A COMPARATIVE STUDY ON PERFORMANCE OF STONE MATRIX ASPHALT WITH CELLULOSE AND COIR FIBER

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ABSTRACT

The stone matrix asphalt (SMA) mixture is a gap-graded mix which is categorized by elevated coarse aggregate content, high asphalt contents and fiber additives as stabilizers. Due to stone on stone make contact and presence of high filler content, it acts as a stiff matrix and is best suitable for high volume roads and urban intersections where braking effects are more. In general, carbon fibers are added in SMA mixes to avoid oozing of bitumen from the mix. In the present study coir fibers and cellulose fibers will be added to the SMA mixes and its properties will be evaluated. Since, the coir fibers are easily available in India and comparatively cheap, it is decided to use in the current investigation. Detailed laboratory investigations will be carried out by preparing asphalt concrete mixtures by adding cellulose and coir fibers with dosages of 0.2%, 0.3%, 0.4% and 0.5% by total mix weight. Volumetric properties of the mixes are determined and various strength tests such as marshal stability are conducted.

Keyword: - *Stone Matrix Asphalt (SMA), Coir fibers, cellulose fibers, marshal stability, etc*

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1. INTRODUCTION

The bituminous pavements play a vital role in Indian pavements at present. Though life cycle of concrete pavements has proved to be very economical over bituminous pavements they were unable to replace bituminous pavements completely because of Initial cost of construction of rigid pavements is more than 25% of flexible pavements.

Asphalt mixtures are mostly used in road construction because its superior qualities. It provides resilient, highly waterproof and durable. It safe guards the underlying pavement structure and base course from damaging effects of water and traffic abrasion. Due to its flexible nature the asphalt mixtures makes the pavement adjust slightly to the deformation and consolidation because of poor sub grade and wheel-loads without reducing the performance of pavement. Flexible pavements may undergo structural damages like fatigue cracks in asphalt bound layer and rutting due to repeatedly application of traffic loads. It also undergoes failure due to climatic factors like temperature and moisture destructing bitumen mix and aggregates.

Types of Asphalt surfacing:
There are three major types of asphalt surfacing, characterized by a mixture of bitumen and stone aggregate. These are Dense Graded asphalt, Stone Mastic Asphalt and Open Graded Asphalt.

Stone mastic asphalt (SMA) is a stone-on-stone like skeletal structure of gap graded aggregate, bonded together by mastic, which actually is higher binder content, filler and fibre to reduce the binder drain. This structure improves the strength and the performance of SMA even higher than the dense graded and open graded asphalt mixtures. High percentage of binder content is important to ensure the durability and laying characteristics of SMA.

SMA is best explained as two-component hot mix asphalt HMA which comprises a coarse aggregate skeleton derived from a gap-graded gradation and a high bitumen content mortar. Since 1960s, Stone Mastic Asphalt (SMA) pavement surfaces have been used successfully in Germany on heavily trafficked roads. In recognition of its excellent performance a national standard was set in Germany in 1984. Since then, because of its excellent performance characteristics, the use of SMA increased in popularity amongst the road authorities and asphalt industry.

Fig-1: (a) Dense graded asphalt (b) Stone Matrix Asphalt (c) Dense-Graded HMA (left) vs. SMA (right)

Table-1: The main differences between SMA and conventional asphalt mix:

Properties	SMA	BC
Definition	SMA is a gap graded mix which contains more amount of coarse aggregates hardly bonded by matrix consisting of filler, bitumen, fine aggregate and stabilizing additives	BC consists of well graded coarse and fine aggregate, filler and bitumen
Coarse Aggregate Content (%)	75% – 80%	50%-60%
Fine Aggregate content (%)	20% – 25%	40% – 50%
Filler content (%)	9% – 13%	6% – 10%
Type of Binder	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	25mm-75mm	30mm-65mm

1.1 Objectives of the Present Investigation

To investigate the performance of SMA, by the usage of Cellulose fibre and coconut (coir) fiber under the influence of change in ostensible maximum sizes of aggregates based up on Indian specifications. The lists of objectives are stated below.

- Comparison of drain down results at varying fiber contents with 7% bitumen at 160C and 170C temperature.

- Comparison of stability, flow and volumetric property of SMA mixes, using VG-30, Cellulose fiber and coir fiber by using Marshall methods.
- Based on cost effectiveness either coir fiber or cellulose fiber to be used.

