A STONE MASTIC ASPHALT IS GAP GRADED BY USING BAGASSE FIBER (SUGAR CANE)

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Abstract

The stone matrix asphalt (SMA) mixture is a gap-graded mix which is characterized by high coarse aggregates, high asphalt contents and fiber additives as stabilizers. Due to stone to stone 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, in addition to the bagasse(sugarcane residue), polyester fibers will be added to the SMA mixes and its properties will be evaluated. Since, the bagasse 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 two types of fibers (bagasse and polyester) with dosages of 0.3%, 0.4% and 0.5% by weight of total mix. Volumetric properties of the mixes will be determined and various strength tests such as marshal stability will be conducted.

Keywords: *Stone Mastic Asphalt (SMA), MoRTH, Bagasse fiber, Filler, Binder, Polyster.*

1. INTRODUCTION

India is one of the fastest growing countries in the world. Infrastructure development is one of the major factors contributing to economic development in many ways by creating production facilities, employment opportunities etc. It stimulates economic activities and reduces transaction cost and trade cost. Infrastructure like roads, railways, ports and airports are used as intermediate goods by the public sector. Without infrastructure, it is very difficult for the existence of private sector market economy.

The bituminous pavements play a vital role in Indian pavements at present. Though life cycle of concrete pavements has proved to be 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.

Initial Cost is the cost of construction of the pavements its mainly depends on the pavement thickness, governed by the strength of sub grade soil and traffic loading, cost of materials and cost of execution of the work.

Maintenance cost includes the maintenance of pavement of the design life of pavement on specified service level.

Asphalt mixtures are used in road construction because of its special qualities. It provides resilient, highly waterproof and durable. It protects the base course and subgrade pavement structure from harmful effects of water and abrasion of traffic. The flexibility of asphalt mixtures allows the pavement structure to adjust slightly to consolidation or deformation due to wheel loads without affecting pavement. Flexible pavement allows stage construction and usage of a wide range of construction materials, often leading to substantial savings through the use of locally available materials.

1.2 Difference between SMA and Conventional mixes

On the contrary, there is no stabilizing agent in conventional mixes since the bitumen content is moderate, which only serves the purpose of filling the moderate amount of voids and binding the aggregates as shown in the below table 1.1.

Table 1.1: Main differences of SMA and Bituminous mix

Properties	**SMA**	**BC**
Definition	SMA is a gap graded mix which consists high amount of coarse aggregates hardly bonded by a strong asphalt matrix consisting of fine aggregate, filler, bitumen and stabilizing additives.	BC consists of well graded coarse and fine aggregate, filler and bitumen .
Mass of Coarse Aggregate Content (%)	75 – 80	50-60
Mass of Fine Aggregate (%)	20 – 25	40 – 50
Mass of Filler content (%)	9 – 13	6 – 10
Binder Type (%)	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	26-74	31-64

2. FEATURES ON STONE MATRIX ASPHALT

Due to the poor mix qualities the wearing courses were not able to resist these studded tyres effecting the pavement service period. Thus ,the idea of asphalt mix with strong coarse aggregate skeleton and filling these voids with mastic (i.e., mix of filler, sand, binder) this mix was typically called as a gap- graded or discontinuous hot asphalt mixture called as Stone matrix asphalt. Firstly, attempts were made by spreading the hot matrix asphalt with rich coarse aggregate over mastic then compacting the surface with road roller. The ratio of mastic to coarse aggregate was 30:70 (by weight), and used mastic of 50/70 or 70/100 penetration grade with 35% filler and 40% crushed sand for preparation.

2.1.1Skid resistance

The surface texture plays an important role in providing the necessary anti-skid property which relies on micro and macro texture of aggregate. The micro texture controls the contact between tyre and pavement surface whereas, the macro texture helps in dispersion of water under tyre without slip there by providing the grip due to aggregate particle arrangement.

2.1.2 Rutting /Evenness resistance

Rutting resistance was the prior reason to select as a stable mixture provided by the arrangement or packing of the coarse aggregate skeleton. Essentially the aggregate type, binder content, air voids (Va), voids in mineral aggregate (VMA), are measurable parameters for testing deformation resistance. Deformation resistance was dependent on shear strength of asphalt mix which is due to blend of aggregate and binder used.

