International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-10, Issue-1, February 2023
https://doi.org/10.55524/ijirem.2023.10.1.9
Article ID IJIRD-1230, Pages 43-50
www.ijirem.org

A Study on Cellulose Fiber Modified Stone Matrix Asphalt and Conventional Stone Matrix Asphalt

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ABSTRACT- Stone Matrix Asphalt (SMA) is a breach separated bitumen combination. It is essential for the mixture that the coarse aggregates have direct stone-on-stone contact with each other. This is one of the requirements for the mixture. In the present investigation, SMA mixes with two different aggregate gradations and two different nominal maximum aggregate sizes, 16mm and 13.2mm, were created. These mixtures were given the designations SMA 1 and SMA 2, respectively. Three different types of fibers, including pelletized Cellulose Fiber (CF), Coconut Coir (CC), and Sisal Fiber (SF), and Shredded Waste Plastics (SWP) were used in mixtures with VG 30 bitumen to control drain down According to the findings of the drain down test, the amount of fiber that could be included in the mixture was capped at 0.3% by weight, while the percentage of SWP that may be included was between 4% and 16% by weight of bitumen. When case SWP combinations were tested, it was found that 8 and 12% plastic percentage generated the best results. The SMA 1 gradation exhibited superior outcomes than the SMA 2 gradation for all sorts of mixtures, with the exception of moisture susceptibility, where both gradations performed virtually identically.

KEYWORDS- Stone Matrix Asphalt, stone to stone contact, drain down, fiber additives, modified bitumen, Shredded Waste Plastic.

I. INTRODUCTION

The nation's transport network is often regarded as one of the most important factors contributing to the nation's overall level of development[1]. Road transportation is typically the most efficient and favored means of transport, for both the movement of freight and passengers, owing to the fact that it is simple to access and can be adapted to suit the specific requirements of each person. Roads are responsible for transporting about 65% of all commodities and 85% of all passenger traffic in India.

The vast majority of roads in India are of the flexible kind, meaning that they have a sub base, base, and surface course built on top of a compacted subgrade layer. In the surface course of a pavement, conventional Hot Mix Asphalt (HMA) mixes with thick aggregate gradation are often employed [2]. The purpose of using asphalt or bituminous mixes is to create a load-distributing medium that is durable, somewhat waterproof, and has a significant amount of stability and durability. The existing arterial road network in India has reached such a crippling stage that significant investments are required in order to restore it to the desired level of serviceability. This stage was brought about by the high volume of vehicular traffic and increasingly heavy axle loads that have been observed on Indian highways. Asphalt pavements may experience structural distress in the form of fatigue cracking, rutting along wheel tracks, ravelling, and potholes as a result of the repeated application of traffic loads and environmental conditions such as temperature change and moisture[3]. As a result, enhancing the performance and longevity of pavements is regarded to be a significant issue by pavement engineers, and this leads to the creation of improved bituminous binders, stabilizing additives, and novel high-performance bituminous combinations.

Stone Matrix Asphalt (SMA) is a bituminous mixture that has a gap graded aggregate structure. It is comprised primarily of two components: a greater percentage of coarse aggregate, and rich binder mastics (bitumen and mineral filler)[4]. A coarse aggregate skeleton is produced as a result of the arrangement of the aggregates in such a manner that stone-to-stone contact is established between them. Because the load in SMA is distributed by stone-to-stone contact, the mixture is both more resistant to rutting and more robust as a result. When compared to dense graded mixes, the coarse aggregate skeleton adds to the shear strength and effective weight distribution pattern of vehicles, allowing them to withstand larger traffic loads. The rich binder mortar that is used in SMA is comprised of bituminous binder, mineral filler, and typically speaking, a stabilizing component as well.

A. Concept of SMA

While developing SMA, the goal was to create a bituminous mixture that was resistant to the wearing induced by the studs in the tires and sufficiently durable to give a long service life. This was one of the reasons why SMA was developed. Zichner was of the opinion that coarse aggregates that have a good resistance to dynamic fragmentation or crushing can guarantee high wearing resistance, and that these aggregates should be the major constituent material in the mixture, with a higher mastic content for durability. In addition, Zichner believed that high wearing resistance can be achieved by using a mixture that has a higher mastic content. Therefore, a bituminous mixture with gap graded aggregate structure, high amounts of coarse aggregate fractions, filler, binder, and most importantly a stabilizing additive may be characterized as a stabilizing mixed aggregate (SMA).