Finally to understand the effect of significant changes in characteristics of the mixes, due to Cellulose fiber and Coir fiber in SMA mixtures.

2. LITERATURE REVIEW

The Stone matrix asphalt (SMA) which was familiar in Germany during 1960's. A German engineer Dr. Zichner who is manager of Central Laboratory for Road Construction at the Strabag Bau AG was its designer. So, during these sixties the tendency in surface courses in Germany was to use "guss asphalt" (mastic asphalt) and also the asphaltic concrete having low coarse aggregate fractions, higher air voids and low bitumen content making its performance degrade especially with studded tyres in winter. Due to the poor mix qualities the wearing courses were not able to resist these studded tyres effecting the pavement service period.

Studies revealed that about 28 or more states using the SMA specifications to have 20-30% increased serviceable. Further the development was trailed at Japan with good success rate and next the Ministry of Communications in Saudi Arabia formulated SMA specifications came up with a trail section construction in East province of Saudi Arabia. In Poland despite of restrictions to allow concepts of West German publications ,they tried to make a road sections due to its affirmative outputs the Polish Central Authority of Public Roads started its practice of constructing SMA surface courses from 1971.

In Spain and France, an ultra-thin surface is being made with SMA to act as composite between SMA and open graded asphalt (OGFC) mixes. The specifications were near match to SMA constraints but bringing a texture such that the fine and binder quantity were reduced maintaining an air void in range of 6-12%. The significant growth of SMA and it application in few regions of North America such as Australia, China and New Zealand making the stone matrix asphalt as a global mix. Coming to place of India the first test section was designed during 2006 at two intersections namely Kajuri Chowk and Brij Puri Chowk, New Delhi.

The various investigations were carried on material, mixture properties and performances among 85 project locations in United States, where these results were illuminated below,

- The Los-Angeles abrasion (LA) values are above 30% for almost 85% of the surveyed projects.
- The SMA mixes mostly designed for 25-30% of material passing 4.75mm sieve size and almost 80% of the time with 7-11% passing 0.075mm sieve
- Almost 40-60% projects had mixes with air voids less than 4% and binder content above 6%.
- Above 90% of investigated locations showed the rutting less than 4mm.
- Improved performances towards pavement distress compared to dense graded asphalt mixtures.
- No evidence of cracking in SMA projects.
- Fat spots were a major point of concern in SMA mixes.

3. 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.

To overcome the problem of draindown the natural stabilizer which is biodegradable, abundantly, economically available coir fiber 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

fiber content of 0.3% (by weight of mix). The Marshall mix design procedure with aid of Super pave gyratory compaction for the significant air void percentage was used to optimize asphalt content for both type of gradations. The optimum binder content are found at 3-4% air voids. The experimental research approach followed in this study shown in the figure below.