2.1.3 Antinoise properties

The absorption characteristic depends on pavement surface and shape of available air voids. In SMA these properties are better offered as compared conventional bituminous concrete (BC) mix but, these performances were not as significant as with porous asphalt mixtures, as the gritting of finer aggregate is recommended to reduce noise levels.

2.1.4 Durability and Cracking resistance

Cracking appears when resistance was not observed against thermal stresses, due to rise the mixtures tensile strength. Thus, this resistance can be offered by appropriate selection of gradation and binder. In general the SMA's distinctive feature is its potential to slow down the occurrence of reflective cracking. This asphalt mix has it durability nature by the result of higher binder content and thicker binder coating.

2.2 Miscellaneous properties

The ratio of mixture to gradation course thickness plays a major role in reducing the permeability. So, controls over maximum aggregate size optimize the void content reducing the permeability. The rolling resistance has an effect on fuel consumption depends upon the macro texture of pavements. The generation of water mist reduces the visibility which takes place when water spray develops behind vehicles was controlled by proper macro texture. Thus role of macro texture distinguishes the light reflection or visibility characteristics.

2.3 Application of natural fibers

The natural fibers are an elongated materials produced by animals and plants which are turned into ropes or threads. These are available in different arrangements like, long-unidirectional, short-randomly oriented and woven. Based on the origin natural fibers classified as leafy (pineapple, sisal, pine), bast (bagasse,banana, jute, flax, hemp), seed or fruit fibers (coir, cotton, palm). These fibers are ,

- Healthier choice for providing natural ventilation.
- Economically vital to provide livelihoods and food security to small-scale farmers and processors.
- Renewable resource and biodegradable in nature.

As these natural fibers are decomposable the durability of pavements can be increased when these fibers are coated with the suitable binder. The performances of these fibers is better in terms of aging of asphaltic concrete.

2.4 Aggregate gradation

Aggregates play an important role in the SMA mixtures. The strength, toughness and rut resistance of SMA depends on aggregates in the mix. SMA contains 70-80% of coarse aggregate of the total stone content. The higher coarse aggregates forms stone-to-stone contact between the aggregates resulting in a good shear strength and high resistance to rutting. The bitumen content fills air voids in the SMA mixtures and forms a thin layer on aggregate surface results a rough surface texture which offers good skid resistance. According to Washington State Department of Transportation technotesthe aggregates of SMA must have the following characteristics.

1. A highly cubic shape and rough texture to resist rutting and movements
2. A hardness which can resist fracturing under heavy traffic loads
3. A high resistance to polishing, and
4. A high resistance to abrasion

Binu et al. 2009 conducted…

Comparing IRC specified mid gradation with AASHTO gradation

- Stiffness modulus of specimen with AASHTO specified gradation is increased by 37.8%
- Elastic strain is reduced by 5.8%
- Rut depth is decreased by 27.4%

Percentage of aggregate passing 13.2mm and 9.5mm sieve sizes are found to have highest influence on the rutting resistance of SMA

Compared to IRC mid gradation

- When percentage passing 13.2mm aggregates is increased to 100%,stiffness modulus is decreased by 7.8%,elastic strain is increased by 3.1%,and rut depth is increased by 8.4%

- When percentage passing 9.5mm aggregates is decreased by 50%, stiffness modulus is decreased by 33.6%, elastic strain is increased by 5.3%, and rut depth is decreased by 77.1%

2.5 Significance of gap- gradation type

The SMA gradation widely used in Unites states defined by guide prepared by the Federal Highway Administration (FHWA) sponsored SMA technical Working Group as a gap-graded asphalt mixture with increased the asphalt cement content and coarse aggregate fraction providing a firm stone to stone contact. Depending upon the type of aggregate size they are various kinds of gradations such as gap or discontinues gradation , open graded and dense graded gradations.The aggregate gradation to be taken care as in case of gap gradation due the involvement of heavy load resistances were offered by the coarser fractions only when their proper stone-on-stone contact as occurred only when the quantity of finer and filler aggregate doesn't disturb the interaction for coarser particles. The gradation of aggregate and optimal binder content are different as compared with other gradations. Comparison studies between IRC and AASHTO gradations showed that the gradation has an effect over the rutting and creep characteristics..

