Laboratory Investigation of Stone Matrix Asphalt Using Bagasse Fiber

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Abstract -The development and use of asphalt materials and mixtures originated primarily in European countries and North America. Stone Matrix Asphalt (SMA) is a gap-graded mix known for its high content of coarse aggregates, elevated asphalt levels, and the inclusion of fiber additives as stabilizers. This study explores the engineering properties of SMA mixtures with and without the addition of non-conventional banana fiber as a stabilizing agent. Laboratory tests were conducted to evaluate the suitability of banana fiber by analyzing flow parameters, stability, and mechanical properties of the mixture. The aggregate gradation for the SMA mix was based on MoRTH specifications, and the binder content was varied from 4% to 7% by weight of the aggregate. The fiber content was maintained at 0.3% by weight of the aggregate, with cement used as a filler and 60/70 grade bitumen as the binder.

Keywords: Stone Matrix Asphalt, Banana Fiber, Stabilizing Agent, Mechanical Properties, MoRTH Specifications, Binder Content, 60/70 Grade Bitumen

1.Introduction

In the early 1960s, the European asphalt industry encountered pressing challenges related to pavement performance, particularly concerning rutting, abrasion, and various distresses induced by increasing traffic volumes and the use of studded tires. In response to these critical issues, Stone Mastic Asphalt (SMA) was developed in Germany, specifically designed to address the shortcomings of traditional asphalt mixtures. Owing to its outstanding performance characteristics, SMA was quickly incorporated into German pavement specifications as a standardized mixture class. Over the past two decades, its effectiveness has led to widespread adoption across numerous European countries.

SMA is recognized for its significant contributions to enhancing the durability and rut resistance of road pavements. It is characterized as a gap-graded mixture, typically composed of 70-80% coarse aggregate, 6-7% binder, 8-12% filler, and approximately 0.3-0.5% fibers or other modifiers. The high proportion of coarse aggregates in SMA creates better stone-to-stone contact, which is fundamental to its structural integrity. This interlocking nature allows aggregates to bear loads without significant deformation, thus greatly reducing the likelihood of rutting. Consequently, the use of high coarse aggregate content not only improves rut resistance but also enhances skid resistance, making SMA a safer option for high-traffic roadways.

The high binder content in SMA plays a critical role in filling the voids between the coarse aggregates, effectively binding them together. This characteristic contributes to the overall durability of the pavement, minimizing issues such as premature cracking and raveling, which can significantly impair pavement lifespan. However, SMA is not without its challenges. Notably, drainage and bleeding can arise, primarily due to difficulties in achieving the necessary compaction levels. The high bitumen content can exacerbate drainage issues, and since lowering storage and placement temperatures is not feasible, this problem remains a significant concern for SMA applications.

To mitigate these challenges, the incorporation of stabilizing additives such as fibers, rubber, and polymers has become increasingly common. These additives enhance the stiffness of the asphalt matrix, effectively reducing drainage and bleeding. This advancement not only improves the workability of SMA but also reinforces its performance characteristics under various environmental conditions.

The advantages of SMA extend beyond its structural integrity and durability. Its high stability against permanent deformation (rutting) and exceptional wear resistance make it a preferable choice for busy roadways. Additionally, SMA exhibits slow aging properties, which further enhances its durability against premature cracking. One of the notable features of SMA is its macro-texture, which is higher than that of dense-graded pavements. This increased texture contributes to better frictional properties, thereby improving vehicle safety through reduced hydroplaning and minimizing surface noise.

Despite its numerous advantages, SMA does come with a higher initial cost—typically 20 to 25 percent more than conventional dense mixes. However, many stakeholders argue that the long-term benefits—such as reduced rutting, extended service life, and improved noise and splash control—justify this added investment. The higher costs associated with SMA are primarily due to the inclusion of mineral fillers, fibers, modified binders, and potentially increased asphalt content. As countries outside Europe, including India, explore the viability of SMA for their pavements, the lessons learned from its successful implementation in Europe will be invaluable.In conclusion, SMA represents a significant advancement in pavement technology, addressing critical issues related to durability and performance in the face of heavy traffic demands. As ongoing research and application continue to evolve, the potential for SMA to contribute positively to road infrastructure globally is promising.