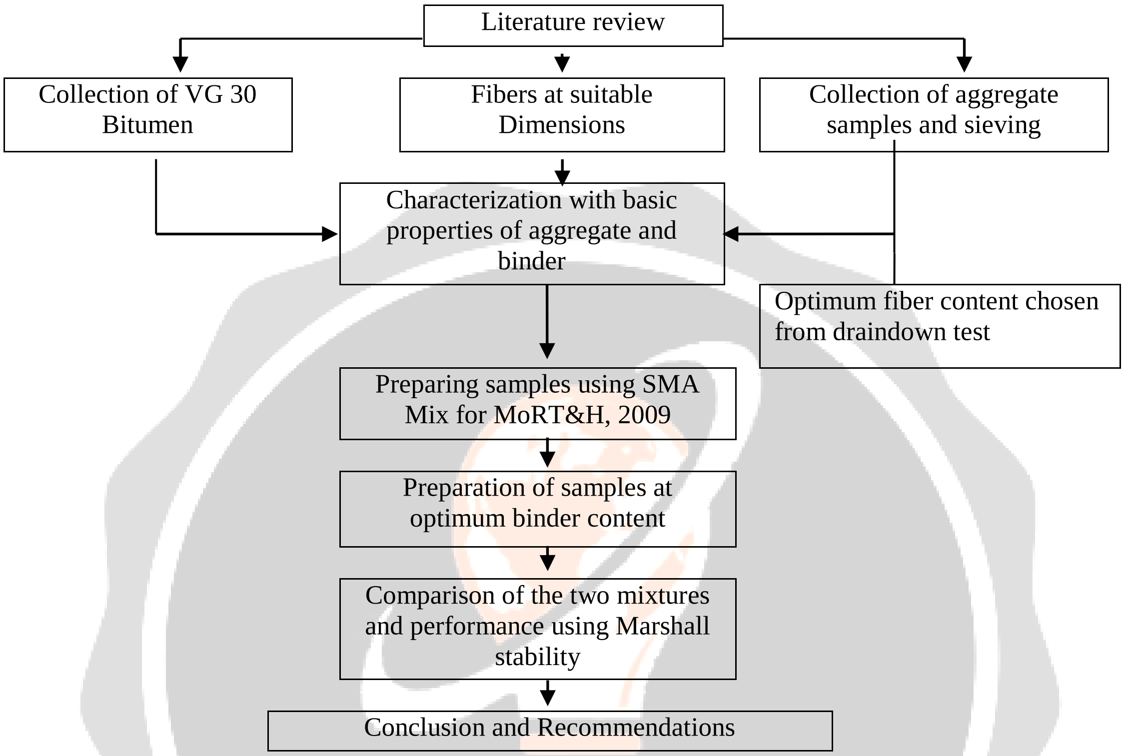


Fig-2: Experimental program

Table-2: SMA mix requirements as per (MoRTH-2009 and IRC:SP:53-2008)

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

3.1 MATERIALS

Aggregate: The aggregate (both Coarse and fine) used in this study was brought from the quarry located near village Belman District. Udupi, Karnataka. These aggregates used in SMA should be highly durable, strong and tough to resist heavy loads.

Coarse Aggregate: The coarse aggregates were of crushed granite rock retained on 2.36 mm sieve. In order to ensure proper stone-on-stone contact the passing 4.75mm sieve is ensured to be less than 30% in the adopted gradation.

Fine Aggregate: A fine aggregate is the passing 2.36 mm sieve and retained on 0.075 mm sieve which are ensured to be clean, durable, and free of organic or other deleterious substances. In the SMA mixes the passing 0.075mm sieve is recommended to be 8-10%, this filler play a role in volumetric properties of mix and optimum asphalt content which significantly distinguishes SMA from conventional mixes.

Aggregate gradation: 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 3.3 and gradation curve was also shown as in Fig

Table-3: Physical properties of the aggregate

Property	Test	Results	Test method	MoRT&H Specifications (2009)
Particle shape	Flakiness and Elongation Index (combined)	21.75%	IS 2386 Part I	30% maximum
Strength	Los Angeles Abrasion Value	24.62%	IS 2386 Part IV	25% maximum
	Aggregate Impact Value	20.39%		24% maximum
Toughness	Aggregate Crushing Value	22.06%	IS 2386 Part IV	30% maximum
Specific Gravity	20 mm	2.654	IS 2386 Part III	2.5 minimum
	10 mm	2.656		
	Stone Dust	2.676		
Water absorption	20 mm	0.104	IS 2386 Part III	2% maximum
	10mm	0.095		
	Stone Dust	0.798		

Table-4: Aggregate gradation as per MoRT&H,2009

Designation	19 mm SMA
Course where used	Binder (Intermediate) Course
Nominal aggregate size	19 mm
IS Sieve (mm)	Cumulative % by weight of total aggregate passing
26.5	100
19	90 – 100
13.2	45 – 70
9.5	25 – 60
4.75	20 – 28
2.36	16 – 24
1.18	13 – 21
0.600	12 – 18
0.300	10 – 20
0.075	8 – 12

Coir Fiber: The coir fiber is chosen as a stabilizer because of its natural abundance in India. The fiber was brought from locally available shops.

Table-5: Properties of coir fiber

Property		Value
Colour		brown and golden brown
single fiber	average length	10 -20mm
	average diameter	0.09-0.12mm
	Aspect ratio (l/d)	120-160
moisture content		> 10%(by weight)

Fig-3: Physical appearance of coir used in the study

Cellulose fiber: The cellulose fiber is the very commonly included fiber in SMA mixtures. Cellulose of a polysaccharide ($C6H10O5$) n, n = 1000 is the main component of this fiber. This organic fiber which is completely harmless is generally acquired from plants and is profusely found in the nature.