2.6 Fibers in Stone matrix asphalt (SMA)

2.6.1 General

The use of combination of two different paving grades making the mix chemically contrastive leading to premature failures. The use of binders like Crumb rubber, natural rubber and Polymer modified bitumen's is common to control the ravelling and rutting but the problem of fatigue cracking was not controlled. As the bituminous mixes are weak in tension the fiber stabilization ceases most of the cracking and permanent deformations. As there's no proper approach and development in the reinforcing mechanism of fiber and optimization of fiber properties like length, diameter, surface texture the growth of asphaltic pavements with fibers has been at minimal stage.

2.7.2 Life cycle Cost

The initial cost of SMA is 20-40% higher than conventional dense graded asphlat mixtures in road applications (Carl et al. 1997).This results from use of higher binder content, fiber, increased quality control requirements and low production rates due to increased mixing times (Rosli et al. 2012).The Alaska DOT (NAPA 1998), has found that approximately 15% increase in SMA cost compared to conventional mixtures is more than offset by a 40% additional life from a reduction in rutting. It appears that SMA could be cost effective with high performance, durability and frictional requirements.The life span of five to ten years will increase in addition to the advantages mentioned above. It is clear that the choice of SMA can be a good investment.

2.7.3 Advantages of fiber stabilization in asphalt mixes

Fibers are added to reduce the draindown in SMA mixes, other than this main use they are various added benefits due to this fiber addition. As per observation by the fibers has no added advantage when the mixes are compacted to desired level. The stability and flow properties are altered due to fibers in the asphalt mixes. They modify the visco elastic and moisture susceptibility properties of mixes. Some fibers have the tensile strength similar to asphalt mix hence, the fibers help in inducing the cohesive and tensile strength for providing the strong reinforcing and toughening physical change to fiber asphalt mixes. The addition fiber or the stabilizer has the additional advantage to the asphalt mix increasing the durability and strength of pavements.

2.7.4 Application of natural fibers

The natural fibers are an elongated materials produced by animals and plants which are turned into ropes or threads. These are available in different arrangements like, long-unidirectional, short-randomly oriented and woven. Based on the origin natural fibers classified as leafy (pineapple, sisal, pine), bast (bagasse,banana, jute, flax, hemp), seed or fruit fibers (coir, cotton, palm). These fibers are ,

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3. MATERIALS AND METHODOLOGY

MATERIALS

3.2.1 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 hould 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. The properties of the aggregate are shown in Table 3.2 and compared with the standard specifications.

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 where in grain size distribution is laid. In table 3.2, the properties of the aggregate are described.

3.2.2 Filler

The filler is a finely divided matter added to the SMA mix to increase the surface area which will assist in reducing the drain down. Fly ash as filler is not permitted as it increase the permanent deformation tendency because of its grain-size particles being rounded, so not generally suitable for SMA mixes. The granite dust for its easy availability form sites was opted and the hydrated lime is chosen as filler materials in present study. The hydrated lime benefits ,

- Reduces stripping and enhance the bond between bitumen-aggregate
- Resistance to fracture at lower temperatures
- Life cycle cost analysis (LCA) show that 38% increase in durability than the conventional HMA mixes
- Favourably alters oxidation ageing kinetics to reduce deleterious effects
- Alters the property of fines to control moisture susceptibility.

The filler is the 0.075mm passing, where for the total 10% filler content, 2% of hydrated lime and 8% of the granite dust is used for sample preparation. The filler shall be graded within the limits as in Table 3.4.

3.2.3 Stabilizer

SMA mixtures have the problem of draindown because of more binder which need to be held by increasing surface area of aggregate skeleton by using either filler or stabilizer. For the present study, bagasse fiber and polyester fiber chosen.