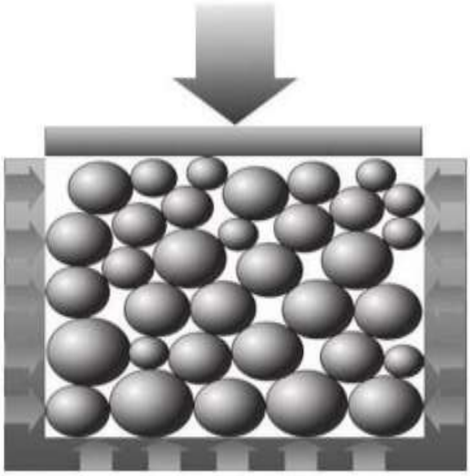

Figure 1: Vertically Loaded Aggregates with Confinements at Sides

The primary component of SMA is known as the coarse aggregate skeleton. This component is a structure made up of aggregates of an appropriate size that rest against one other and are interlocked with one another. In the mixture, aggregates can be divided into two categories: those that form skeletons and carry loads (referred to as active aggregates), and those that fill in the voids in the skeleton without carrying loads (referred to as passive grains). Each category is based on the function that the aggregates perform [4,5]. If certain aggregates, assuming a spherical form, are compacted in a cubical pot as illustrated in Figure 1 and loaded, the result will offer the greatest potential compressive strength.

Due to the lack of this stone-to-stone contact between the coarse aggregates, the role is performed by the fine or passive aggregates, which weakens the pavement structure. It is vital to make use of gap graded aggregate gradation in order to guarantee that there is an adequate supply of active aggregates and to prevent the chance of losing aggregates due to stone-on-stone contact[6]. Because excessive compaction may lead to the breakdown of aggregates, the compactive effort in SMA mixes should be restricted only until the direct contact occurs between active aggregates. This is because excessive compaction might cause aggregates to break down.

B. SMA in India

The first field trial section for the design and construction of SMA surface was built in India in October 2006 between Khajuri Chowk and Brij Puri Chowk on Road No. 59 in Delhi. This part served as a test for the surfacing (Highway Research Record 2007). The Central Road Research Institute (CRRI), located in New Delhi, was in charge of laying down the test stretch. It was placed on one of the busiest corridors, which had mixed traffic conditions and heavy cars. In order to determine how well SMA surfacing works, it was intended to evaluate the performance of these test portions at intervals of six months (both before and after the monsoon)[7]. The Indian Roads Congress (IRC) released a specification for SMA in 2008 , which was based on the guidelines published by Kandhal (2007). Roads Even though a few research on SMA were carried out by a few institutions in the recent past, the combination was not used to its full potential in India.

C. Objectives and Scope of the Work

The purpose of the present research is to construct Stone Matrix Asphalt mixes with two distinct aggregate gradations by using various kinds of binders and stabilizing additives. The following are the goals of the study:

- A study to determine the volumetric properties and Marshall characteristics of bitumen at varied concentrations.
- Evaluation of fatigue behavior in addition to the assessment of the indirect tensile strength of the material.
- Evaluation of the parameters of the sensitivity to moisture.
- Analysis of the costs associated with SMA mixes.

II. MATERIALS AND METHODOLOGY

The variety and qualities of ingredients employed in every bituminous combination are critical. In this study, aggregates, bituminous binder, mineral filler, stabilizing additive, and other ingredients are combined to create a SMA combination.

A. Aggregates

Aggregates are the major component of bituminous mixtures, accounting for 80-85% of the total. Aggregates must be firm, robust, and clean in order to be used in SMA mixes. Crushed granite boulders acquired from a stone crushing factory near Karkala, Karnataka, were employed in this research after their appropriateness in SMA was determined using IRC recommendations. The physical characteristics of aggregates were examined using IS 2383 procedures and found to meet the specifications. Table 1 displays the test results.

Table 1: Properties of Coarse Aggregates

Property	Test	Method	Results	IRC Specifications
Strength	Aggregate Impact Value	IS 2386	21.2%	24% maximum
	Los Angeles Abrasion Value	IS 2386	20.56 %	25% maximum
Water Absorption	Water Absorption	IS 2386	0.20%	2% maximum
Particle shape	Combined Flakiness and Elongation Index	IS 2386	28%	30% maximum

B. Bituminous Binder

As the binder ingredient in SMA mixes, one standard bitumen and three kinds of modified bitumen were employed in this investigation. Viscosity. The typical bitumen utilized in this investigation was graded bitumen

30, a regularly used bitumen type in India. Polymer Modified Bitumen (PMB) grades 40 and 70, as well as Crumb Rubber Modified Bitumen (CRMB) grade 55, were utilized to create SMA mixes. Mangalore Refineries and Petroleum Limited and Hincol, Mangalore, Karnataka, provided the bitumen types utilized in the research. Each bitumen was evaluated for various qualities according to IS regulations and was determined to meet IS 73 (2013) and IRC SP 53 (2002) criteria for regular and modified bitumen kinds, respectively. Tables 2 and 3 list the characteristics of bitumen.