Fig-4: Physical appearance of cellulose used in the study

4. RESULTS AND DISCUSSIONS

4.1 Study approach

In this study the research has been emphasized on the optimum quantity of coir fiber to be used in the preparation of asphalt mixes for the comparative analysis between two opted gradations. The coir fibers length are fixed in a range of 10-20 mm (to prevent lumps forms during mixing), but the percentage fiber (by weight of total mix) is decided on draindown test results. Maintaining the fiber length more than 20mm further increase air gap between aggregates degrade the mix behaviour. Later using the obtained optimal fiber quantity with constant length is used in the mixes of nominal aggregate sizes of 13.2 mm Indian and 16 mm Chinese SMA Gradations for the performance testing.

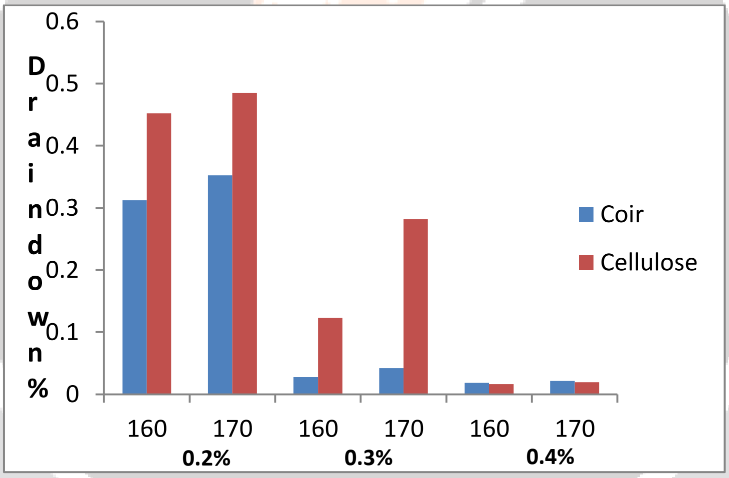
4.2 Performance tests

Table-6: Draindown values of SMA mix (Cori fiber)

Fiber Content %	Draindown %		
	Draindown at 160°C	Draindown at 170°C	MoRT&H Specification
0.2	0.3124	0.3524	0.3 Maximum
0.3	0.0279	0.0421	
0.4	0.0185	0.0213	

Table-7: Draindown values of SMA mix (Cellulose fiber)

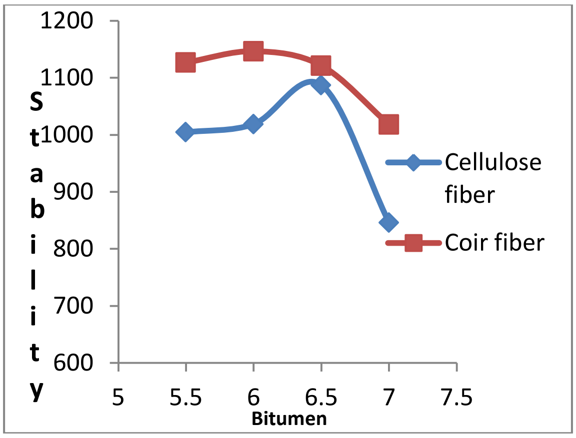
Fiber Content %	Draindown %		
	Draindown at 160°C	Draindown at 170°C	MoRT&H Specification
0.2	0.4521	0.4853	0.3 Maximum
0.3	0.1229	0.2820	
0.4	0.0164	0.0194	

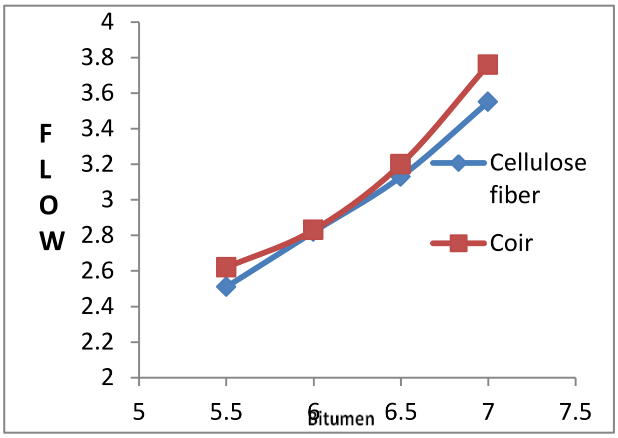


4.3 Marshall Properties

The Marshall stability first increases and then decrease with bitumen content, as initially when the bitumen holds aggregates in tight to carry the load, but when the voids are further filled by bitumen the load is instead carried by hydrostatic pressure through bitumen. The stability was maximum and more than 10.54 % in case of Chinese than the Indian as of its nominal size effect.

