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EVALUATING THE POTENTIAL INTEGRATION OF HEMP FIBER WITHIN STONE MATRIX ASPHALT FOR OPTIMIZED STRUCTURAL VIABILITY

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Abstract:
Stone Matrix Asphalt (SMA) is a specialized type of bituminous mixture distinct from conventional bituminous mixes, primarily due to its higher content of coarse aggregates. This composition ensures a robust and interlocking aggregate skeleton, providing enhanced structural stability. In addition to coarse aggregates, the SMA mix includes essential components such as binders, fillers, and fibers. The incorporation of fibers into the SMA mix plays a crucial role in stabilizing the mixture by preventing binder drain-down and enhancing overall durability. The high proportion of coarse aggregates within the SMA mix creates a strong structural skeleton, which significantly improves the load distribution network. This feature is essential for achieving superior performance under heavy traffic loads. The thick asphalt binder film in SMA not only enhances durability but also protects the mix from weathering and wear over time. The presence of fibers is particularly beneficial as it prevents the drain-down of the binder during mixing and compaction, ensuring a uniform distribution of materials. Furthermore, the fibers contribute to maintaining the rough texture of the pavement surface, which is critical for achieving adequate friction, even as the top binder layer is gradually worn away by traffic. This research aims to explore the engineering properties of SMA by introducing a non-conventional fiber—hemp fiber—into the mix. Hemp fiber, derived from the Cannabis plant, is typically regarded as agricultural waste in India and remains underutilized. By incorporating this natural fiber into SMA, the project seeks to investigate its potential benefits and evaluate its performance against standard requirements. This research builds on that foundation by specifically examining the impact of hemp fiber on the engineering properties of SMA. To assess the viability of hemp fiber in SMA, a series of laboratory tests, including the Marshall Stability Test, were conducted. These tests aimed to evaluate key performance indicators such as stability, flow, density, air voids, and voids filled with bitumen. The results were compared against established standards to determine whether the addition of hemp fiber meets the desirable performance criteria for SMA mixes. The study's findings could potentially pave the way for the use of hemp fiber as a sustainable and cost-effective alternative in road construction, contributing to both environmental and economic benefits.

Keywords:
Hemp Fiber, Stone Matrix Asphalt, Flexible Pavement, Marshall Stability Test.

1. Introduction

In the mid-1960s, European asphalt production companies faced the need for a surface course capable of resisting rutting, abrasion, and challenges posed by heavy traffic and studded tires. In response to this demand, Stone Matrix Asphalt (SMA) was developed. Initially introduced in Germany, SMA quickly gained recognition for its superior performance and was eventually standardized in their asphalt specifications. Due to its enhanced rut resistance and durability, SMA has been widely adopted in various European countries for over two decades. Inspired by this success, several countries, including India, have begun utilizing SMA or exploring its applicability for their asphalt mixtures. Research indicates that the use of SMA in road surfacing significantly improves the durability and rut resistance of the mix. SMA typically comprises 70-80% coarse aggregates, a minimal amount of fine aggregates, 5-7% binder, 8-12%

filler, and approximately 0.3-0.5% fiber or modifier. The high content of coarse aggregates forms a strong stone-on-stone structure, which greatly reduces deformation under load, thus enhancing rut resistance and skid resistance. The substantial binder content effectively fills the voids between aggregates, binding them together and contributing to the mix's durability by preventing premature cracking and raveling. However, SMA can encounter issues such as drainage and bleeding, often resulting from difficulties in achieving adequate compaction. The high binder content can lead to drainage, particularly when storage and placement temperatures cannot be sufficiently lowered. To mitigate these issues, stabilizing additives like fibers, rubbers, and polymers are incorporated to strengthen the mixture and minimize drainage and bleeding. While traditional stabilizing agents are effective, they are generally expensive. This has created a need for lower-cost alternatives that can achieve similar performance. In this context, the current study explores the use of a natural fiber—hemp fiber—as a cost-effective stabilizer in SMA mixes. By investigating the potential of hemp fiber, this study aims to provide a sustainable and economical alternative to conventional stabilizing additives, maintaining the desired performance characteristics of SMA.

2. Literature Review

Bastidas-Martínez et al. 2024 investigated the use of textile fibers as stabilizing additives in SMA mixtures. The research focused on the resistance to moisture damage, a critical factor affecting pavement durability. Laboratory tests, including indirect tensile strength and resilient modulus assessments under moisture exposure, indicated that textile fibers performed effectively. The findings suggest that textile fibers could serve as sustainable substitutes for commercial cellulose fibers in SMA mixtures, offering both environmental and performance benefits.