Table 2: Properties of Normal Bitumen (VG 30)

Property Established	Method	Results	IS 73 Requirements
Penetration at 25°C, 0.1 mm, 100g, 5s	IS 1203	75	45 Minimum
Softening point, (R&B), °C	IS 1205	55	47 Minimum
Ductility at 25°C (5 cm /minute pull), cm	IS 1208	> 115	-
Specific Gravity	IS 1202	1.10	-
Flash point, COC, °C	IS 1448	295	220 Minimum
Absolute Viscosity at 60°C, Poises	IS 1206 Part 2	2830	2400 – 3600
Test on residue from rolling thin film oven test:			
Viscosity ratio at 60°C	IS 1206 Part 2	3.6	4.0 Maximum
Ductility after thin film oven test at 25°C, cm	IS 1208	65	40 Minimum

Table 3: Properties of Modified Bitumen

Property Tested	Test method	Results		
		CRMB	PMB 40	PMB 70
Penetration at 25^0C, 0.1 mm, 100g, 5s	IS 1203	48	46	70
Softening point, (R&B), °C	IS 1205	81 (Min. 60)	69 (Min. 60)	74 (Min. 55)
Flash point, COC, °C	IS 1209	290 (Min. 220)	254 (Min. 220)	286 (Min. 220)
Elastic recovery of half thread in ductilometer at 15°C, per cent	Annex 2 of IRC SP 53	75 (Min. 60)	100 (Min. 60)	88 (Min. 60)
Thin film oven tests and test on residue:				
Loss in mass, per cent	IS 9382	0.091 (Max. 1)	0.069 (Max. 1)	0.069 (Max. 1)
Increase in softening point, °C	IS 1205	3.9 (Max. 5)	4.0 (Max. 5)	5.2 (Max. 6)
Reduction in penetration of residue, at 25°C per cent	IS 1203	29 (Max. 35)	25 (Max. 35)	26.7 (Max. 35)
Elastic recovery of half thread in ductilometer at 25°C, per cent	Annex 2 of IRC SP 53	67 (Min. 50)	71 (Min. 50)	80 (Min. 50)

C. Mineral Filler

Mineral filler in bituminous mixes is typically finely split mineral materials. Granite stone dust and hydrated lime were utilized in this investigation, with the amount of lime limited to 2% by weight of aggregates. Hydrated lime improves mixture resistance to moisture degradation by enhancing the stiffness, strength, and toughness of the mastic, and also improves stripping resistance by boosting the asphalt-aggregate interfacial bonding. This also enhances bituminous mixes' permanent deformation properties and fatigue durability, especially at higher temperature. The filler material was rated according to IRC's Table 4.

Table 4: Gradation Requirement for Mineral Filler

IS Sieve (μ)	Cumulative % by weight of total aggregate passing
600	100
300	95-100
75	85-100

D. Stabilizing Additives

In light of the drain down issue with SMA mixes, an appropriate stabilizing ingredient is usually utilized. Different governments and institutes commonly advocate cellulose, mineral, and polymer fibers in this respect, while IRC suggests utilizing cellulose fiber in pelletized form.

E. Fiber Materials

Non-traditional fiber materials such as Coconut Coir (CC) and Sisal Fiber (SF) were tested as stabilizer materials in SMA in this study, along with the IRC-recommended Cellulose Fiber (CF), in pellet form. The CF utilized in the research is a combination of 66.6% ARBOCEL ZZ 8-1 and 33.3% VG 30 bitumen by weight. To guarantee adequate mixing with the aggregates and binder, CC was obtained from Thiruvananthapuram, Kerala, while SF was delivered from Mumbai, Maharashtra. Both fibers were hand chopped into tiny pieces of less than 35mm length.

III. MIXTURE NOTATIONS

In this study, mixes containing three fiber additions, three modified bitumens, and four levels of SWP dose were created for both SMA 1 and SMA 2 aggregate gradations. These blends are named as shown in Table 5 for ease of description.