The average flow of the mixes was 3.04., here the flow values of Chinese will be low as the aggregate size increases the binders which need to be coated around increase and hence improve the consistency of the mixture. The properties of these stability and flow at different binder contents have been tabulated below. The comparison between two gradations has been shown in figure.





4.4 Volumetric properties

The Percent air voids help in densification under vehicular loadings to prevent bleeding of asphalt pavements in warmer climates So, the variation in air-voids is selected in between 3-4% to minimize the fat spots and rutting

Table-8: Properties of SMA samples prepared using Coir fiber

Property	Bitumen content (by weight of aggregate)			
Nominal aggregate size of 19 mm , Indian SMA	**5.50%**	**6.00%**	**6.50%**	**7.00%**
Marshall stability (Kgs)	1126.8	11046.6	1121.4	1098
Flow Value (mm)	2.62	2.83	3.2	3.56
Bulk density (gm/cc)	2.373	2.517	2.343	2.36
Volume of voids Vv (%)	5.611	4.21	3.721	3.11
Voids in Mineral Aggregate VMA (%)	17.702	17.733	18.068	18.706
Void filled with bitumen VFB (%)	68.303	76.258	79.406	83.374
Marshall Quotient (Kgs/mm)	430.076	405.159	350.438	308.427
VCA Mix	23.313	19.039	24.989	24.8
VCA Mix/ VCA Dry	0.64	0.53	0.69	0.69
Optimum Bitumen content (%)	**6.23%**			

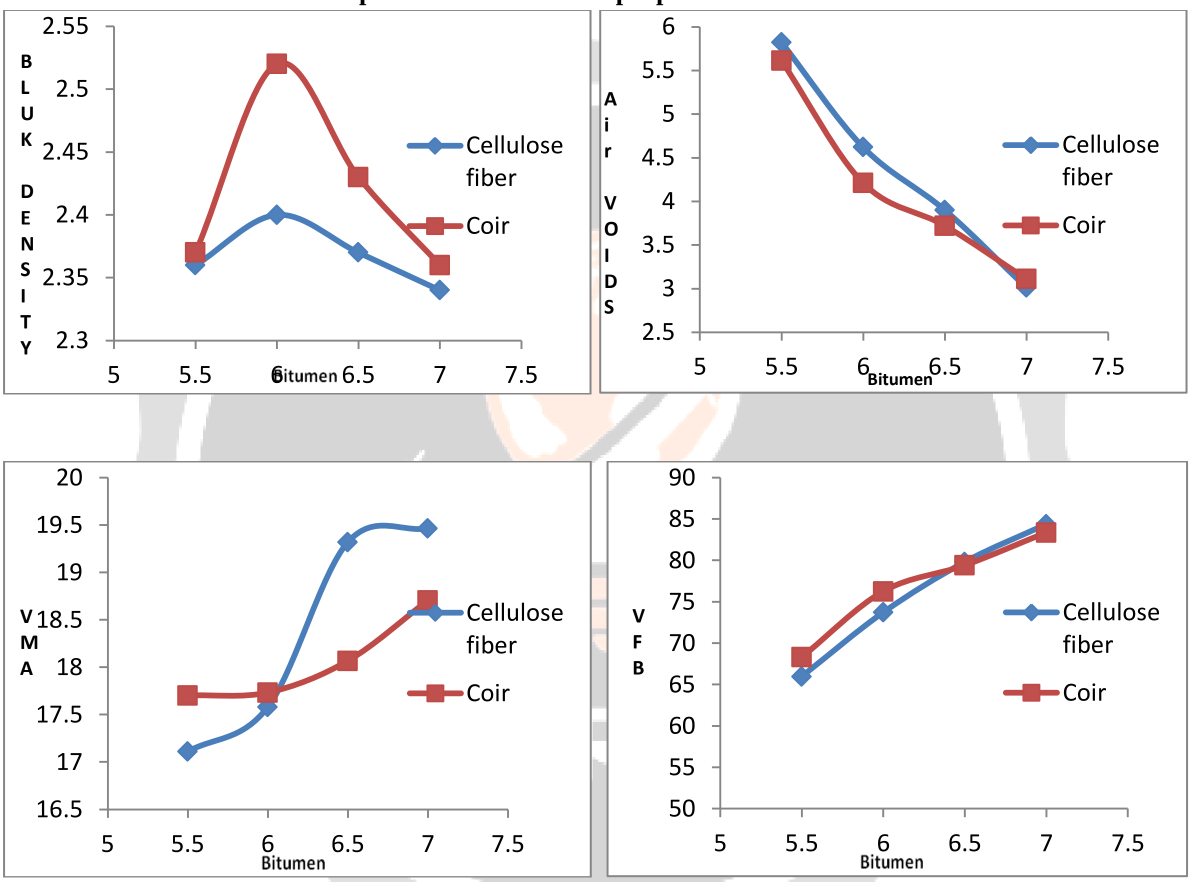
Table-9: Properties of SMA samples prepared using Cellulose fiber

