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# An Experimental Study of Effects of Binder Quality and Pine Apple Fiber on Stone Matrix ASPHAT Mixtures

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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 pine apple 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 pine apple 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 pineapple fiber significantly improves the Marshall properties of SMA mixes. Addition of nominal 0.3% fiber considerably improves the draindown, of SMA mixes with conventional bitumen, which would otherwise have not been able to meet the prescribed criteria.

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

## INTRODUCTION

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.

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”.

### *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.. Further, SMA has a rough texture which provides good friction properties after surface film of the binder is removed by the traffic. 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.

### *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.

### *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 pine apple 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 drain down 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 pine apple fiber contains certain amount of pine apple, normally used in SMA mixes to prevent drain down of binder mortar. Hence, an attempt has been made in this study to utilize a naturally and abundantly available low-cost material such as pine apple fiber, in preparation of SMA mixes.

### *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 pine apple 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
- 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 pine apple 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.

Marshall test

Marshall properties such as Marshall stability value, flow value, unit weight value and air void content of the SMA mixes have been studied. These parameters have been used to estimate the optimum binder content (OBC) and optimum fiber content (OFC) of the mixes. In general, the Marshall stability values have been found to increase with addition of fiber up to 0.5% but considering a particular mix the OBC percentage decreases when fiber is added to it. The next sets of experiments were carried out on mixes prepared at their OBC and OFC.

Draindown test

Draindown test is carried out on SMA mixes to evaluate the draindown percent of the binder used. It is observed from the drainage test conducted on SMA mixes with three types of binder that there is no draindown of binder in case of all the mixes with fiber. Mixes with 80/100 and 60/70 bitumen yield better results with addition of fiber.

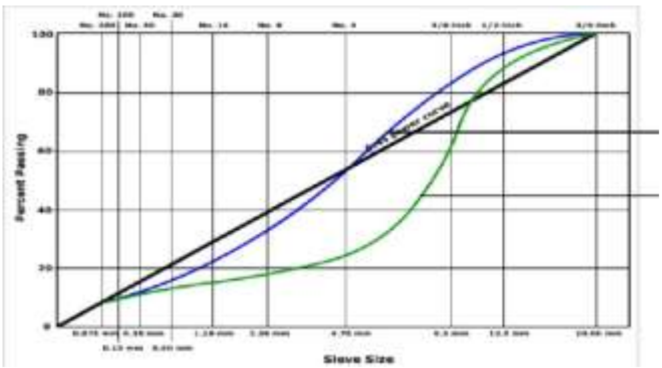
Static indirect tensile test

Static indirect tensile tests have been carried out to determine tensile strength of SMA mixes with and without fibers prepared at their OBC and OFC. It is observed from the results that addition of fiber improved the tensile strength of the mix. The effect of temperature on tensile strength of SMA mixes is also being evaluated using this method as the same is time consuming in case of repeated load test. The results indicate that with increase in test temperature the tensile strength value decreases.

### *GENERAL*

Majority of the roads all over the world are made up of flexible pavements. Flexible pavements consist of a bituminous layer on the surface course and sometimes in base course followed by granular layers in base and sub base courses over the subgrade. Asphalt Concrete Pavement or Hot Mix Asphalt pavement are the bound layers of a flexible pavement structure at the surface course. The most common type of flexible pavement surfacing used in India is a premix bituminous material, commonly called outside as Hot Mix Asphalt (HMA). HMA is a mixture of coarse and fine aggregates and asphalt binder. HMA, as the name suggests, is mixed, placed and compacted at higher temperature. HMA is typically applied in layers, with the lower layers supporting the top layer, which is known as surface course or friction course. The aggregates used in the lower layer are to prevent rutting and the aggregates which are used in the top layer are generally selected on the basis of their friction properties and durability. There are several types of HMA mixes. These include conventional Dense Graded Mixes (DGM), Stone Matrix asphalt (SMA) and various Open graded HMA. The HMA mixes differ from each other mainly in maximum aggregate size, aggregate gradation and binder content or type of binder used. Figures 2.1, 2.2 and 2.3, show pictures of typical dense graded HMA, SMA and open graded friction course (OGFC) mixes respectively.