Table 5: Mixture Notations

Aggregate Gradation	SMA 1	SMA 2
Mixture Constituents	Notations	
VG 30 Bitumen + Cellulose Fiber	1-CF	2-CF
VG 30 Bitumen + Coconut Coir	1-CC	2-CC
VG 30 Bitumen + Sisal Fiber	1-SF	2-SF
CRMB (No Stabilizing Additive)	1-CB	2-CB
PMB 40 (No Stabilizing Additive)	1-P40	2-P40
PMB 70 (No Stabilizing Additive)	1-P70	2-P70
VG 30 Bitumen + 4% SWP	1-W4	2-W4
VG 30 Bitumen + 8% SWP	1-W8	2-W8

VG 30 Bitumen + 12% SWP	1-W12	2-W12
VG 30 Bitumen + 16% SWP	1-W16	2-W16

IV. METHODOLOGY

For the purpose of this research, the mix design approach developed by Marshall was used. This method was chosen because it adhered to the specifications outlined by the Asphalt Institute (AI) in Manual Series – 2 (MS – 2). Table 6 lays forth the IRC's requirements for the SMA combination, which may be found in the table. For the purpose of determining the maximum theoretical density (Gmm), drain down, and stripping behavior, loose SMA mixes were used. In order to examine the volumetric properties, Marshall characteristics, Indirect Tensile (IDT) strength, Fatigue behavior, and moisture susceptibility features of SMA mixes, cylindrical specimens were produced and tested. In order to prepare the test specimens, a Troxler 4140 Superpave Gyratory Compactor (SGC) was used. After adding 5.0, 5.5, 6.0, 6.5, and 7.0 percent of bitumen by total weight of mixture, 100 gyrations were performed in order to compact the specimen. In order to investigate the rutting behavior, specimens in the form of rectangular slabs were created.

Table 6: SMA Mixture Requirements as per IRC

Mix design parameters	Requirement
Air void content, %	4.0
Bitumen content, %	5.8 min.
Cellulose fibers	0.3% minimum by weight of total mix
Voids in Mineral Aggregate (VMA), %	17 min.
VCAMIX, %	Less than dry rodded VCA (VCADRC)
Asphalt drain down, % (AASHTO T 305)	0.3 max
Tensile Strength Ratio (TSR), % AASHTO T 283	85 min.

The mix's preparation and compacting will now take place according to this technique.
Loose Mixture Preparation:

- The aggregates were heated to a temperature between 150 and 170 degrees Celsius after being proportioned and blended according to the gradation that was used.
- When making mixes using waste plastic, solid waste products (SWP) were added to heated aggregates in varying ratios (4, 8, 12, and 16% by weight of bitumen), and the mixture was then well combined.
- The bitumen was heated to between 150 and 165 degrees Celsius before being added to the hot aggregates in the requisite amount (5.0, 5.5, 6.0, 6.5, and 7.0 percent by weight of mix).
- The mixture was then well mixed while the temperature was maintained between 150 and 165 degrees Celsius.
- When working with modified bitumens, the temperature of the aggregate and binder should be elevated to between 165 and 185 degrees Celsius, and the temperature of the mixture should be between 150 and 170 degrees Celsius.

A. Compaction in SGC

The mixture was then poured into an SGC mold that had been preheated and measured 100 millimeters in diameter. The asphalt was poured into the mold, which already had a puck in it, so that it could be used to make specimens.
Following the completion of the leveling process on the top surface, the mold was stored inside of the Superpave, and the glass door was then secured.

- The pressure was set to 600 kPa in the menu status, the angle of gyration was set to 1.25 degrees, the gyration rate was set to 30 revolutions per minute, the number of gyrations was set to 100, and the number of dwell gyrations was set to 10.
- After pressing the START button, the ram proceeded downward in order to impart the constant pressure of 600 kPa to the mixture.
- After that, the mold was tipped forward by 1.25 degrees, but the upper and lower pucks remained parallel to one another and perpendicular to the cylinder's initial axis of rotation throughout the process.
- The mold was gyrated at 1.25 degrees around the mold's original central axis at 30 revolutions per minute while the pressure was kept constant and the mold was prevented from spinning.
- The height of the specimen was measured after each gyration that was performed during the compacting process, and the results were shown to the closest 0.1 mm. The data were written out using a dot matrix printer. The completion of one hundred gyrations and ten dwell gyrations, the ram advanced to the next level on its own.
- After that, the mold was removed, and using the extruder, the specimen was extracted via the opening at the top of the mold.
- It was determined that the specimens' diameters, as well as their weights in air and water, were recorded.

