Performance of Stone Mastic Asphalt Pavements with the Usage of Carbon and Glass Fiber

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Abstract - This study investigates the performance of Stone Matrix Asphalt (SMA) by incorporating carbon and glass fibers and assessing their influence on the mix under varying aggregate sizes, based on Indian standards. The research compares the drain-down properties of SMA mixes at different fiber contents using VG-30 bitumen. Stability, flow, and volumetric characteristics are examined through the Marshall method to assess the effects of these fibers. Specimens with a constant fiber content were prepared with binder contents ranging from 5.5% to 7%, utilizing Superpave Gyratory Compaction. The results highlight the optimal fiber and bitumen content for improved performance in SMA mixes. **Keywords**: Stone Matrix Asphalt, carbon fiber, glass fiber, Marshall method, Superpave, volumetric properties, aggregate size, bitumen content.

1.Introduction

India, as the second-largest growing economy, is rapidly developing its road infrastructure through large-scale projects like the National Highway Development Project (NHDP) and Pradhan Mantri Gram Sadak Yojana (PMGSY). However, the increasing traffic and vehicle overloading on conventional bituminous roads shorten their lifespan and reduce riding quality, resulting in higher vehicle operating costs and frequent maintenance due to pavement failures. Providing durable roads is a challenge in India, given its diverse climate, terrain, and soil conditions. Significant research is being conducted nationwide to address these pavement issues, and Stone Mastic Asphalt (SMA) has emerged as a promising solution for long-lasting highways.

1.1 Types of Asphalt Surfacing

There are three primary types of asphalt surfacing, which include Dense Graded Asphalt, Stone Mastic Asphalt, and Open Graded Asphalt. SMA is distinct due to its stone-on-stone structure, formed by a gap-graded aggregate, mastic, binder, filler, and fiber, which significantly enhances its strength and performance compared to dense and open-graded mixtures. The high binder content in SMA improves durability and laying characteristics.

SMA, which originated in Germany in the 1960s, is recognized for its superior performance under heavy traffic. By the 1980s, it was standardized in Germany and has since been adopted globally due to its excellent durability and rut resistance.

1.2 Differences Between SMA and Conventional Mixes

The key difference between SMA and conventional mixes lies in their structural skeleton. SMA comprises 70-80% coarse aggregate, forming a strong interlocking mechanism that provides better rut resistance and durability. In contrast, conventional mixes contain only 40-60% coarse aggregate, which often results in a less stable matrix. Additionally, SMA uses a higher binder content (about 6.5%) compared to conventional mixes (5-6%). This higher binder content contributes to SMA's longevity and prevents premature pavement failures.

Another distinction is the use of stabilizing additives in SMA to reduce binder drain down, which is not required in conventional mixes. These additives fill the voids in SMA, enhancing its stability. Conventional mixes rely more on the cohesion and internal friction of the matrix rather than additives.

1.3 Coarse Aggregate Skeleton in SMA

The coarse aggregate skeleton in SMA provides essential structural strength, enabling the pavement to withstand heavy vehicular loads. Proper compaction ensures that the interlocking of the aggregate forms a strong and durable mixture. The skeleton is designed to transfer loads uniformly across the pavement, preventing premature deformation.

1.4 Mastic Composition and Additives in SMA

Mastic, which consists of fine aggregate, filler, stabilizer, and bituminous binder, plays a crucial role in SMA by adhering to the coarse aggregate, smoothing surfaces to prevent crushing during compaction, and providing strength against temperature and load stresses. Fine aggregate fills voids between coarse particles and adds stability, while fillers like fly ash or hydrated lime influence the mixture's moisture resistance and stiffness.

Binders in SMA are often polymer-modified bitumen (PMB) to enhance resistance to fatigue, deformation, and temperature variations. Stabilizers, such as fibers, are added to prevent binder drain down during transportation and placement. These fibers improve the mixture’s performance, especially under high temperatures, ensuring the long-term durability of the pavement.

1.5 Merits of SMA

SMA offers several advantages, including long service life, improved strength and wear resistance due to aggregate interlock, enhanced fatigue resistance, and delayed aging, which prevents early pavement cracking. It also provides effective noise reduction and better control over temperature susceptibility. Although the initial construction cost of SMA is higher, its longer service life and resistance to deformation make it a cost-effective solution for heavily trafficked roads.