Devulapalli et al. 2024 examined the characteristics of aggregate gradation, drain-down, and stabilizing agents in SMA mixtures. The review highlighted the challenges associated with SMA mixtures, such as drain-down and the need for proper aggregate gradation. The study emphasized the importance of selecting appropriate stabilizing additives, including natural fibers, to mitigate these issues and improve the overall performance of SMA pavements.

Behiry et al. 2024 focused on the laboratory evaluation of resistance to moisture damage in asphalt mixtures. The research assessed the effectiveness of various fibers, including natural fibers, in enhancing the moisture resistance of SMA. The study concluded that incorporating natural fibers could significantly improve the durability and longevity of SMA pavements by mitigating moisture-induced damage.

Akkharawongwhatthana et al. 2023 investigated the mechanistic performance of hybrid asphalt concretes incorporating reclaimed asphalt pavement (RAP) and recycled concrete aggregate (RCA), reinforced with natural hemp fibers (HF). The study assessed various factors, including RAP/RCA ratios, HF lengths, and HF contents, to determine their impact on both static and dynamic performance metrics. Findings indicated that while the static properties of HF-RAP-RCA asphalt concrete were comparable to conventional mixtures, dynamic performance was significantly lower, suggesting suitability primarily for low-traffic roads. The research highlighted that an optimal hemp fiber content of 0.05% improved resilient properties, thereby enhancing fatigue life and rutting resistance. Additionally, increasing RCA content positively influenced the benefits of hemp fiber reinforcement, promoting the use of HF-RAP-RCA asphalt concrete as a sustainable material for low-volume roads.

Devulapalli et al. 2022 examined the characteristics of aggregate gradation, drain-down, and stabilizing agents in Stone Matrix Asphalt (SMA) mixtures. The research highlighted the challenges associated with SMA mixtures, such as drain-down and the need for proper aggregate gradation. The study emphasized the importance of selecting appropriate stabilizing additives, including natural fibers, to mitigate these issues and improve the overall performance of SMA pavements.

3. Research Methodology

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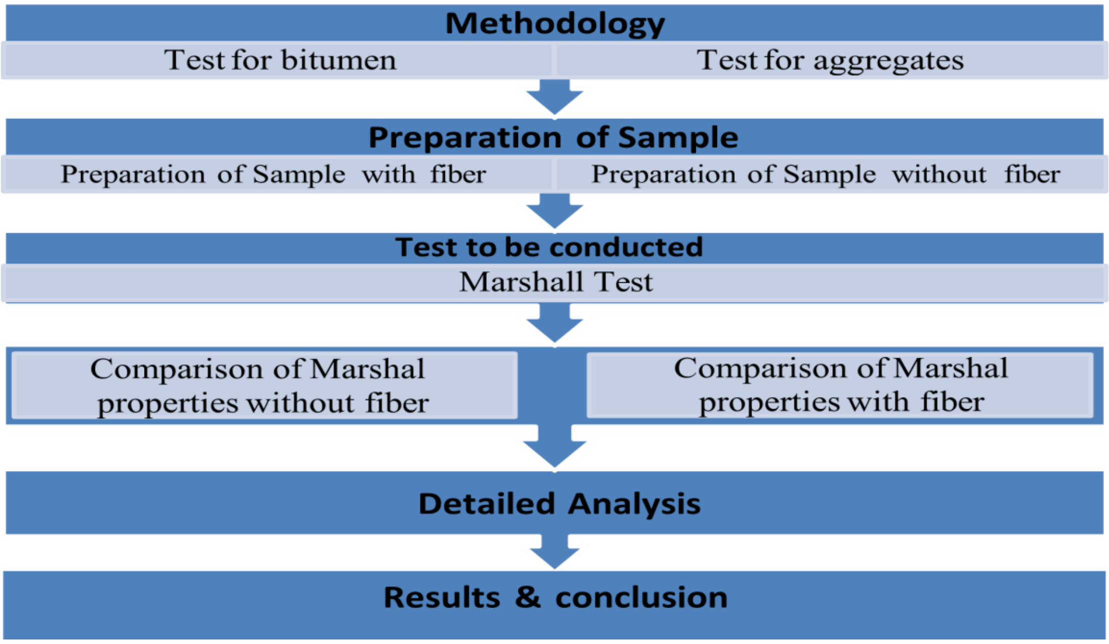

Fig 1: Methodology to be adopted

A large portion of research activities made on SMA incorporates the Marshall test for deciding the flow value and for making SMA a stable mix.