B. Volumetric Properties

1)Maximum Theoretical Density

Since it may offer the value after the absorption of bitumen by aggregates, the Maximum Theoretical Density of the mixture (Gmm) is measured for the mixture of aggregates and bitumen in loose uncompacted condition. This is done in order to ensure accurate results. For the purpose of determining Gmm, loose SMA mixes were made..
Through the use of Equation 1, we were able to determine the maximum specific gravity of the combination.

$$G_{mm} = \frac{A}{[A-(C-B)]} \quad 1$$

$Where,$
G_{mm} $is\ the\ maimiumun\ therotical\ density\ of\ the\ mixture$
$A\ is\ the\ mass\ of\ dry\ specime\ in\ air, g$
B is the $mass\ of\ dry\ specime\ in\ air, g\ and$
C is the $mass\ of\ dry\ specime\ under\ water, g$
We were able to calculate the theoretical maximum density for SMA mixes that had either 6% or 6.5% bitumen content based on the weight of the mixture. Equation 2 was used in each scenario in order to ascertain the effective specific gravity of the aggregates; the average of the two values was then taken into consideration.

$$G_{sb} = \frac{p_{mm} - p_b}{\frac{p_{mm}}{G_{mm}} - \frac{p_b}{G_b}} \quad 2$$

Gse is the effective specific gravity of aggregates

Gmm is the average theoretical maximum specific gravity
Pmm is the percentage by weight of total loose mixture
Pb is the bitumen content percentage by total weight of mixture
Gb is the specific Gravity of Bitumen

The Gmm of mixes with unlike bitumen contents was then calculated as follows (Equation 3.3):

$$G_{mm} = \frac{p_{mm}}{\frac{P_s}{G_{se}}+\frac{P_b}{G_b}} \quad 3$$

Ps is the Aggregate content, per cent by total weight of mixture

2) Bulk Specific Gravity of Aggregates

By knowing the specific gravities of the various materials that were used, we were able to compute the bulk specific gravity of aggregates, also known as Gsb, for each specimen. Equation 3.4 was used to do the calculation.

$$G_{sb} = \frac{100}{\frac{W_1}{G_1}+\frac{W_2}{G_2}+\frac{W_3}{G_3}+\frac{W_4}{G_4}} \quad 4$$

where, W1 is the % by weight of coarse aggregates in total aggregate
W2 is the % by weight of fine aggregates in total aggregate
W3 is the % by weight of filler in total aggregate
W4 is the 0% by weight of lime in total aggregate
G1 is the specific gravity of coarse aggregates
G2 is the specific gravity of fine aggregates
G3 is the specific gravity of filler and
G4 is the pecific gravity of lime

3) Bulk Density of Compacted Sample

Bulk density of each compacted specimen (Gmb) was calculated from Equation 5
Gmb = Wa /(Wssd − Ww) 5
where, Wa is the weight of specimen in air .
Ww is the weight of specimen in water
Wssd is the saturated Surface Dry (SSD) weight of specimen

4) Air Voids in Total Mix (Va)

The amount of air that is trapped in tiny pockets between coated aggregate particles throughout a compacted mix is referred to as "voids in total mix," and it is stated as a percentage of the bulk volume of the compacted mix. Equation 6 was used so that Va could be calculated.
Va = 100x(Gmm – Gmb)/ Gmm 6
Where, Gmm is the maximum theoretical density of the mixture and
Gmb is the bulk density of the compacted specimen

5) Voids in Mineral Aggregates (VMA)

The amount of intergranular void space that exists between the aggregate particles of a compacted paving mixture is referred to as VMA. This space comprises the air voids as well as the volume of asphalt that is not absorbed into the aggregates. The equation for VMA may be found in equation (7):
VMA = 100 – (Gmb. Ps)/ Gs 7

6) Voids Filled with Bitumen (VFB)

VFB is the percentage of the volume of the air voids that is filled with bitumen and was calculated using Equation 8.
VFB =100x(VMA – Va)/ VMA 8

C. Marshall Characteristics

The Marshall test is an evaluation of the resistance of bituminous mixes to plastic flow that is often carried out as a standard component of the Marshall mixture design. After the specimens had been prepared, they were maintained submerged in water that was kept at a temperature of 60 1 degrees Celsius for a period of 30 to 40 minutes. The specimens were removed, positioned in the Marshall test head , and put through a series of tests to establish the Marshall Stability (MS) value. This value is a measurement of how strong the combination is. It is the maximum resistance in kN that it will create at a temperature of 60 degrees Celsius when measured using the standard equipment used by Marshall. Equation 3.12 was used in order to arrive at MS. The entire deformation that takes place in the specimen between no load and the highest load that is being applied during the test is referred to as the flow value. In order to produce the test specimens, varied amounts of bitumen were added in increments of 0.5 percent across a range that provides a clearly defined maximum value for specimen density and stability. The values of the stability and flow were used in the calculation of the Marshall Quotient (MQ) (Equation 9 and10).

