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Influence of natural fibres on the compressive strength of Stone Matrix Asphalt mixtures

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Abstract

Development of stabilized Stone Matrix Asphalt (SMA) mixtures for improved pavement performance has been the focus of research all over India for the past few decades. India, being an agricultural economy produces fairly huge quantity of natural fibres. This paper focuses on the influence of additives like coir, sisal, banana fibres (natural fibres), on the compressive strength of SMA mixtures. A preliminary investigation is conducted to characterize the materials. Compressive strength tests are conducted to study the resistance to crushing to withstand the stresses due to traffic loads. All stabilized mixtures show the maximum value of compressive strength at 0.3% fibre content. SMA with coir fibre exhibits higher compressive strength indicating its higher crushing resistance. The indices of retained strength for all mixtures satisfy the limiting value of 75%. But for control mixture, it is only about 60%, which substantiate the necessity of additives in SMA mixtures.

Keywords: *Stone Matrix Asphalt, fibres, compressive strength, index of retained strength*

1. Introduction

Stone Matrix Asphalt (SMA) has been first introduced in Europe for resisting damage from the studded tires better than other type of HMA [1]. In recognition of its excellent performance, a national standard was set up in Germany in the year 1984. The Indian Roads Congress has adopted a tentative SMA specification [2]. One test road was constructed in Delhi in October 2006, using SMA as a surfacing course [3]. By considering the advantage of the proven field performance of this test track and in other regions of developed countries with climatic conditions reasonably close to that of India, SMA can be considered as the right choice for long lasting pavements.

SMA is a gap graded bituminous mixture containing a high proportion of coarse aggregates and filler with relatively less medium sized aggregates [4]. It has rich mastic comprised of bitumen, fines, and mineral filler. Additives such as fibres or polymers are used as a stabilizer to secure the mastic within the overall structure which will strengthen the bonding between the aggregates provided by the binder. This enhances the stone to stone contact resulting in an increasing resistance to crushing and resulted in a stiffer and tougher mix with considerable improvement in compressive strength.

Compressive strength is the capacity of pavement materials to withstand axially directed compressive forces. The bituminous mixture starts crushing, when the compressive stress due to loads exceeds the strength of the mixture. They should possess resistance to crushing to withstand the stresses due to traffic loads. Along with other physical properties of the mixture, the compressive strength also plays a major role in mixture characteristics, which is one of the most important factors determining its suitability for use under the given loading and environmental conditions as a highway paving material[5].

Presence of additives strengthen the bonding between the aggregates provided by the binder and thereby enhancing the stone to stone contact which will result in increasing the resistance to crushing. This gives rise to a stiffer and tougher mix with considerable improvement in compressive strength. Additives do not cause the SMA mixture to weaken when exposed to moisture. Actually they are enhancing the resistance to moisture susceptibility of the mixture. Fibres [6] or polymers can be used as the additives. In this study the influence of natural fibres coir, sisal and banana fibre on the compressive strength characteristics of SMA mixtures are studied.

2. Material characterisation

Aggregate of sizes 20mm, 10mm and stone dust procured from a local quarry at Kochi, Kerala is used in the present investigation and the physical properties of aggregates are given in Table1. Ordinary Portland cement from a local market which makes a better bond with aggregate, bitumen and additive is used as the filler material and the physical properties are shown in Table 2. Bitumen of 60/70 penetration grade obtained from Kochi Refineries Limited, Kochi, is used in the preparation of mix samples and the physical properties of bitumen are given in Table 3. Three natural fibres are used as stabilizing additives for the present study. The photographs of these fibres are shown in Fig.1. The coir fibres and sisal fibre for the present work had locally procured from Alappuzha, and banana fibre from Banana Research station, Thrissur, Kerala and their properties are given in Table 4.

Table 1: Physical properties of aggregates

Property	**Values obtained**	**Method of Test**
Aggregate impact value (%)	16	IS:2386 (IV)
Los Angeles Abrasion Value	27	IS:2386 (IV)
Combined Flakiness and Elongation Index (%)	18	IS:2386 (I)
Stripping Value	Traces	IS 6241:1971 (R2003)
Water Absorption (%)	Nil	IS:2386 (III)
Specific gravity	2.65	IS:2386 (III)

Table 2: Physical properties of cement

Physical property	Values obtaine d
Specific gravity	3.12
% passing 0.075 mm sieve (ASTM C117)	96