2. Objectives

The primary objective of this project is to explore the potential of replacing conventional fibers with a non-conventional natural waste fiber, specifically bagasse fiber, which is derived from the residual biomass after the extraction of juice from sugarcane. This study aims to investigate the effects of bagasse fiber on various properties of Stone Mastic Asphalt (SMA).

Additionally, the project seeks to compare the Marshall properties of SMA samples that incorporate varying binder concentrations. By analyzing the data obtained from the Marshall tests, the study aims to determine the optimum binder content for SMA formulations.

Another key objective is to examine the drain-down characteristics of the SMA mixes prepared at the optimum binder content (OBC). This assessment will provide insights into the stability and performance of the SMA when incorporating bagasse fiber.

Furthermore, the project intends to evaluate other engineering properties of the SMA samples, such as static indirect tensile strength, also measured at the optimum binder content.

Ultimately, this research aims to establish the suitability of bagasse fiber for use in SMA, contributing to sustainable pavement solutions by utilizing a natural waste material that could enhance the performance and durability of road surfaces.

3.SCOPE OF THE PRESENT STUDY:

The objective of this study was accomplished by designing various SMA mixtures using different binder content and a specific fiber content. The binder used was of 60/70 penetration value. The fiber percentage as laid down by as per MORTH standards was 0.3% [4]. Here we have tried to use 0.3% fiber as we are intended to see the response of SMA with minimum fiber content as per MORTHstandards. The tests were conducted to obtain the various Marshall properties from which the optimum binder content were determined at 0.4% air voids. It was also used to determine the drain down characteristics and static indirect tensile strength. Finally these engineering properties were compared to obtain the results, hence making the purpose of the study complete.

4.Materials and Methodology

Wt. Of oven dried sample(in gm) A	Wt.of aggregate retained through 2.36mmIS sieve (in gm)	Wt.of aggregate Passing through 2.36mmIS sieve (in gm) B	Crushing Value	Avg Impact value (%)
3.162	2.600	0.562	17.77	17.39
3.161	2.593	0.568	17.01	

Component	Percent
Cellulose	45-55%
Hemi cellu lose	20-25%
Lignin	18-24%
Ash	1-4%
Waxes	<1%

4.1 Material Used:

1. Coarse and Fine aggregate
2. Bitumen as binder (60/70)
3. Fiber as stabilizer(Bagasse fiber)
4. Cement as filler

4.2 Properties of Material

The following tests were conducted on the soil. The index and engineering properties of soil were determined.

1. Grain size analysis confirming (IS: 2720-part 4, 1985)
2. Consistency limits or Atterberg's Limits using Uppal’s method confirming (IS: 2720-part 5. 1985)
3. Compaction test confirming (IS: 2720- Part 8: 1983)
4. California bearing ratio test confirming (IS: 2720-Part 16: 1987)

Table: 1. Aggregate Crushing Value

The weight of the oven-dried sample was measured at 3.162 grams, with 2.600 grams of aggregate retained on the 2.36 mm IS sieve and 0.562 grams passing through. For a second measurement, the sample weight was 3.161 grams, yielding 2.593 grams retained and 0.568 grams passing through. The crushing value was determined to be 17.77% for the first sample and 17.01% for the second. The average impact value across both samples was calculated to be 17.39%, indicating the material's overall resistance to crushing and impact, which are critical parameters in assessing aggregate quality. As shown in above table.

4.3 TESTS

1. Marshall Test

Marshall Tests were performed on various Stone Mastic Asphalt (SMA) specimens, both with and without fibers, to evaluate key properties such as stability, flow, air voids, and unit weight. These results were instrumental in determining the optimum binder content (OBC) for subsequent tests. Previous research indicates that stability values are low at lower binder contents, increase with higher binder levels, reach a maximum, and then decline with further increases in binder content.