Overall, SMA has proven to be a durable, rut-resistant surfacing material suitable for India’s diverse road conditions, offering significant improvements in pavement performance and longevity. Quarry dust in highway constructions. Studies on pond ash in various applications are Bera A.K. et al (2007), Raju Sarkar et.al (2009) have studied the compaction and strength characteristics of pond ash. Amalendu Ghosh et al (2005), Venkatappa Rao G et al (2011), Kumar. R. et al (2007), Temel Yottamole et al (2005) have studied the behavior of pond ash with Geosynthetics and reinforced with randomly distributed fibers. Kolay P.K. et.al (2011) has used pond ash as stabilizer of peaty soil. Sridharan et al (1996, 1999) studied geotechnical characteristics of pond ash as a structural fill. The results showed that the use of pond ash increase the peak friction angle, peak compressive strength, CBR value.

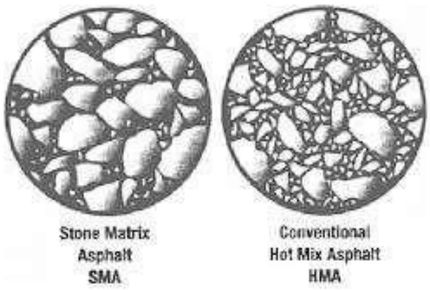

Fig.1.1 shape bonding of stone and concrete hot mixes

2. Objectives

1.To investigate the performance of Stove Matrix Asphalt (SMAL with the usage of Carbon fiber and glass fiber under die influence of change in motorial mat Aggregate sizes based on Indian specifications. The lists of objectives are stated below

2.Comparison of drain down results at varying finer contents with 160 Cast 170 C temperature bitumen at

3.Comparison of stability, flow and volumetric properties of SMA mixes, VOD 3. Carbon fibr

e and Glass fibre by using Marshall Methods

4.Finally, to understand the effect of significant changes in characteristics of the Mixes due to Carbon fiber and Glass fiber in SMA

2.1 SCOPE OF THE PRESENT STUDY:

Previous studies have been focused on finding the optimal fiber contents and specifications, evaluation of engineering properties when modifications for aggregate or the fiber has been made. As, alterations in the particle size distribution will influence the void ratio and load size dispersion of aggregates in the present study the influence of changes in fires over the properties of asphalt mixture has been studied. The scope of the present study covers, methodology to determine the engineering properties of SMA mixtures using the Carbon fibre and Glass fiber by means of the laboratory procedures in order to ensure the suitable Carbon and Glass content, using the drain-down test results experiments are carried out choosing constant fiber content.
Samples were prepared as per Indian (NMAS 13.2mm) by varying trail binder contents from 5.5-7% using Marshall method by Super pave Gyratory Compaction to ensure the specified percentage void contents. These specimens are further tested for their stability, flow and

volumetric properties. The optimum bitumen content for the mix with unmodified VG-30 graded bitumen for those two fibers were calculated

These samples prepared with optimal fiber and bitumen contents are analyzed for different Marshall Stability properties.