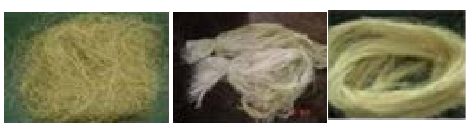

Fig .1 Coir fibre ,Sisal fibre, Banana fibre

Table 3: Physical properties of bitumen

Property	Result	Test procedure as per specification
Specific Gravity @ 27˚C	1	IS:1202 - 1978
Softening Point (˚C) (R&B Method)	50	IS:1205 - 1978
Penetration @ 25˚C,0.1 mm 100g, 5 sec	64	IS:1203 - 1978
Ductility @ 27˚C (cm)	72	IS:1208 - 1978
Flash Point (˚C) Fire Point (˚C)	240 270	IS:1209 – 1978
Viscosity at 60 ˚C (Poise)	1200	IS:1206 – 1978
Elastic recovery @ 15˚C (%)	11	IRC: SP:53 – 2002

Table 4: Physical properties of fibres

Property	**Coir fibre**	**Sisal fibre**	**Banana fibre**
Diameter (µm)	100 - 450	50 - 200	80 - 250
Density (g/cm ^{3})	1.45	1.40	1.35
Cellulose content (%)	43	67	65
Lignin content (%)	45	12	5
Elastic modulus(GN/m^2)	4-6	9 -16	8 -20
Tenacity (MN/m^2)	131 - 175	568 - 640	529 - 754
Elongation at break (%)	15 - 40	3 - 7	1.0 – 1.2

3. Experimental programme

The sieve analysis, blending and the specified limits of the SMA mixture are given in Table 5 as per NCHRP, TRB[7]. For the proposed design mix gradation, four specimens are prepared for each bitumen content within the range of 5.5 – 7.5% at increments of 0.5 percent, in accordance with ASTM D 1559 using 50 blows/face compaction standards. All bitumen content shall be in percentage by weight of the total mix. As soon as the freshly compacted specimens have cooled to room temperature, the bulk specific gravity of each test specimen shall be determined. The stability and flow value of each test specimen shall then be determined in accordance with ASTM D 1559. After the completion of the stability and flow test, specific gravity and voids analysis shall be carried out to determine the percentage air voids in mineral aggregate and the percentage air voids in the compacted mix and voids filled with bitumen. The average values of bulk specific gravity, stability, flow, VA, VMA and VFB obtained above are plotted separately against the bitumen content and a smooth curve drawn through the plotted values. Average of the binder content corresponding to VMA of 17 % and an air void of 4% are considered as the optimum binder content [8]. Stability and Flow values at the optimum bitumen content are then found from the plotted smooth curves The optimum bitumen content (OBC) for the SMA mixture is determined and is found to be 6.42 % (by wt. of total mix). The SMA mixture without additives is considered as the control mixture for the compressive strength test.

Table 5: Gradation of aggregates and their blends for SMA mixture

Sieve size (mm)	Percentage passing				Adopted	Specified
	20 mm (A)	10 mm (B)	Stone dust (C)	Cement (D)	Grading A:B:C:D	Grading NCHRP, TRB

					50:30:11:9	
25.0	100	100	100	100	100	100
19.0	98	100	100	100	99	90 -100
12.5	20	100	100	100	60	50 - 74
9.50	4	58	100	100	39	25 - 60
4.75	0	6	100	100	22	20 - 28
2.36	0	0	92	100	19	16 - 24
1.18	0	0	77	100	17	13 - 21
0.6	0	0	64	100	16	12 - 18
0.3	0	0	45	100	14	12 - 15
0.075	0	0	6	96	9	8 - 10

3.1. Compressive strength of SMA mixtures

This test measures the compressive strength of compacted bituminous mixtures. The test specimens are cylinders of 101.6 mm in diameter and 101.6 ± 2.5 mm in height. The size of test specimens has an influence on the results of the compressive strength test.

Aggregate is heated to slightly above the mixing temperature to allow for dry mixing prior to adding the bitumen binder. In no case the mixing temperature should exceed 175˚C. Preheat the bowl and batch of aggregate in an oven to a temperature that complies with the aggregate temperature. This will result in an acceptable temperature after dry mixing. With the bowl of aggregate, quickly pour the prescribed mass of hot bitumen on the hot aggregate and immediately mix the bitumen into the aggregate. The mixing shall be completed within 90 to 120 s, during which time the temperature should have dropped to about 3 to 5˚C above the compacting temperature. This will result in the mixture being at the compacting temperature when compaction begins, which may commence immediately. For preparing the stabilized mixtures, additives are added in heated aggregate prior to mixing them with heated bitumen.