Table 2.1 Main differences of SMA and Bituminous Mix.

| Properties | SMA | BC |
|---|---|---|
| Definition | SMA is a gap graded mix which consists of high amount of coarse aggregate firmly bonded together by a strong asphalt matrix consisting of fine aggregate, filler, bitumen and stabilizing additives. | BC consists of well graded coarse and fine aggregate, filler and bitumen. |
| Gradation Curve | BC SMA  | |
| Schematic Representation | SMA Sample  | CC Sample  |

| | | |
|---|---|---|
| Mass of Coarse Aggregate Content, % | 75 – 80 | 50 – 60 |
| Mass of Fine and Stone Dust, % | 20 – 25 | 40 – 50 |
| Mass of Filler content, % | 9 – 13 | 6 – 10 |
| Binder Type | 60/70, PMB- 40 | 60/70, 80/100 and modified binders |
| Minimum binder content by weight of mix, % | > 6.5 | 5 – 6 |
| Stabilizing Additives by weight of mix, % | 0.3 – 0.5 | ---- |
| Air Voids, % | 3 – 4 | 3 – 6 |
| Layer Thickness, mm | 25 – 75 | 30 – 65 |

## MATERIAL CHARACTERISTICS

### *Mineral aggregates*

There are various types of mineral aggregates which can be used in bituminous mixes. The aggregates used to manufacture bituminous mixes can be obtained from different natural sources such as glacial deposits or mines. These are termed as natural aggregates and can be used with or without further processing. Deori (2006) has mentioned that if these are used without processing it is termed as “back run or pit run” materials. The aggregates can be further processed and finished to achieve good performance characteristics. Industrial by products such as steel slag, blast furnace slags etc. are sometimes used as a component along with other aggregates to enhance the performance characteristics of the mix. Reclaimed bituminous pavement is also an important source of aggregate for bituminous mixes.

Aggregates play a very important role in providing strength to SMA mixtures as they contribute a greater part in the matrix. SMA contains 70-80 percent coarse aggregate of the total stone content. The higher proportion of the coarse aggregate in the mixture forms a skeleton-type structure providing a better stone-on-stone contact between the coarse aggregate particles resulting in good shear strength and high resistance to rutting. According to WSDOT (2000) the Federal Highway Administration, McLean Virginia, has suggested the following characteristics for aggregates used in SMA mixture. The aggregates must possess;

- A highly cubic shape and rough texture to resist rutting and movements,
- A hardness which can resist fracturing under heavy traffic loads,
- A high resistance to polishing and
- A high resistance to abrasion.

### *Mineral fillers*

Mineral fillers have a significant impact on the properties of SMA mixtures. Mineral fillers increase the stiffness of the asphalt mortar matrix. According to Mogawer and Stuart (1996) mineral fillers also affect workability, moisture resistance, and aging characteristics of HMA mixtures. Mineral fillers also help to reduce the draindown in the mix during construction, which improves the durability of the mix by maintaining the amount of asphalt initially used in the mix. It also helps to maintain adequate amount of voids in the mix. Different types of mineral fillers are used in the SMA mixes such as stone dust, ordinary Portland cement (OPC), slag cement, fly Ash, hydrated lime etc.

### *Bitumen*

Bitumen acts as a binding agent to the aggregates, fines and stabilizers in SMA mixtures. SMA mixes are rich in mortar binder which provides durability to the mix. The characteristics of bitumen which affects the bituminous mixture behaviour are temperature susceptibility, viscoelasticity and aging. The behaviour of bitumen depends on temperature as well as on the time of loading. It is stiffer at lower temperature and under shorter loading period. Bitumen must be treated as a viscoelastic material as it exhibits both viscous as well as elastic properties at the normal pavement temperature. Though at low temperature it behaves like an elastic material and at high temperatures its behavior is like a viscous fluid.