3.2.4 Bagasse Fiber

India is the second largest producer of sugarcane in the world. it produces about 40 million tonnes of bagasse every year. Bagasse is a derived from sugarcane which is essentially a fibrous residue that remains after crushing the stalks, and contains short fibers .Due to crushing it breaks down into small pieces and the milling process takes out all the juices.). It consists of water, fibers, and small amounts of soluble solids which may vary depending on various conditions.

Table 3.1: Physical properties of the aggregate

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

Table 3.2: SMA mix requirements as per (MoRTH-2009 and IRC:SP:53-2008)

Property	Test	Results	Test method Reference code	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 3.3: Gradation requirements of filler (IRC:SP:79 2008)

IS Sieve (mm)	Cumulative % passing by weight of total aggregate
0.600	100
0.300	95 – 100
0.075	85 – 100

Table 3.4: 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

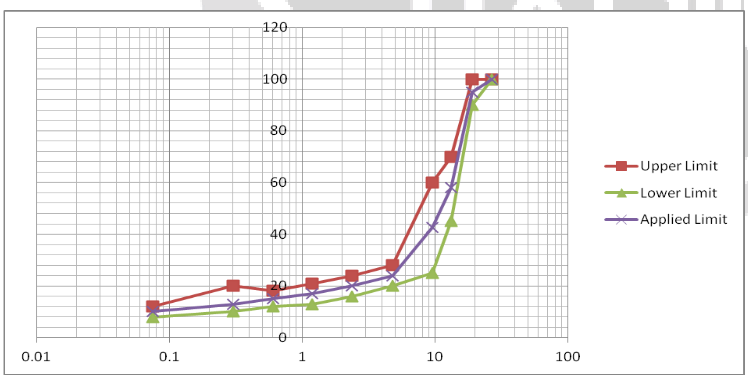


Fig 3.2SMA grain size distribution curve for the MoRT&H,2009,Indian specific

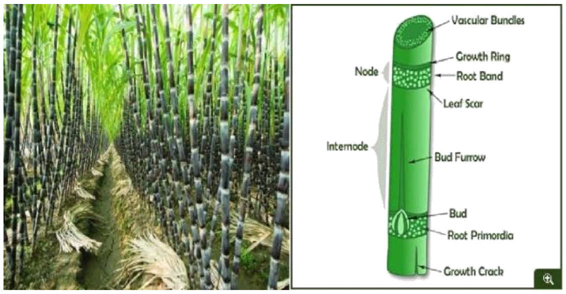


Fig 3.3: Illustration of general Bagasse

Fig 3.4 : Physical appearance of bagasse used in the study

Polyester fiber

Polyester was one of the great man-made fibre discoveries of the forties and has been manufactured on an industrial scale since 1947. Polyester fibres are the first choice for clothing. A manufactured fiber in which the fiber forming substance is any long-chain synthetic polymer composed of at least 85% by weight of an ester of a substituted aromatic carboxylic acid, including but not restricted to substituted terephthalic units, p(-R-O-CO- C6H4-CO-O-)x and para substituted hydroxy-benzoate units, p(-R-O-CO-C6H4-O-)x

Fig 3.5 : Physical appearance of polyester used in the study

Table 3.6 Properties of Polyester fiber

Property	**Value**
Specific Gravity	1.38
Adhesion rate	92.8%
Average fiber length	6mm
Average fiber diameter	4mm
Melting point	260^0C

3.2.4 Binder

The bitumen for the fiber-stabilized stone matrix asphalt adopted was viscosity grade VG-30 having the penetration of complying with Indian Standard specification for paving bitumen IS 73:2006. The obtained physical properties of VG-30 such as penetration, ductility, softening point and specific gravity and their requirements as per specifications are tabulated in Table 3.7 The durability factor requires more binder in SMA mixes.

Table 3.7: Physical properties of binder

Property Tested	Test Method	Results Obtained	Requirement as per IS-73
Penetration (100 gram, 5 seconds at 250C) (1/10th of mm)	IS 1203-1978	62.78mm	50-70
Softening Point 0C (Ring & Ball Apparatus)	IS 1205-1978	49.82°C	Min 47
Ductility at 270C (5 cm /min pull), cm	IS 1208-1978	>100	Min 75
Specific Gravity	IS 1202-1978	1.01	Min 0.99

3.3 METHODOLOGY

Optimal fiber content

In order to derive the standard or the fixed content of stabilizer to be added, the drain down test is conducted for reference. These drain down experiments are tested for the loose SMA mixes prepared for both coir fiber and cellulose fiber.