D. Marshall Stability

MS (kN) = 0.0808 × (Proving Ring Reading) − 0.0176 9
Marshall Quotient, MQ (kN/mm) = Marshall Stability /Flow 10

E. Optimum Bitumen Content

The Optimum Binder Content, also known as the Optimum Bitumen Content (OBC), for SMA mixes is typically chosen so as to generate air voids in the range of 3.0–4.0%. In general, Marshall stability and flow values are measured for informational purposes, but they are not utilized for acceptance purposes. The binder content (5.0, 5.5, 6.0, 6.5, and 7%) was plotted against the air voids, and the plots were used to determine the binder content that corresponds to the required air voids (4%). The binder concentration at 4% of air voids was used as the OBC for the SMA combinations in this investigation. When compared with the specification values, each of the attributes that were measured at OBC to determine whether or not they were within the acceptable range was checked.

V. RESULTS AND DISCUSSION

A. Drain Down

The findings of a drain down test that was performed on SMA mixes with a bitumen concentration of 7% and fiber contents of 0.2, 0.3, and 0.4% by weight of mixture are shown in Figure 2. In contrast to the limit that is commonly advised, which is 0.2%, the highest permitted drain down that the IRC advises is 0.3%. On the basis of the findings, the fiber content was determined to be 0.3% for each individual fiber, and further experiments were carried out using this dose. After calculating OBC based on volumetric attributes, drain down was examined for each combination at the OBC that corresponded to it. The results of this testing are shown in Figure 3.

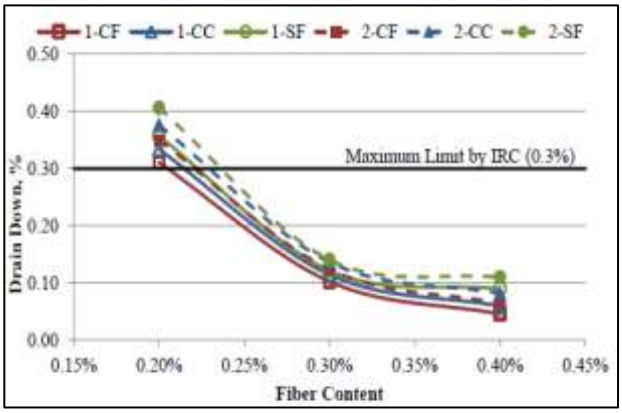

Figure 2: Drain Down of SMA mixtures with Fibers

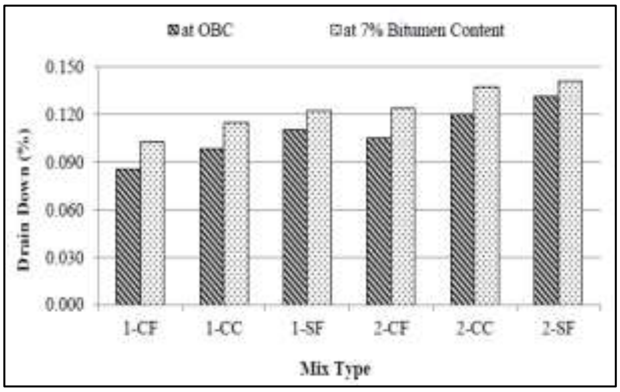

Figure 3: Drain Down of SMA mixtures with 0.3% Fiber Content

B. Volumetric and Marshall Properties

Tables 7–10 exhibits the volumetric properties and Marshall characteristics of mixes of SMA 1 and SMA 2 including cellulose fiber, coir fiber, and sisal fiber respectively. Also given are the Marshall characteristics of these mixtures. Gmm was found to decrease with increasing bitumen percentage for all six combinations, but Gmb grew with increasing bitumen content initially, reached a maximum value, and subsequently fell,. This pattern of behavior was seen for Gmm. Following the typical pattern seen in bituminous mixes, air voids decreased as bitumen content increased; the values for SMA 1 and SMA 2 gradations, respectively, fell within the ranges of 6.21–3.00% and 6.46–3.06%. Air voids decreased as bitumen content increased. VMA levels were found to be higher than 17% across the board, making it possible to demonstrate compliance with the IRC mandate. Because VCADRC is dependent solely on the kind of aggregate and the gradation, it does not alter depending on the amount of bitumen or stabilizer material. The results of this research showed that SMA 1 had a prevalence of 43.16 whereas SMA 2 had a prevalence of 40.85%. It was found that the value of VCAMIX was lower than the value of the equivalent VCADRC for all combinations, indicating that there was contact between the individual stones in the mixtures.