3. **Materials and Methodology**

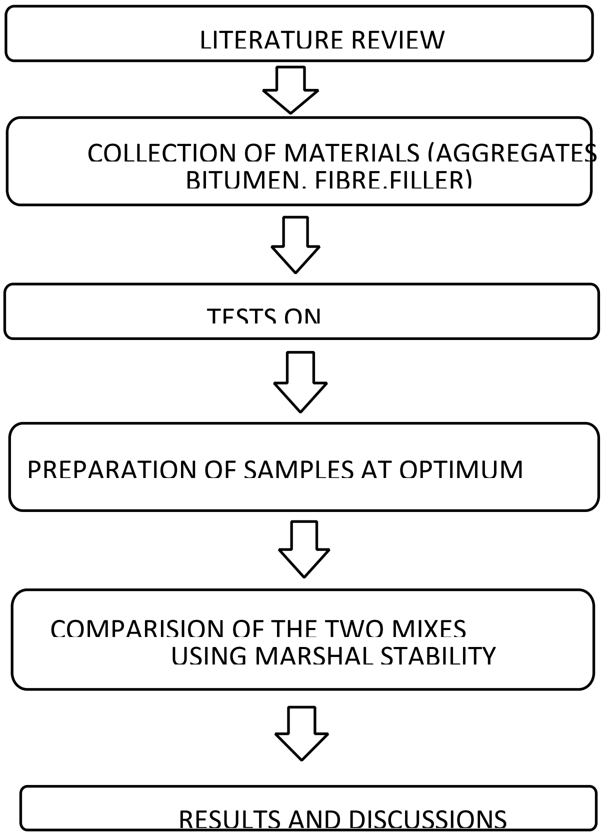

Fig.1.2 flow chart for methodology

The present research study is focused on the gap-graded hot asphalt mix called the Stone matrix asphalt (SMA), which is designed to maximize the resistance against the permanent deformations using the stone-on-stone aggregate skeleton. The volumetric properties of an asphalt mix depend on the kind of gradation adopted. It is difficult to achieve the exact mid gradation from a quarry having wide size range in aggregates. Hence, it's essential to study the characteristics of SMA over changes in gradation based on the fatigue and rutting characteristics. For this study, comparison between two aggregate gradations namely, Chinese gradation adopted in airfields and the MoRT&H, 2009 gradation having the nominal aggregate size of 16mm and 13.2mm respectively are chosen. To overcome the problem of drain down the natural stabilizer which is biodegradable, abundantly, economically available coir fibre is chosen using the mechanical tests of samples its feasibility was verified. Using the conventional binder VG-30 samples prepared with varying contents 5.5%-7.0% (by weight of mineral aggregate) and with fixed fibre content of 0.3% (by weight of mix). The Marshall Mix design procedure with aid of Superpave gyratory compaction for the significant air void percentage was used to optimize asphalt content for both type of gradations. The optimum binder content is found at 3-4% air voids.

The experimental research approach followed in this study shown in the Fig 1 In the preliminary step the properties of aggregate and asphalt are evaluated. Next the feasible fibre content was evaluated for the two gradations using the drain down testing methodology. In the next stage the optimization of mix is done. Later, the comparison of both mixes using the performance tests such as Marshall Stability.

3.1 Laboratory Testing result

Property	Criteria
Design air voids, %	4
Bitumen, %	5.8 minimum
Voids in Mineral Aggregates (VMA),%	17 minimum.
Voids in Coarse Aggregates mix (VCA Mix), %	Less than Voids in Coarse Aggregates (dry rodded) (VCADRC)
Asphalt drain down, % AASHTO T 305	0.30 maximum
Tensile Strength Ratio (TSR), % AASHTO T 283	80 minimum

Table.1: SMA Mix requirements as per (MoRTH)

properties and criteria for designing Stone Mastic Asphalt (SMA):

Design Air Voids: The design air voids are set at 4%, which ensures adequate void space for compaction without compromising durability.

Bitumen Content: A minimum of 5.8% bitumen is required to achieve the desired stability and longevity of the pavement.

Voids in Mineral Aggregates (VMA): A minimum of 17% is necessary to ensure sufficient space for the binder and fine aggregate, contributing to better performance.

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- Voids in Coarse Aggregate (VCA Mix): The VCA Mix must be less than the Voids in Coarse Aggregates when dry rodded (VCADRC), ensuring proper stone-on-stone contact, crucial for strength and durability.
- Asphalt Drain Down: According to AASHTO T 305, the maximum allowable asphalt drain down is 0.30%, which prevents excessive binder loss during transportation and placement.
- Tensile Strength Ratio (TSR): The TSR, as per AASHTO T 283, must be a minimum of 80%, indicating good moisture resistance and durability of the SMA mix. As shown in table.1

These criteria ensure that the SMA mix performs well under heavy traffic and varying environmental conditions.

3.2 Grain Size Analysis

The aggregate gradations influence in the present study is compared between the MoRT&H, 2009 and the Chinese airfield gradation specifications. The MoRT&H gradation i.e,. the Indian gradation having the nominal maximum aggregate size of 19mm has been described in Table 4.5 and gradation curve.