3.3.1 Drain Down Test

Draindown test was led as per ASTM D 6390 in a wire basket made up of standard sieve cloth of 6.3 mm size as shown in Fig 4.6. The test was conducted for loose mixtures at OBC (Optimum Binder Content) and at maximum binder content of 7 % to ensure that the mastic draining property of the SMA mixtures was within permissible values of 0.30 % for Indian gradation. It also provided an evaluation of the draindown potential of SMA mix in the field. The test is to be conducted one at plant production temperature (160°C) and other at 10°C above the anticipated production temperature (170°C).

Fig 3.6: Wire Basket Assembly for Drain down Test

Testing procedure:

1. About 1200 ± 200 grams of hot bituminous mixture placed in a wire basket.
2. The wire basket was made up of a standard sieve cloth of 6.3mm sieve cloth.
3. The wire basket with the bituminous mixture was hung in a forced draft oven for 1hr ± 5 min at the anticipated plant production temperature of 160°C
4. A catch plate of known mass was placed below the basket to collect material drained from the sample.

5. The mass of the drained material was determined to calculate the amount of drain down as a percentage of the mass of the total bituminous mix sample.
6. The test was repeated at a temperature 100C higher i.e., at 170°C

Before doing this test ensures that the oven temperature is at desired degrees.

The amount of binder draindown was calculated using equation,

Drain down % = 100 * D-C/B-A

where,

A= mass of empty wire basket (g)

B= mass of wire basket plus sample (g)

C= mass of the empty catch plate (g)

D= mass of the catch plate plus drained material (g)

3.3.2 Design of SMA mix

Marshall's method of mix design as per the specification lay down by Asphalt Institute in Manual Series – 2 (MS – 2) was adopted for the present study. Cylindrical specimens with 100 mm diameter moulds were used to evaluate the volumetric properties, Marshall characteristics, Indirect Tensile Strength (ITS) and Fatigue behavior of SMA mixtures. Test specimens were prepared in Superpave Gyratory Compactor (SGC) by adding 5.5%, 6.0%, 6.5% and 7.0% of bitumen by weight of aggregates. The samples were casted using the Superpave gyratory compactor (SGC) with 100 gyrations, 600KPa with dwell gyrations of 10 as specified in process was used in SGC based on literature. In order to study the rutting behavior rectangular slab specimens were prepared based on the requirements of optimized mix. Loose SMA mixtures were used to determine the maximum theoretical specific gravity (G_{mm}) and drain down.

Compaction in Marshall method:

- The mix was placed in preheated Marshall mould of 10.16 cm outer diameter and 6.35 cm height with a base plate. After leveling the top surface, the mix was compacted by a rammer of 4.54 kg weight and 45.7 cm height of fall with 50 blows on either side at a temperature of 1500C. The mixing and compaction temperatures should be 160°C and 150°C.

Although the Marshall test gives stability and flow values, in general for SMA mixtures they are measured for information, but not for acceptance. The volumetric properties are more appropriate for designing than reference with Marshall Stability.

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 $\pm 1^0$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 60^0C 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.

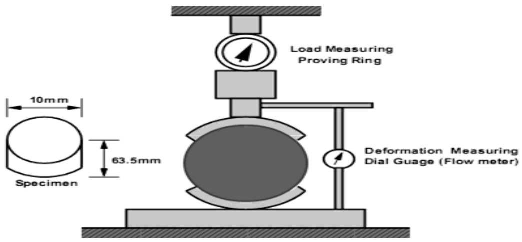


Figure 3.7: Marshall Test Setup

Marshall Stability = 0.0603 x (Proving Ring Reading) – 0.0109
The Marshall Quotient was determined from the stability and flow values.

