit.	11.75	4%	12.09	4.5%	14.52	4.5%	9.71	5%
CRMB 60	12.19	4.5%	13.61	5%	19.78	5%	10.16	4.5%

3.2.1.2 Flow Value

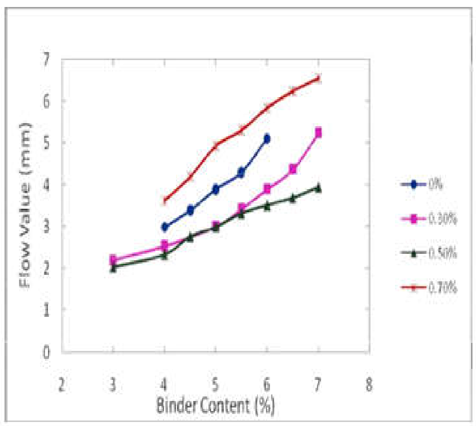
The variation of flow value with binder content for SMA mixes with different binders i.e. 80/100 and 60/70 bitumen and CRMB 60 binder at different fiber contents are shown in Figures 4.3 (i) to (iv). It can be observed that as per the normal trend, the flow value increases with increase in binder content and decreases with increase in stiffness of the binder. It can be clearly seen that for mixes without fiber the decrease in flow value with increase in stiffness of binder types is almost constant. It is observed that for 0.5% fiber content, at higher binder content mixes with 60/70 bitumen has higher flow value than that of 80/100 bitumen. Mixes with 0.7% fiber has higher flow value than that of other mixes. This may be due to result of a heterogeneous mix with fibers forming lumps and causing the increase in deformations under load. Generally a flow value of 2 mm to 4 mm is recommended for SMA mixes. Table 4.2 gives the binder content requirement of different SMA mixes for a flow value of 3 mm, the average of the recommended range.

Table 3.2 Binder Content (%) for 3 mm flow value for different mixes

Fiber Content (%) / Type of Binder	0	0.3	0.5
80/100 Bit.	4	5	5
60/70 Bit.	4.5	5.3	5.4
CRMB 60	4.7	6.5	6

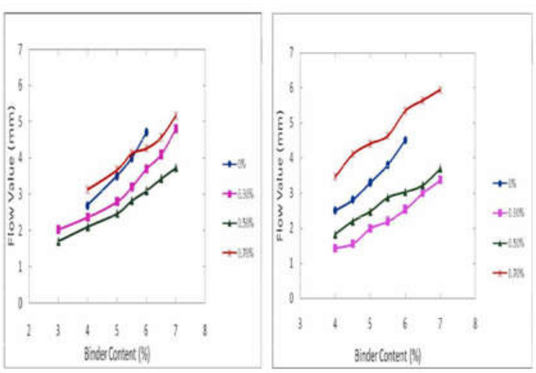


(i) 0% Fiber (ii) 0.3% Fiber



(i) 80/100 Bitumen

Fig. 3.3 Variation of flow value with binder content for different binders



(ii) 60/70 Bitumen (iii) CRMB 60 Binder

Fig. 3.4 Variation of flow value with binder content at different fiber contents

IV. CONCLUSIONS

Three types of binders, such as conventional 80/100 and 60/70 penetration grade bitumen and a modified binder such as CRMB 60 have been tried for preparation of mixes with and without fiber. Coconut fiber, which is a low cost and abundantly available natural fiber has been used in the mixes. It has been observed that a marginal fiber concentration of 0.3% considerably improves the Marshall properties of SMA mixes even for the same with 80/100 bitumen. The optimum binder contents are found to reduce considerably by addition of fibers, which is an important advantage from economy and quality point of view. It has been observed that the draindown and moisture susceptibility characteristics have improved by using modified binder and fiber in the mix. It is also found that addition of fiber substantially increases the tensile strength of mixes with any binder type. The mixes with CRMB 60 binder result maximum tensile strength. These mixes also perform satisfactorily under repeated load test conditions and in terms of fatigue characteristics. From the overall discussion of the test results on SMA mixes with three types of binders, it can be concluded that all the mixes made at 0.3% fiber content perform satisfactorily and can be used in mixes in the wearing courses of flexible pavements. However further studies such as permanent deformation and creep properties need to be carried out, and for validation of the above test results, experimental track should be laid to study the performance of pavements with such SMA mixes.

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