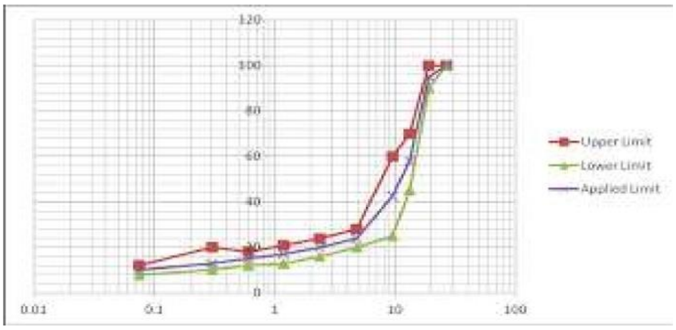

Fig.2 SMA grain size distribution curve for the MoRT&H

Property Tested	Test Method	Results Obtained	Requirement as per IS-73:2006
Penetration (100 gram, 5 seconds at 250C) (1/10th of mm)	IS 1203-1978	61.87mm	50-70
Softening Point OC (Ring & Ball Apparatus)	IS 1205-1978	48.92°C	Min 47
Ductility at 2700 (5 cm/min pull), cm	IS 1208-1978	>100	Min 75
Specific Gravity	IS 1202-1978	1.12	Min 0.99
Flash Point and fire point, OC	IS 1209-1978	265 285	Min 220

Table.2: coarse aggregate Mix requirements as per (MoRTH)

The bitumen for the fibre-stabilized stone matrix, asphalt adopted was viscosity grade VG-30 having the penetration of complying with Indian Standard specification for paving bitumen IS 71:2006. The obtained physical properties of VG-30 have penetration, ductility, softening point and specific gravity and their requirements per specifications.

3.3 Marshall Stability Test

Marshall Stability test was conducted on cylindrical SMA specimens to find out their stability and flow values. The principal features of the method were a density-voids analysis and a stability-flow test of compacted specimen. The specimen was kept in thermostatically controlled water bath maintained at 60 ±1°C for 30 to 40 minutes. Then it was placed in Marshall test head and tested to determine Marshall stability value which was a measure of strength of the mixture. It was the maximum resistance in kilo Newton, which it would develop at 60°C when tested in the standard Marshall equipment. The flow value was the total deformation in units of mm, occurring in the specimen between no load and maximum load during the test. The test specimens were prepared with varying bitumen content in 0.5 per cent increments over a range that gives a well-defined maximum value for specimen density and stability .

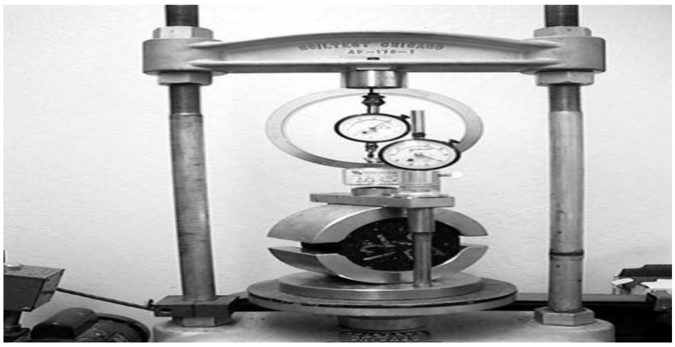

Fig.3 Marshall Test Setup

4.Results and Discussion

Fibre Content %	Drain down %		
	Drain down at 160°C	Drain down at 170°C	MoRT&H Specification
0.2	0.345	0.485	0.3 Maximum
0.3	0. 1912	0.2095	
0.4	0.0194	0.0456	

Table.3 Drain down values of SMA Mix (Glass fiber)

The drain down percentages for different fiber contents at varying temperatures are as follows:

- At 0.2% fiber content, the drain down is 0.345% at 160°C and0.485% at 170°C, exceeding the MoRT&H maximum limit of 0.3%.

At 0.3% fiber content, the drain down decreases to 0.1912% at 160°C and 0.2095% at 170°C, both within the acceptable range.

At 0.4% fiber content, the drain down is minimal at 0.0194% at 160°C and 0.0456% at 170°C, well below the limit, indicating optimal performance.