Marshall Quotient, kN/mm= Marshall Stability/ Flow

3.3.4 Optimum Bitumen Content

Graphs were plotted for bitumen content against bulk density, air voids, VMA, VFB, Marshall stability and Flow. The Optimum Binder Content (OBC) for SMA mixtures is usually selected to produce the specified air voids. The binder content, corresponding to the specified air voids (4%) was found from the plots and is considered as OBC for SMA mix. All these values are compared with the specification values to check whether they were in specified limits.

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 behavior. 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. The experiments carried out on SMA mixes mentioned in previous chapter, with the present mixes results and observations are discussed in this chapter.

4.2 Performance tests

4.2.1 Drain down of binder

The loose asphalt mixtures are prepared for the drain down test. Either of the gradation Indian or Chinese is chosen from the pocket of aggregates, a 1000 g sample is prepared in each case. The analysis was made between two fibers and trail contents of 0.2%, 0.3% and 0.4% of fiber. The feasibility in its application is checked based on specifications of ASTM D6390 and Chinese for Indian and Chinese pavements respectively. The sample performance is tested at 160°C and 170°C for the maximum binder content of 7% and later checked for Optimum binder content (OBC).

The draindown test for loose SMA mixes was performed using the basket drainage test as per ASTM D 6390 (2005). The results of the draindown are presented for both the maximum binder content of 7%, and also at the optimum binder contents obtained for the two fibers are tabulated below in Table 4.1, Table 4.2 .

Table 4.1: Draindown values of SMA mix (Bagasse fiber)

Fiber Content %	Draindown %		
	Draindown at 160°C	Draindown at 170°C	MoRT&H Specification
0.2	0.3416	0.3821	0.3 Maximum
0.3	0.1906	0.2134	
0.4	0.0084	0.0115	

Table 4.2: Draindown values of SMA mix (Polyester fiber)

Fiber Content %	Draindown %		
	Draindown at 160°C	Draindown at 170°C	MoRT&H Specification
0.2	0.3212	0.3425	0.3 Maximum
0.3	0.0937	0.1142	
0.4	0.0045	0.0141	

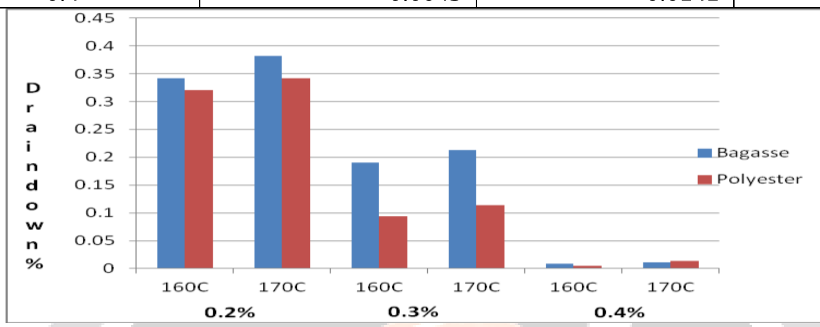


Fig 4.1: Comparison of draindown results at varying binder and fiber contents

From the figure we observe that the overall draindown values are in the range of 0.0045% - 0.3821%. For the case of maximum binder content (7%) when there is 0.2% there's more drain down of 0.3416% in case of Bagasse fiber ,while the lowest of 0.3212% was observed in the case of Polyester fiber. As per ASTM minimum draindown should be 0.3%, for both the fiber at 0.2% it's not meeting the requirement.

In the 0.3% fiber case the overall range was in 0.0937% - 0.2143% satisfying the specification requirements for both fibers. So, here the test trail percentage excluded the need of 0.4% fiber as there's almost no draindown even much lesser than the Bagasse fiber.

The feasibility of this 0.3% was also verified with obtained optimum binder content for both fibers derived from Marshall test results. At this OBC the range was 0.0937% - 0.1142%, again concluding that Bagasse fiber has the draindown within the limits we can use for design.

Hence its evident here that polyester fiber is providing significant stabilization as compared to mixes with two fiber. Excess fiber quantity is restricted to prevent the overcrowding which may add up as finer fraction effecting mixture performance (Chen et al. 2005) i.e., more fiber create extra voids in the mix as due to increased surface area of aggregates and fiber requiring more binder to be coated with (**Hadiwardoyo 2013**) which may lead to problem of fat spots. In this examination fiber of 10-20mm length and 0.3% (of total mix) content was kept constant.