2. Drain Down Test

The drain down test was conducted to measure the drain down percentage in SMA samples at the OBC, comparing results with and without fibers. The findings revealed that the use of fibers significantly reduces the drain down percentage, indicating improved stability in the mix.

3. Static Indirect Tensile Test

The static indirect tensile test was utilized to assess the tensile strength of SMA samples containing fibers under static loads at the OBC. This test also examined how tensile strength varies with temperature, providing insights into the temperature effects on the performance of SMA.

Table: 2. Chemical Composition of Bagasse

Currently, approximately 85% of bagasse production is burned, leading to an excess of this natural resource. Bagasse is utilized in several significant fields, including:

Various studies have explored the use of both natural and synthetic fibers in Stone Mastic Asphalt (SMA), yielding promising results. For instance, Huaxin Chen and Qinwu Xu investigated five different polymers—two polyesters, one polyacrylonitrile, one lignin, and one asbestos—in SMA to assess their physical properties, reinforcing effects, and mechanisms for stabilizing asphalt binder. Their tests examined water absorption, drain down, and temperature effects. The results indicated that these fibers effectively enhanced the asphalt binder's resistance to rutting, flow, and dynamic shear modulus, with polyester and polyacrylonitrile fibers exhibiting superior network effects compared to lignin and asbestos.

Additionally, Esmaeil Ahmadinia and colleagues studied the effects of waste plastic bottles (Polyethylene Terephthalate, or PET) in SMA by varying the quantity of plastic used. Their findings demonstrated improvements in SMA quality and highlighted the environmental benefits of utilizing waste materials.

Sandra Oda and her research team analyzed the use of natural fibers and asphalt rubber binders in discontinuous asphalt mixtures, employing coconut, sisal, cellulose, and polyester fibers. Their mechanical tests showed that mixtures containing natural fibers displayed high resistance and effectively prevented drain down of the asphalt.

Given its high availability and underutilization in India, the purpose of incorporating bagasse fiber into our research is to demonstrate its potential benefits in the transportation industry, leveraging a sustainable resource to enhance pavement performance.

Table 3. Impact values

SNo.	Wt. Of oven dried sample (in gm) A	Wt. of aggregate retained through 2.36mmIS sieve(ingm)	Wt. of passing aggregate(in gm) B	Impact Value (%)	Avg. Impact Value (%)
1	673.5	602.4	71.1	10.56	
2	693.1	619.4	73.7	10.63	10.75
3	678	605.4	72.6	11.06	

Abrasion Value Test (IS:2386(PIV)
For Class B
20-12.5mm= 2500gm
12.5-10mm=2500gm
No of balls=11
Abrasion value =(B/A) *100,
Where B= Wt. of passing aggregate (in gm) A=Wt.of oven dried sample(in gm) . as shown in table.

4.4 Mixing of components

Putting in mould The prepared mixture was transferred to a pre heated mould as quickly as possible so as to ensure that the mixture does not cool before hammering. The diameter of the mould is 100 mm. The mixture was laid down in 3 layers with proper tamping done after putting each layer.

Putting the asphalt mix into the mold is a crucial step in preparing test specimens or forming samples for quality assessment. After the mix is heated and thoroughly blended, it is poured into a preheated mold to ensure proper compaction and shaping. The mold, typically made of metal, is designed to give the sample the desired shape and size. The mix is evenly distributed and compacted using manual or mechanical tampers to remove air voids, ensuring a dense, well-formed specimen. Proper compaction within the mold is essential to replicate field conditions and ensure the material's performance can be accurately tested.

Fig 1: A typical mould

4.5 Hammering (Compaction)

The mixture was then compacted with the help of a hammer having a dimension of and falling from a height of mm. 50 blows were given on each face of the sample. Research has shown that more blows would cause the deterioration of aggregates. For hammering the mold was attached to a fixed arrangement to prevent that staggering of mould during hammering.