An optimum bitumen content of 6.42 % as found from Marshall control mix design (by wt. of total mix) is used in preparing all the stabilized mixes to maintain consistency throughout the study. A total of 200 Marshall specimens are prepared for the five different additives at different percentages of additives. Allow the test specimens to cool at room temperature for at least 2 hours after removal from the oven. Test specimens are subjected to axial compression at a uniform vertical deformation rate of 3.2mm/min. The compressive strength is determined by dividing the maximum vertical load obtained during deformation at the rate specified by the original cross-sectional area of the test specimen (ASTM D 1074 – 09). The compressive strength is reported as the average of three specimens in each case. In order to know the temperature effect on the compressive strength of mixtures, the tests are carried out at two different temperatures 25˚C and 60˚C (which represent the intermediate and high pavement temperatures).

3.1.1 Effect of water on compressive strength

In order to investigate the effect of water on the compressive strength of SMA mixtures with different additives, the index of retained strength is determined. This value is an indicator of their resistance to moisture susceptibility. The test was conducted [9] at a temperature of 25˚C and the load at which the specimen fails is taken as the dry strength of the bituminous mix. Conditioned specimens are prepared by placing the samples in a water bath maintained at 60˚C for 24 hours and after that keeping the samples at 25˚C for two hours. These conditioned specimens are then tested for their strength. The ratio of the compressive strength of the water-conditioned specimens to that of dry specimens is taken as the index of retained strength. The indices of retained strength for different mixtures with different type and varying percentage of additives are determined.

4. Results and discussion

The variation of the compressive strength with increasing percentage of additive content for the two different temperatures, viz. 25˚C and 60˚C for fibres are shown in Table 6. All stabilized mixtures shows higher compressive strength than the control mixture. This may be due to the increase in stiffness of the SMA mix. Presence of additive may strengthen the bonding between the aggregates provided by the binder and thereby enhancing the stone to stone contact. This will result in increasing the resistance to crushing. It is also observed that the compressive strength decreases with the increase in temperature. But the percentage decrease in strength decreases with the increase in fibre content up to a certain level.

Table 6: Compressive strength (MPa) of fibre stabilised SMA samples at 25˚C and 60˚C

Fibre(%)	**Compressive strength of SMA samples with**					
	Coir fibre		Sisal fibre		Banana fibre	
	25˚C	60˚C	25˚C	60˚C	25˚C	60˚C
0	5.10	4.13	5.10	4.13	5.10	4.13
0.1	5.19	4.25	5.16	4.22	5.15	4.20
0.2	5.71	5.22	5.58	5.15	5.54	5.01
0.3	5.96	5.87	5.80	5.67	5.76	5.57

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0.4	5.96	5.85	5.80	5.66	5.75	5.54

Coir fibre stabilized SMA shows the maximum compressive strength as compared to sisal and banana fibre mixtures. From Fig. 2 and 3, it is evident that all fibre stabilized mixtures show the maximum value of compressive strength at 0.3% fibre content. It can also be seen that fibre reinforcing effect increases initially with increasing fibre content, but at high fibre content, they could induce coagulation of fibres and thus reduce its reinforcing effect. This can be the reason why the strength of SMA mixes decreases beyond 0.3% fibre content.
Fig.4 and 5 show the percentage increase in compressive strength for fibre stabilized SMA mixtures at 25˚ C and 60˚C with respect to the control mixture. It can be observed that the percentage increase in strength with respect to the control mixture at 0.3% fibre content for coir fibre stabilized mixes at 25˚C and 60˚C are 17% and 42% respectively. Similarly, the percentage increase in strength is about 14% and 13% at 25˚C for sisal and banana fibre respectively and the respective increase at 60˚C are about 37% and 35%. Thus coir fibre stabilized mixture shows the higher resistance to crushing than the other fibre stabilized mixtures.