Property	Bitumen content (by weight of aggregate)			
Nominal aggregate size of 19 mm , Indian SMA	**5.50%**	**6.00%**	**6.50%**	**7.00%**
Marshall stability (Kgs)	1004.4	1018.8	1087.2	846
Flow Value (mm)	2.51	2.82	3.31	3.55
Bulk density (gm/cc)	2.357	2.405	2.373	2.343
Volume of voids Vv (%)	5.821	4.62	3.9	3.01
Voids in Mineral Aggregate VMA (%)	17.11	17.581	19.32	19.464
Void filled with bitumen VFB (%)	65.978	73.721	79.81	84.375
Marshall Quotient (Kgs/mm)	400.159	361.277	328.459	238.350
VCA Mix	23.831	22.64	24.028	25.35
VCA Mix/ VCA Dry	0.66	0.63	0.66	0.70
Optimum Bitumen content (%)	**6.43%**			

Table-10: Properties of SMA mixes at Optimum binder content

Property	Type of Fiber	
	Coir	**Cellulose**
Bulk density (gm/cc)	2.437	2.39
Voids in Mineral Aggregate VMA (%)	17.887	18.381
Void filled with bitumen VFB (%)	77.706	74.43
Marshall stability (Kgs)	1135.008	1026.643
Flow Value (mm)	9.528	10.093
Marshall Quotient (Kgs/mm)	379.987	328.459

Comparison of Volumetric properties in SMA mixes



Volume basis was more reliable in design of mixes, so VMA is used a reference parameter which will not be affected by aggregate specific gravity. Hence, the minimum VMA has been specified as 17 which was satisfied for both fibers. The details of mixture properties were specified in both tables 4.3 & 4.4. Here the VCA in all mixes if less than 1 the stone contact will be perfectly established also satisfied in these samples.

5. CONCLUSIONS

The basic purpose of this study was to evaluate the use of coconut (coir) fiber instead of cellulose fiber. As the coir fiber is locally available material and more over its cost is too less comparing with cellulose fiber. Thus, the results of the use of 10-15mm length fibers with along with conventional VG-30 graded binder in the SMA can be summarized as follows:

- The fiber content of 0.3% was found to be optimum satisfying the draindown of the binder and also at the Optimum binder content of bitumen.

- The optimum binder was evaluated to be 6.23% and 6.43% for Coir and Cellulose fiber respectively with 5.5% as minimum binder content to prevent fat spots. The binder content required was more in Cellulose fiber.
- The percent draindown at OBC the range was 0.0021% - 0.0648 %, concluding that Coir fiber to be better then Cellulose fiber.
- The stability value at OBC and 0.3 % fiber content was 1135.00Kgs and 1026.643Kgs for the Coir and Cellulose respectively i.e., almost 9.55% increase in stability as compared to Cellulose. The flow values are 3.56mm and 3.55mm for Coir and Cellulose fiber respectively as prescribed standards in range of 2 - 4 mm.
- Hence by adding the coir fiber 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 and Coir fiber will be cost effectiveness rather then cellulose fiber.

Scope for further research

- To check the feasibility of SMA mixes using coir fiber by choosing different nominal aggregate sizes from the specifications such as in IRC:SP:2008, NAPA , NCHRP 425 especially adopted in United States and Germany.
- To study effect of fatigue, strength properties on performance of SMA using modified bitumen’s like CRMB, PMB etc.
- Study the variation in performance of different dimensions and content in the SMA.

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