4. RESULTS & DISCUSSIONS

4.1 Gradation of aggregates:

Table 4.1 Gradation of aggregates

Sieve size.	Upper limit.	Lower limit	Adopted
19	100	100	100
13.2	100	90	95
9.5	75	50	63
4.75	40	25	33
2.36	28	20	25
1.18	26	18	21
0.6	22	15	18
0.3	20	12	15
0.15	15	8	12
0.075	12	8	11

4.2 Aggregates testing results:

Table 4.2 Test for Los Angeles abrasion as per IS: 2386 (P-4)

Total weight of aggregate sample (w1).	2.5 kg
Weight of aggregates retained (w2)	1952 gm
Weight of aggregates passing from 1.7mm sieve (w3)	540 gm
Abrasion value = w1-w2/w1*100	22 % less than < 25 %, satisfactory value.

Table 4.3 Impact test as per IS: 2386 (P-4)

Weight of mould	1.275 kg
Weight of mould with sample	1.794 kg

Weight of sample (w1)	535 gm
Percentage retained	500 gm
Percentage passing from 2.36 sieve after 15 blows by hammer (w2)	40 gm
Impact value = w2/w1*100	10 % < 18 % , satisfactory

Table 4.4 Crushing value test

Weight of oven dried sample in gm (A)	Weight of retained aggregates on 2.36 mm sieve in gm	Weight of passing aggregates in gm (B)	Abrasion value
10000	8502	1498	14.98 < 25%

Table 4.5 Specific gravity test

Total weight of aggregates	2.0 kg
Weight of bucket in air	0.9 kg
Weight of submerged bucket (w2)	0.7 kg
Weight of bucket + Aggregates	2.9 kg
Weight of bucket + aggregates (submerged)/ w1	1.9 kg
Dry weight of aggregates (w3)	1.8 kg
Specific Gravity = w3/w3-(w1-w2)	Specific gravity= 2.9 , should be 2.5 to 3

Table 4.6 Water Absorption test

Dry saturated weight W1 in grams	Combined weight of material and basket in waterW2 in grams	Water absorption %
1996	2014	0.90

4.3 Binder test results:

Binder used is VG-30 grade for sample preparation and various test results are as follows.

Table 4.7 Bitumen test results

Tests	**Test methods**	**Value obtained**
Penetration test in mm	IS. :1203-1978	67.9
Softening test. (degree)	IS. :1203-1978	48.6
. Specific gravity	IS. :1203-1978	1.03.
Ductility in cm	IS:1203-1978	41.5cm/min

Sieve analysis for Mix:

Total weight of sample = 1200 gm

Table 4.8 Gradation of samples without fibers

Sieve. . Size. in mm	Intermediat e.	adopte d	%. age. retaine d	Amount of aggregates. taken in this binder content					
				4%.	4.5%	5%	5.5%	6%	7%
				1152.	1146	1140	1134	1128	1116
19	100	100		0%	0%	0%	0%	0%	0%
13.2	90-100	95	5	57.6	57.3	57.00	56.7	56.4	55.8
9.5	50-75	63	32	368.64	366.72	364.8	362.88	360.96	357.12
4.75	25-40	33	30	345.6	343.8	342	340.2	338.4	334.8
2.36	20-28	25	8	92.16	91.68	91.2	90.72	90.24	89.28
1.18	18-26	21	4	46.08	45.84	45.6	45.36	45.12	44.64
0.6	15-22	18	3	34.56	34.38	34.2	34.02	33.84	33.48
0.3	12-20	15	3	34.56	34.38	34.2	34.02	33.84	33.48
0.15	8-15	12	3	34.56	34.38	34.2	34.02	33.84	33.48
0.075	8-12	11	2	23.04	22.92	22.8	22.68	22.56	22.32
Filler	0	0	10	115.2	114.6	114.0	113.4	112.8	111.6
Binder .				48.	54	60.	66	72.	84

Table 4.9 Stability and flow values for samples without fibers

Bitumen. (%)	Wsa.	Wsw.	flow	stability	Avg. flow	Avg. stability
4	1207	724	2.2	6.4230	2.20	6.834
4	1204	710	1.9	6.8910		
4	1202	713	2.1	7.1907		
4.5	1198	709	3.0	8.6190	3.03	8.7594
4.5	1200	723	3.2	8.7084		
4.5	1206	722	2.9	8.9510		
5	1205	717	3.5	8.8021	3.56	8.899zaa
5	1199	707	3.9	8.1103		
5	1205	715	3.3	7.9573		
5.5	1207	726	4.5	7.3691	4.1	8.5237
5.5	1201	711	3.8	9.3076		
5.5	1210	730	4.0	8.8945		