Bitumen along with different additives (fibers, polymers etc.) acts as a stabilizer for the SMA mix. Polymer modified bitumen can also be used as a stabilizer with or without additives in the mixture. Different types of bitumen have been used by various researchers to study the SMA mixture properties. Penetration grade bitumen such as 60/70, modified bitumen such as CRMB, PMB, and Superpave performance grade bitumen are used to evaluate SMAmixtures.

### *3.1.2 Stabilizing additives*

SMA is a gap graded mix, having higher amount of voids in the mix. Therefore stabilizing additives are used in the mixture to prevent mortar draindown and to provide better binding. Initially SMA was developed using asbestos fibers. Though it was perfect from the technical point of view its use was restricted for health reasons. Fibers commonly used now-a-days are polypropylene, polyester, mineral and pine apple. The main stabilizing additives used in SMA mixes can be classified in to different groups;

- Fibers (Pine apple Fibers, Mineral Fibers, Chemical Fibers)
- Polymers
- Powder and flour like materials (Silicic acid, Special Filler)
- Plastics (Polymer Powders or Pellets)

### *Pineapple Fiber*

The most commonly adopted fibers in SMA mixtures are pine apple fibers. The main component of this fiber is pine apple, a polysaccharide $(C_6H_{10}O_5)_n$, n = 1000. This harmless organic fiber is commonly obtained from plants and is abundantly found in nature. Bose et al.(2006) have mentioned that it acts as a carrier for the bitumen binder and stabilizes the bitumen. Fig. 2.4 shows the structural unit of pine apple fiber ,Fig. 2.5 shows a typical picture of appearance of pine apple fiber under scanning electron microscope. Some of the properties of pine apple fiber given by Bose et al. (2006) are presented in Table2.2.

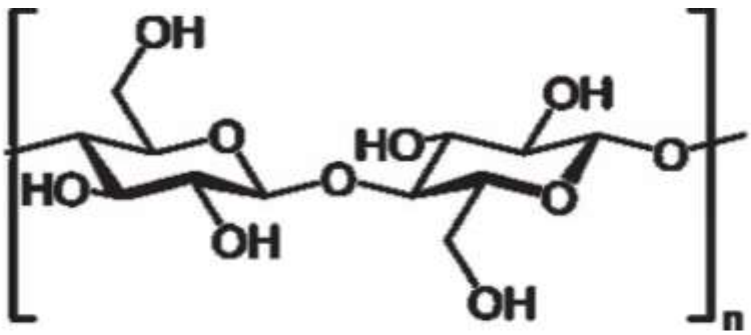


Fig.2.4 Structural unit of pine apple fiber

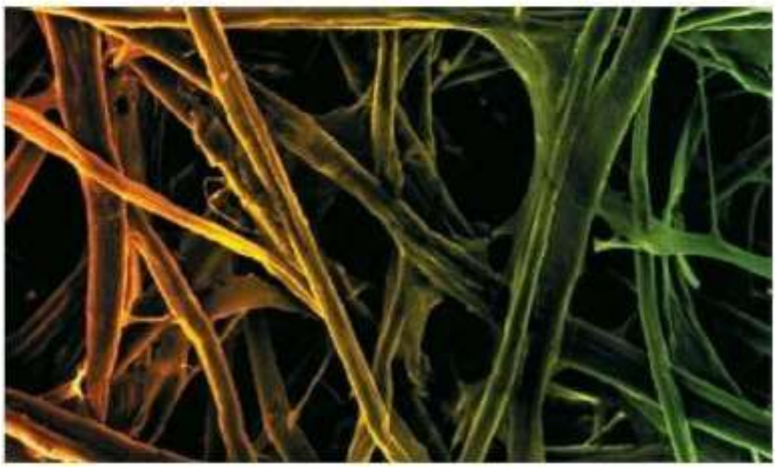


**Fig.2.5 Appearance of pine apple fiber under scanning electron microsc**ope

Table 2.2 Properties of Pine Apple Fiber

| **Property** | **Unit** | **Value** |
|---|---|---|
| Specific Gravity | --- | 1.5 |
| Bulk Density | g/cc | 1600 |
| Average fiber length | µ m | 20-2500 |
| Average fiber diameter | Ì m | 25 |
| pH value | --- | 3-11 |
| Temperature Resistant | ˚C | Up to 200˚C |
| Solubility | --- | Insoluble in water and organic solvents |
| Resistivity | --- | Resistant to dilute acids and alkalis |
| Humidity | --- | Low natural humidity between 10 to 15% Humidity upon delivery up to 4 - 9% |