A piece of paper of size of mould was put in mould over fitting so that mix is not glued to fitting. For the same purpose oiling was done in inner faces of mould and bottom of hammer.

Fig 2 : A typical Hammer

5. Results and Discussion

The previous chapter detailed the experiments conducted. In this chapter, the results of these experiments are presented, analyzed, and discussed. This section aims to provide insights into the findings and their implications,
building on the methodology established in the earlier chapter.

Binder%	Stability without fiber	Stability with fiber
4	6.65	7.16
4.5	8.079	7.52
5	7.812	8.7
5.5	7.732	8.05
6	6.91	6.87
7	6.54	5.99

Table: 4 stability with and without fibers

5.1 Parameters Used

Here are the corrected formulas for each calculation:

1. Bulk Specific Gravity (Gsb) of Aggregates:
2. Theoretical Maximum Specific Gravity (Gmm) :
3. Bulk Specific Gravity :

1.Voids inmineral aggregates(VMA)

$$VMA = \left[\left(\frac{Mmix}{Gmb} - \frac{Mmix\,Ps}{Gsb}\right) / \frac{Mmix}{Gmb}\right] * 100$$

Where Psis the percent of aggregate present ,by total mass of the mix (that is, Magg = Ps * Mmix)

So VMA=(1−Gmb/Gsb)*Ps*100

1. Air voids(VA)

$$VA = \left[1 - \frac{Gmb}{Gmm}\right] * 100$$

2. Voids filled with bitumen (VFB)

$$VFB = \frac{VMA - VA}{VMA} * 100$$

Marshall Test Results

The Marshall properties of the experiments performed are presented and discussed below:

5.2 Stability vs Bitumen Content

The relationship between stability and bitumen content in Stone Mastic Asphalt (SMA) is crucial for understanding the performance of the mixture. As bitumen content increases, stability typically rises up to a certain optimal level. Initially, lower bitumen content may lead to insufficient bonding between aggregates, resulting in lower stability. However, as the binder content increases, the cohesive forces within the mix improve, enhancing stability.

At an optimal bitumen content, the mixture achieves maximum stability due to effective coating and interlocking of aggregate particles. Beyond this optimal point, excessive bitumen can lead to a reduction in stability, as the mixture may become overly saturated, causing deformation under load.

Therefore, identifying the optimal bitumen content is essential for ensuring the durability and performance of SMA, as it directly impacts the mixture's stability and resistance to rutting and other distresses.

Binder %	D	H1	H2	H3	H4	avg H
4	10	6	6	6.1	6.1	6.05
		6.2	6.2	6.3	6.3	6.25
		6	6.1	6.2	6.3	6.15
4.5	10	6	6.1	6	6	6.025
		6.2	6.1	6.1	6.1	6.125
		6	6.2	6.1	6.1	6.1
5	10	6.3	6.1	6.2	6.2	6.2
		6	6.2	6.1	6.1	6.1
		6.1	6.1	6.1	6.1	6.1
5.5	10	6	6.3	6.1	6.1	6.125
		6.1	6.1	6.1	6.1	6.1
		6	5.8	5.9	5.9	5.9
6	10	6.1	6.3	6.2	6.2	6.2
		6.3	5.9	6.1	6.1	6.1
		6.1	6.1	6.1	6.1	6.1
7	10	6.1	6	6	6	6.025
		6	6.1	6	6	6.025
		6.1	6.1	6.1	6.1	6.1

Table 5. Stability vs. binder%

The relationship between stability and binder percentage in Stone Mastic Asphalt (SMA) is critical for determining the performance characteristics of the mixture. Typically, as the binder percentage increases, stability improves up to a certain optimal level.

At low binder percentages, the aggregate particles may not bond effectively, resulting in lower stability and increased susceptibility to deformation under load. As the binder percentage increases, the cohesion among aggregate particles strengthens, enhancing stability. This improvement continues until the optimal binder content is reached, where the mixture exhibits maximum stability due to adequate coating and interlocking of the aggregates.