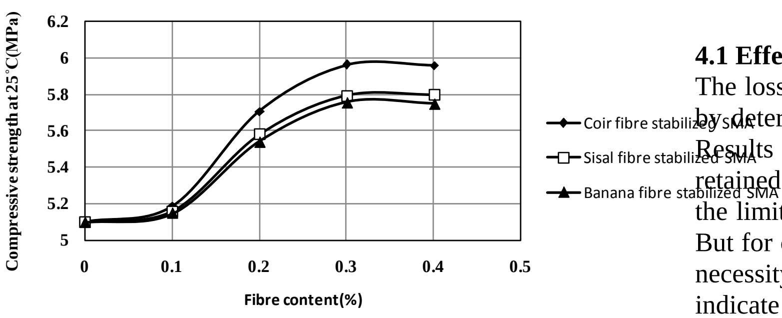

Fig. 2 Variation of compressive strength at 25˚C

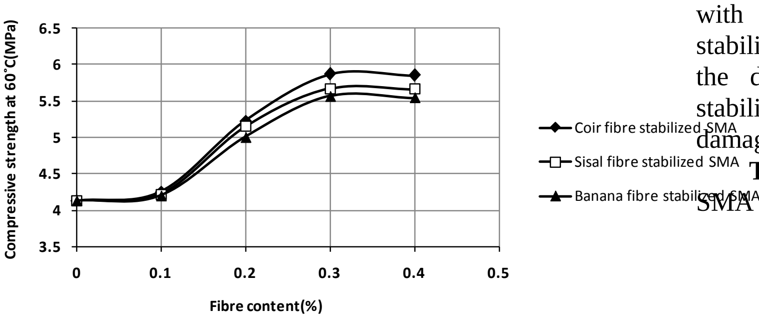

Fig. 3 Variation of compressive strength at 60˚C

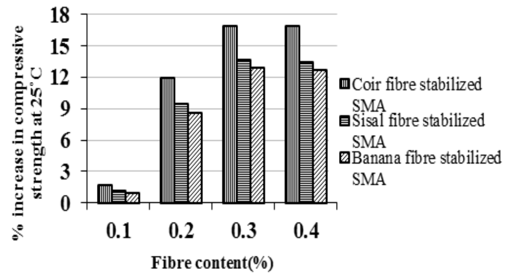

Fig. 4 Percentage increase in compressive strength at 25˚C

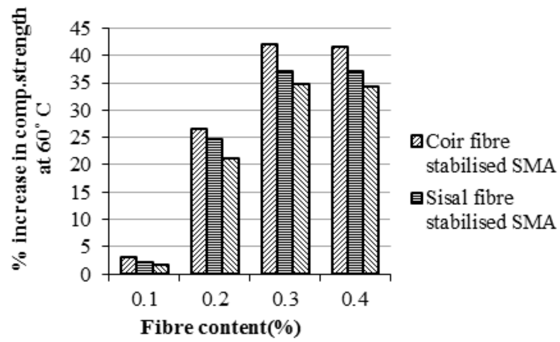

Fig. 5 Percentage increase in compressive strength at 60˚C

4.1 Effect of water

The loss of adhesion of aggregate with bitumen is studied by determining the percentage index of retained strength. Results reported in Table 7 show that the indices of retained strength (IRS) for all stabilized mixtures satisfy the limiting value of 75% as specified by ASTM D 1075. But for control mixture, it is only about 60%, showing the necessity of additives in SMA mixtures. The test results indicate that the adhesion between bitumen and aggregate can be improved significantly by the additives. The presence of fibres in SMA mixture resulted in a mixture with superior water resistance property. Coir fibre stabilized mixtures give the maximum value. Considering the different SMA mixtures investigated, coir fibre stabilized SMA mixtures have the minimum water induced damage.

Table 7: Variation of index of retained strength of SMA mixtures with various fibre contents

%Fibre	Index of retained strength (%) for SMA mixtures with		
	Coir fibre	Sisal fibre	Banana fibre
0	61.37	61.37	61.37
0.1	82.23	80.00	80.18
0.2	92.31	90.70	90.72

0.3	97.21	96.77	97.01
0.4	96.42	95.76	95.74

5. Conclusions

Presence of fibres in SMA mixture enhances the stone to stone contact of aggregates in the gap graded mixture by strengthening the bonding between them. These fibres also enhance the adhesion between aggregate and bitumen, which results in less stripping of SMA mixture. All these give rise to a stiffer and tougher mix with considerable improvement in compressive strength.

fibres do not cause the SMA mixture to weaken when exposed to moisture. Actually they are enhancing the resistance to moisture susceptibility of the mixture. The indices of retained strength for all stabilized mixtures satisfy the limiting value of 75%. But for control mixture, it is only about 60%, which substantiate the necessity of additives in SMA mixtures. Although all the fibres significantly improve the performance of the SMA mixtures in terms of compressive strength, coir fibre gives the best result.

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