Table 7: Properties of SMA 1 Mixture with Cellulose Fiber (1-CF)

Property	**Bitumen content by weight of mix**				
	5.0	**5.5**	**6.0**	**6.5**	**7.0**
Gmm (g/cc)	2.56	2.50	2.53	2.38	2.39
Gmb (g/cc)	2.43	2.42	2.28	2.29	2.42
Vv (%)	6.33	5.27	4.46	3.75	3.20
VMA (%)	18.79	17.99	19.56	19.85	20
VFB (%)	68.0	73.57	76.51	80.58	84.96
VCAMIX (%)	40.08	38.57	38.54	40	39.95
VCAMIX/ VCADRC	0.912	0.925	0.934	0.941	0.946
Marshall Stability (kN)	12.85	13.85	14.98	13.65	12.35
Flow Value (mm)	3.0	3.16	3.28	3.36	3.41
Marshall Quotient (kN/mm)	4.21	4.38	4.76	4.34	3.53
OBC (%)	6.25				

Table 8: Properties of SMA 1 Mixture with Coconut Coir (1-CC)

Property	Bitumen content by weight of mix				
	5.0	5.5	6.0	6.5	7.0
Gmm (g/cc)	2.3	2.6	2.4	2.4	2.5
Gmb (g/cc)	2.6	2.4	2.6	2.5	2.4
Vv (%)	6.39	5.64	4.38	3.58	3.32
VMA (%)	19.35	19.28	19..5	18.89	20.0
VFB (%)	70.35	76.70	80.96	80.45	85.64
VCAMIX (%)	38.86	40.37	40	41.3	39.95
VCAMIX/ VCADRC	0.915	0.91	0.92	0.93	0.94
Marshall Stability (kN)	9.85	12.75	12.46	12.05	10.85
Flow Value (mm)	3.0	3.85	3.46	3.58	3.82
Marshall Quotient (kN/mm)	3.67	3.93	4.45	3.63	2.75
OBC (%)	6.25				

This may be because SMA 1 gradation contains a greater proportion of coarse aggregate sizes. Across the board, the flow values for SMA 2 mixes were noticeably lower than those of their counterparts.

Table 9: Properties of SMA 1 Mixture with Sisal Fiber (1-SF)

Property	Bitumen content by weight of mix				
	5.0	5.5	6.0	6.5	7.0
Gmm (g/cc)	2.485	2.466	2.447	2.428	2.410
Gmb (g/cc)	2.331	2.340	2.347	2.340	2.337
Vv (%)	6.21	5.08	4.06	3.61	3.00
VMA (%)	18.32	18.41	18.60	19.28	19.81
VFB (%)	66.10	72.38	78.16	81.26	84.85
VCAMIX (%)	39.13	39.20	39.34	39.85	40.25
VCAMIX/ VCADRC	0.907	0.908	0.912	0.923	0.933
Marshall Stability (kN)	10.77	12.64	15.05	13.81	11.33
Flow Value (mm)	3.03	3.21	3.42	3.60	3.70

Marshall Quotient (kN/mm)	3.56	3.94	4.40	3.83	3.06
OBC (%)	6.14				

Table 10: Properties of SMA 2 Mixture with Cellulose Fiber (2-CF)

Property	Bitumen content by weight of mix				
	5.0	5.5	6.0	6.5	7.0
Gmm (g/cc)	2.58	2.46	2.52	2.32	2.39
Gmb (g/cc)	2.49	2.52	2.46	2.54	2.45
Vv (%)	6.56	6.35	5.68	6.85	4.35
VMA (%)	19	19.5	19.8	20.2	19.58
VFB (%)	68.45	72.65	79.56	82.65	84.25
VCAMIX (%)	38.2	38.45	36.9	38.45	39.23
VCAMIX/ VCADRC	0.93	0.94	0.94	0.97	0.96
Marshall Stability (kN)	9.8	12	11.85	11.95	11.85
Flow Value (mm)	2.7	2.9	3.3	3.2	3.5
Marshall Quotient (kN/mm)	3.39	4.0	4.65	4.15	4.43
OBC (%)	6.45				

Table 11: Properties of SMA 2 Mixture with Coconut Coir (2-CC)