However, beyond this optimal binder percentage, further increases can lead to diminishing returns in stability. Excess binder may create a condition where the mixture becomes overly flexible, increasing the risk of deformation and reducing overall stability.
Thus, finding the right balance in binder percentage is essential for achieving optimal stability and ensuring the durability and performance of SMA in road applications.

5.3 OPTIMUMBINDER CONTENT

Theoptimumbitumencontentforthemixdesignisfoundout bytakingtheaveragebitumen content of three Marshall Properties. These are:

- Bitumen content at maximum stability
- Bitumen content at maximum unit weight
- Bitumenpercentagecorrespondingto4%airvoids.

The method suggested above may not be suitable in SMA mixes due to its high coarse aggregate percentage. Hence, we followed the Morth and IRC SP79,2008 specifications to find the optimum binder content which decides the OBC value based on 4 % air voids. Here we obtained the OBC with respect to 4%air voids. Hence the optimum binder was obtained as 4.2 %

- **Marshall Properties at OBC**

Stability (KN)	Flow(mm)	VMA	VA	VFB
7.25	2.64	13.37	4	68.03

Table.6 forMarshallPropertiesat OBC

5.4 DRAIN DOWN CHARACTERISTICS

Drain down characteristics refer to the ability of the binder in asphalt mixtures, particularly Stone Mastic Asphalt (SMA), to remain properly integrated with the aggregate during mixing and storage. Excessive drain down can lead to binder separation, compromising the stability and durability of the pavement.

Key factors influencing drain down include binder content, fiber addition, temperature, and mix design. Higher binder content may increase the risk of drain down if not balanced appropriately, while the inclusion of fibers can significantly reduce this tendency by enhancing binder viscosity and adhesion to aggregates.

Testing for drain down characteristics, such as the drain down test, measures the percentage of binder that separates from the aggregate over time, providing insights into the effectiveness of the mix. Understanding these characteristics is essential for optimizing SMA performance, ensuring workability, and enhancing the long-term durability of road surfaces. The result of this wire basket drain down test is given below.

Mass of empty wire basket A(gm)	Mass of wire basket plus sample B(gm)	Mass of empty catch plate C(gm)	Mass of catch plate plus drained material D(gm)	Draindown%
251.1	1452.5	424.2	424.30	0.008

Table 7. Drain down by wire basket method

6.Conclusion

The study investigates the impact of varying bitumen content on the properties of Stone Mastic Asphalt (SMA) mixes, both with and without fibers. SMA samples were prepared using bitumen content ranging from 4% to 7%, and the results showed that stability initially increases with higher bitumen content but declines beyond a certain point. This is because, while initial increases in bitumen strengthen the aggregate-binder bond, excessive bitumen leads to hydrostatic pressure, reducing friction across aggregate contact points and causing plastic deformation. The fiber-reinforced mixes consistently demonstrated higher stability due to the fibers acting as stabilizers, filling voids, reducing drain down, and improving homogeneity. However, at 4.5% bitumen, improper mixing might explain the lower stability in fiber mixes.

Flow values, representing deformation at failure, increased with bitumen content for both mixes. Fiber-reinforced mixes initially showed higher flow due to effective void filling at lower bitumen content but experienced more deformation as the binder dominated at higher contents, forming lumps.

The Voids in Mineral Aggregate (VMA) values generally decreased with increasing bitumen content, stabilized, and then rose at higher contents due to aggregate movement caused by a thicker bitumen film. Both mix types displayed similar VMA trends, though fiber mixes exhibited slightly higher values at 6% bitumen due to lump formation.

Air voids (VA) decreased with increased bitumen content, with fiber mixes showing lower VA because the fibers filled voids early on. Voids Filled with Bitumen (VFB) increased as more bitumen filled the voids in the mix. Drain down, a common SMA issue due to high bitumen content, was mitigated by the use of fibers, which helped stabilize the mix.

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