6	1201	702	4.7	8.3920	5.03	7.8762
6	1199	704	5.5	7.9537		
6	1203	721	4.9	7.3430		
7	1197	716	5.9	6.3964	6.2	6.5042
7	1190	704	6.1	6.1682		
7	1196	708	6.4	6.9480		

Table 4.10 Stability and flow value for the samples with fibers

Binder. (%)	Wsa	Wsw	Flow	stability	Avg. flow	Avg. stability
4	1204	716	2.9	6.4190	2.966	6.8764
4	1202	713	3.1	6.8854		
4	1199	709	2.9	7.3248		
4.5	1203	711	3.0	8.1123	3.16	8.4408
4.5	1198	720	3.3	8.8854		
4.5	1200	717	3.2	8.3248		
5	1205	706	3.3	9.8105	3.366	9.909
5	1199	713	3.6	9.7808		
5	1207	709	3.2	10.1359		
5.5	1204	715	3.9	9.9210	4.01	8.5088
5.5	1208	717	3.8	8.8014		
5.5	1196	711	4.3	7.704		
6	1202	714	5.6	8.379	4.8	7.860
6	1207	713	4.6	6.710		
6	1200	716	4.2	8.501		
7	1198	703	5.2	7.0124	5.7	6.5389
7	1203	705	6.1	6.492		
7	1204	715	5.8	6.1121		

Marshal test results:

Various Marshall Properties determined during performing the experiment are stability, flow values. The stability portion for samples is calculated by providing the samples a supported load which is given at 50.8 mm/min. As the sample starts to show failure and the maximum load measured at dial gauge till failure is stability for the sample.

4.11 Table: Marshall Parameters for samples with fibers

Binder. Content. (%)	Avg. VMA	Avg. Va.	VFB	Stability (KN)	Flow (mm)
4	14.04	4.66	70.78	6.876	2.96
4.5	13.97	3.90	78.68	8.440	3.16
5	13.88	2.96	84.56	9.909	3.36
5.5	14.78	2.81	86.55	8.508	4.01
6	15.72	2.88	89.92	7.860	4.8
7	16.19	2.11	93.02	6.538	5.7

5. CONCLUSION

The study reveals that for stability value the Marshall samples were made at different binder contents as 4%, 4.5%, 5%, 5.5%, 6% and 7%. These samples showed a gradual increment in their stability values at their initial stage and by further increase of binder to these samples, they showed decrease in stability value it was because with increase of binder content the bond between aggregates and bitumen gets stronger and with further addition it decreases and the bond gets weaker showing plastic deformation and stability falls. The same is the case with samples made with fiber but, instead of it they showed greater stability value when compared with samples made without fiber at same binder content and also at OBC. This proves that by adding fiber as stabilizer to SMA Mix which not only increases stability but also helps in decreasing the air voids present in mix. By adding fiber the drain down of the binder also decreases from the asphalt film. It enables a sought of homogeneity to the mix and also has proved less noise production of pavements made of SMA Mix. Flow value of Marshall Samples is the value when samples go through deformation under load at failure. Flow value of samples without fibers showed a constant increase in flow, but the samples with fibers showed a little increase in initial binder content and then later showed a gradual increase in flow value. This was due to the fact that at initial stages the fibers helps in maintaining homogeneity of the mix but later on it gets lost with the increase of binder content. The flow value for SMA Samples or mix lies between 2 to 4 mm. VMA values for mix samples should show a constant increase theoretically, but here it was observed that when bitumen content was low starting from initial addition, the VMA values gets decreased and after with more addition of bitumen it finally starts increasing at high bitumen content. The VMA values at initial falls because of the re-orientation of the aggregates with binder added which is low. With high binder content the VMA value gets increased because aggregates starts moving a bit form a thick film and fiber starts forming lumps resulting in increased VMA value. The VFB of the mixture shows an increment in its value as the binder content is increased. In results we also found the VFB of samples with fibers and also the samples without fibers showed a gradual increase in VFB with increase in binder content. This is because as the binder content is increased the voids present in the mix get filled by bitumen or binder. The air voids theoretically decreases when binder addition is increased it is due to the fact that it fills up the voids present in mix. The Va was less near OBC of samples with fiber because of the fact that on addition of bitumen and fiber the voids present in mix got filled up. If there is any increase in air voids after OBC is due to improper mixing of samples.

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