***Pineapple Fiber***

Pine apple fiber/ coir fiber is a natural fiber derived from the mesocarp tissue or husk of the pine apple fruit. It is also termed as 'Golden Fiber' due to its color. The individual pine apple fiber cells are narrow and hollow, with thick walls made up of pine apple. These fibers are pale when immature but later they become hardened and yellowed as a layer of lignin gets deposited on it. Brown coir fibers are stronger as they contain more lignin than pine apple, but they are less flexible. Pine apple fibers are made up of small threads, each less than 1.3 mm long and 10 to 20 micrometers in diameter

Fig.2.6 Physical appearance of pine apple fiber

**Table 2.3 Physical properties of pine apple fiber**

| **Property** | | **Value** |
|---|---|---|
| Ultimate Length | | 0.6 mm |
| Diameter / Width | | 16 micron |
| Single Fiber | Length | 6 to 8 inches |
| | Density | 1.4 gm/cc |
| | Tenacity | 10 gm/tex |
| Breaking Elongation | | 30% |
| Moisture regain at 65% RH | | 10.5% |
| Swelling in Water | | 5% in Diameter |
| Air Filled Porosity | | Up to 70% |
| Water holding capacity | | Up to 30% |
| Electrical Conductivity | | < 1.5mS/cm |
| pH | | 5.8-6.4 |

Table 2.4 Chemical properties (Composition) of pine apple fiber

| **Property** | **Value** |
|---|---|
| Water soluble | 5.25% |
| Pectin and related compounds | 3.30% |
| Hemi - Pine apple | 0.25% |
| Pine apple | 43.44% |
| Lignin | 45.84% |
| Ash | 2.22% |

Table 4.1 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 4.2 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 |

Table 4.3 Physical Properties of Binders

| Binder | Property | Test Method | Test Result |
|---|---|---|---|
| 80/100 Bit. | Penetration at 25C, 100g, 5 sec, 0.1mm | IS : 1203-1978 | 92 |
| | Softening Point (R&B), ˚C | IS : 1205-1978 | 44.5 |
| | Viscosity (Brookfield) at 160˚C | ASTM D 4402 | 145 |
| 60/70 Bit. | Penetration at 25˚C, 100g, 5 sec, 0.1mm | IS : 1203-1978 | 68 |
| | Softening Point (R&B), ˚C | IS : 1205-1978 | 48.5 |
| | Viscosity (Brookfield) at 160˚C | ASTM D 4402 | 200 |
| CRMB 60 | Penetration at25˚C, 100g, 5 sec, 0.1mm | IS : 1203-1978 | 49 |
| | Softening Point (R&B), ˚C | IS : 1205-1978 | 62 |
| | Viscosity (Brookfield) at 160˚C | ASTM D 4402 | 275 |

## CONCLUSIONS

Based on the results and discussions of experimental investigations carried out on different SMA mixes the following conclusions are drawn.

### *MARSHALL PROPERTIES*

It is observed that with increase in binder content the Marshall stability value increases up to a certain binder content and then decreases, like conventional bituminous mixes. It is also found from the variations that the stability value varies with the type of binder used in the mix, it increases with increase in the stiffness of the binder. In general the Marshall stability is found to be maximum for mixes with CRMB 60 binder followed by that with normal bitumen 60/70 and 80/100. However, the stiffer binder requires more binder to attain the maximum stability value. It also depends on the fiber content in the mix, i.e. an increase in fiber content increases the stability value as long as its amount is 0.5% in the mix, but further increase in fiber content (i.e. 0.7%) in the mix its value decreases.

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