Property	Bitumen content by weight of mix				
	5.0	5.5	6.0	6.5	7.0
Gmm (g/cc)	2.525	2.636	2.535	2.543	2.398
Gmb (g/cc)	2.238	2.345	2.524	2.489	2.409
Vv (%)	6.5	5.5	4.4	3.7	3.2
VMA (%)	19.32	19.5	19.0	18.56	21.68
VFB (%)	66.58	70.27	76.36	82.65	85.05
VCAMIX (%)	38.4	36.98	38.07	38.95	39.45
VCAMIX/ VCADRC	0.932	0.945	0.936	0.965	0.948
Marshall Stability (kN)	9	9.5	11.5	11.05	10.56
Flow Value (mm)	2.8	2.9	3.2	3.4	3.5
Marshall Quotient (kN/mm)	3.18	3.46	3.75	3.35	2.72
OBC (%)	7.05				

Table 12: Properties of SMA 2 Mixture with Sisal Fiber (2-SF)

Property	Bitumen content by weight of mix				
	5.0	5.5	6.0	6.5	7.0
Gmm (g/cc)	2.56	2.60	2.53	2.54	2.62
Gmb (g/cc)	2.42	2.47	2.43	2.41	2.42
Vv (%)	6.4	5.8	4.3	4.5	4.0
VMA (%)	19.25	19.72	19.25	18.55	20.1
VFB (%)	66.33	70.89	75.98	80.36	83.76
VCAMIX (%)	38.02	38.95	38.65	39.05	39.37
VCAMIX/ VCADRC	0.95	0.95	0.93	0.94	0.95
Marshall Stability (kN)	10	11.65	12.56	12.68	11.65
Flow Value (mm)	3.25	3.7	3.5	36	3.8
Marshall Quotient (kN/mm)	3.3	3.8	3.9	3.5	3.56
OBC (%)	7.55				

From Table 11-13 shows that the OBC was calculated to be 6.04, 6.10, and 6.12% for CF, CCF, and SF correspondingly in SMA 1 combinations, but in SMA 2 mixtures, it was calculated to be 6.12, 6.19, and 6.22% respectively. When compared to other fibers, the structure of the SF was the thinnest; as a consequence, there were a greater number of fibers present in mixes that had a greater surface area, which led to the greatest OBC. The quantity of bitumen that has to be added is smaller since CF already comes in pelletized form with a bitumen covering; as a result, the amount of OBC produced is also lower. Table 13 outlines the characteristics of mixtures obtained from OBC. Because Cellulose Fiber has increased qualities, CF combinations were able to achieve the highest density and stability values. This is owing to the improved properties of the Cellulose Fiber. In comparison to combinations containing Coir, mixtures including Sisal Fiber have a higher tensile strength, which results in superior characteristics for the mixture. Fibers, in general, result in an enhancement in strength via the bridging effect, and in the case of SF mixes, this impact is exacerbated by the presence of a greater number of fibers.

Table 13: Properties of SMA Mixtures with Different Fibers at OBC

Mixture	1-CF	1-CC	1-SF	2-CF	2-CC	2-SF
OBC	6.14	6.25	6.00	6.28	6.12	6.25
Gmm (g/cc)	2.52	2.45	2.74	2.641	2.54	2.35
Gmb (g/cc)	2.350	2.345	2.347	2.343	2.338	2.339
Vv (%)	3.98	3.91	3.91	4.01	3.95	3.95
VMA (%)	19.5	18.00	18.25	19.65	19.49	19.78
VFB (%)	79.56	80	79.20	79.85	79.86	80
VCAMIX (%)	40.05	39.86	39.55	38.12	38.49	38.78
VCAMIX / VCADRC	0.927	0.925	0.924	0.938	0.942	0.942
MS (kN)	15.7	14.5	15.3	14	12.35	13.8
Flow Value (mm)	3.34	3.32	3.50	3.15	3.25	3.45
MQ (kN/mm)	4.9	4.55	4.55	4.60	3.92	3.79

VI. CONCLUSION

The results of the drain down test demonstrated that these modified bituminous binders do not need the addition of any stabilizing component in order to limit the amount of drain down that occurs in the mixture.

- The drain down condition is met by SMA 1 and SMA 2 mixes with CRMB and PMBs (without stabilizing component) and mixtures with VG 30 bitumen with 0.3

and 0.4% fiber additions (cellulose pellets, coconut coir, and sisal) with varied SWP concentrations.

- Both SMA 1 and SMA 2 combinations exhibited comparable trends in terms of IDT strength.
- For both conditioned and unconditioned instances followed a pattern that was comparable to the trend of the other characteristics, although the moisture resistance of the mixes was virtually the same regardless of the binder type.
- Moisture susceptibility is comparable for all fiber added mixtures, although SWP combinations outperform them.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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