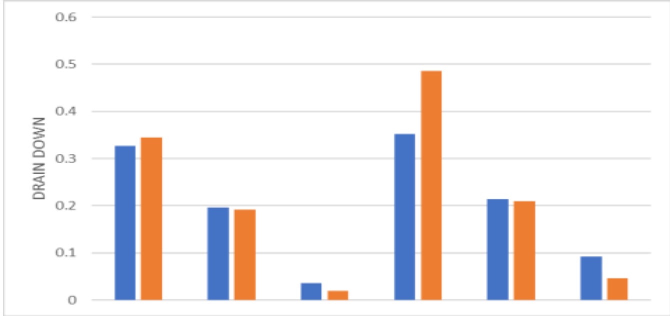

Fig.4: Comparison of drain down results at varying binder contents

From the figure we observe that the overall drain down values is in the range of 0.0365%0.3524% For the case of maximum binder content (7%) when there is 0.2% there's more drain down of 0.485% in case of Glass fibre, while the lowest of0.345% was observed in the case of Carbon fibre. As per ASTM minimum drain down should be 0.39%, for both the fibre at 0.2% it's not meeting the requirement

In the 0.3% fibre case the overall range was in 0.1912%-0.214% satisfying the specification requirements for both fibres So, here the test trail percentage excluded the need of 0.4% fibre as there's almost no drain down.

The feasibility of this 0.3% was also verified with obtained optimum bunder content for both fibres derived from Marshall Test results. At this OBC the range was 0.1789%- 0.02019%, again concluding that Carbon fibre has the drain down within the limits we can use for design.

Hence its evident here that carbon fibre is providing significant stabilization as compared to mixes with no fibre. Excess fibre quantity is restricted to prevent the overcrowding which may add up as finer fraction effecting mixture performance to, more fiber creates extra voids in the mix as due to increased surface area of aggregates and fibre requiring more binder to be coated with which may lead to problem of fat spots In this examination fibre of 10-20mm length and 0.3% (of total mix) content was kept constant.

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Sample no.	Bitumen Content (%) (by Wt. of Agg	Marshal stability (kg)	Flow value(mm)	Bulk Density (gm/cc)	Volume of Voids Vv (%)	Voids in Mineral Agg. VMA (%)	Vaida filled with Bitumen, VEB (%)	Marsh all Quotient (kg/m m)
1	5.5	842.718	3.21	2.45	6.59	13.09	70.14	262.52
2	5.5	880.032	3.06	2.47	6.48	13.79	64.08	287.59
3	5.5	1063.36	3.34	2.43	6.43	13.68	68.17	325.18
Avg	5.5	928.70	3.27	2.45	6.51	13.59	67.40	291.76
1	6.0	900.9	4.06	2.37	3.98	14.34	74.96	221.89
2	6.0	876.26	4.00	2.54	4.57	13.83	79.31	290.065
3	6.0	875.5	3.97	2.41	4.34	14.35	76.59	220.52
	6.0	884.22	4.01	2.43	4.26	14.12	77.80	220.50
1	7.0	773.55	4.637	2.37	3.95	16.34	80.87	165.64
2	7.0	823.22	4.89	2.35	3.93	16.05	83.19	168.35
3	7.0	744.6	4.93	2.24	3.95	16.61	79.29	161.03
	7.0	780.45	4.82	2.32	3.95	16.36	80.26	161.67
1	7.5	683.32	4.97	2.31	2.10	17.03	88.64	137.48
2	7.5	767.54	5.02	2.24	2.17	16.97	92.70	152.89
3	7.5	654.225	5.06	2.20	2.14	17.34	89.03	129.29
	7.5	701.695	5.01	2.25	2.14	17.12	90.34	140.05

Table .4 Showing average values of control mix samples using Marshall test

The test results show that as bitumen content increases, there is a gradual decrease in Marshall stability and a corresponding increase in flow values, indicating a reduction in the mixture's resistance to deformation. At 5.5% bitumen, the stability is highest, with moderate flow and void values, suggesting a strong and well-compacted mix. Increasing bitumen to 6.0% slightly decreases stability but improves the filling of voids, making the mix more flexible. However, further increases to 7.0% and 7.5% result in significantly lower stability, higher flow values, and reduced resistance to deformation, making these mixes less suitable for high-stress conditions. The optimal balance appears to be at 6.0% bitumen, offering a good compromise between stability and flexibility.

Sample No.	Bitumen content (by Wt of Agg.)	Marshall Stability (Kg)	Flow value (mm)	Bulk density (gm/cc)	Volume of Voids Vv (%)	Voids in Mineral VMA (%)	Voids filled with bitumen, VFB (%)	Marshall Quotient (kg/mm)
1	5.5	1094.59	2.28	2.38	5.64	24.41	74	480.08
2	5.5	1027.01	2.55	2.36	4.93	24.69	82	402.74
3	5.5	1039.87	2.43	2.28	5.21	24.58	79	427.93
Avg.	5.5	1053	2.42	2.34	5.26	24.57	78	435.12
1	6.0	1079	2.93	2.40	4.28	24.69	87	368.25
2	6.0	1069.97	2.71	2.30	4.74	24.33	76	394.82
3	6.0	1082	2.80	2.36	4.40	24.58	81	386.42
Avg.	6.0	1076.4	2.81	2.35	4.47	24.16	81	383.06
1	6.5	1184.32	2.98	2.28	3.87	24.83	89	397.42
2	6.5	1194.18	3.07	2.40	4.28	25.12	76	389.96
3	6.5	1174.91	3.28	2.38	4.09	24.91	83	357.89
Avg.	6.5	1186.4	3.10	2.35	4.08	24.96	83	382.70
1	7.0	1065	3.37	2.36	3.70	25.29	84.34	316.02
2	7.0	1034	3.51	2.28	3.69	26.06	80.87	294.58
3	7.0	1029	3.40	2.38	3.74	25.59	89.23	302.64
Avg.	7.0	1042	3.43	2.34	3.70	25.63	85	303.79

Table. 5 volumetric properties of SMA samples using Carbon fibre

The test results show that with increasing bitumen content, the Marshall stability generally increases until 6.5% bitumen, where the stability reaches the highest value of 1186.4 kg, indicating improved strength. However, at 7.0% bitumen, stability decreases to 1042 kg, suggesting a decline in load-bearing capacity. Flow values also increase with higher bitumen content, reflecting greater flexibility but lower resistance to deformation, especially at 7.0%. Bulk density remains relatively stable, while the volume of voids decreases slightly as bitumen content increases, indicating better compaction. Voids in Mineral Aggregates (VMA) and Voids Filled with Bitumen (VFB) increase with higher bitumen content, reaching maximum values at 7.0%, showing better void filling but reduced stability. The best balance between stability and flexibility appears to be at 6.5% bitumen.

5.conclusion

The basic purpose of this study was to evaluate the use of Carbon fibre instead of Glass fibre. As the coir fibre is locally available material more over its cost is too lens comparing with cellulose fibre. Thus, the results of the use of 10-15mm length fibres with along with conventional VG-30 graded binder in the SMA can be summarized as follows

The fibre content of 0.3% was found to be optimum satisfying the drain down of the binder and also at the Optimum binder content of bitumen.

The optimum binder was evaluated to be 6.605% and 6.55% for Carbon and Glass fibre respectively with 5.5% as minimum binder content to prevent fat spots. The binder content required was more in Carbon fibre.

The percent drain down at OBC the range was 0.0021% -0.0648%, concluding that Carbon fibre to be better then Glass fibre

The stability value at OBC and 0.3% fibre content was 1156.076Kgs and 1021.68Kgs for the Carbon and Glass respectively i.e., almost 11.625% increase in stability as compared to Carbon. The flow values are 3.1693mm and 3.3087mm for Carbon and Glass fibre respectively as prescribed standards in range of 2-4 mm

Hence by adding the Carbon fibre the drain-down can be arrested. The role of aggregate skeleton played an important role in behaviour of the mixes in the stability, tensile strength. An average performance was observed from the rutting and fatigue evaluations.

5.1 Scope for further study:

1.To check the feasibility of SMA mixes using coir fibre by choosing different nominal aggregate sizes from the

specifications such as in IRC: SP-2008, NAPA. NCHRP 425 especially adopted in United States and German.
2.To observe the special effect over the fatigue strength adopting the modified bitumen's like CRMB, PMB etc.
3.Influence over the carbon fibre with different dimensions (Length and Diameter) and content in the mix .

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