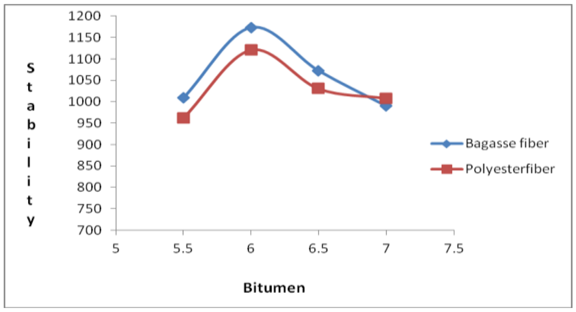
5.2.2 Bagasse and Polyester reinforced SMA mix design

SMA specimens were prepared for both fibers. Samples were prepared with 0.5% increments bitumen content varying from 5.5-7% of weight of aggregate used. The properties of the samples prepared using SGC are discussed below.

5.2.2.1 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 (**Beena et al.2011**). 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 Fig 4.2.



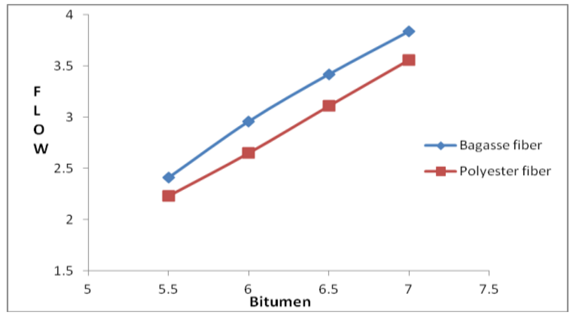


Fig 4.2 : Comparison of Stability and Flow in SMA mixes

4.2.2.2 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 (**Brown et al. 1997**). Here the OBC has been chosen for these air void content as reference in mix design. In these mixtures the void content was between 4.83 – 2.5% in Bagasse fiber and 4.51 – 2.9% for Polyester fiber. At a fixed void content higher the binder more the VMA, so if at all followed for this may lead to bleeding or rutting due to higher asphalt contents. As from literature it's observed that maintaining air voids between 3- 5% pavements behave to be less susceptible to rutting. So, the critical binder was chosen as 5.5% for the design of SMA mix (**Qiu et al. 2006**). The optimum binder content was 5.98% and 6.05 % in Bagasse fiber and Polyester fiber. 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 (**Tashman et al. 2011**) also satisfied in these samples

Table 4.3: Properties of SMA samples prepared using Bagasse fiber

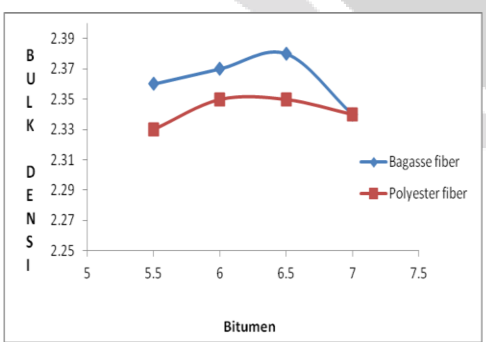
Property	**Bitumen content (by weight of aggregate)**			
Nominal aggregate size of 19 mm , Indian SMA	**5.50%**	**6.00%**	**6.50%**	**7.00%**
Marshall stability (Kgs)	1009	1172.8	1072	990
Flow Value (mm)	2.41	2.96	3.42	3.84
Bulk density (gm/cc)	2.36	2.37	2.38	2.34
Volume of voids Vv (%)	4.83	3.98	2.91	2.5
Voids in Mineral Aggregate VMA (%)	23.96	24.65	25.64	25.66
Void filled with bitumen VFB (%)	79.85	83.44	88.62	90.25
Marshall Quotient (Kgs/mm)	418.672	396.216	313.45	257.812
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 (%)	**5.98%**			

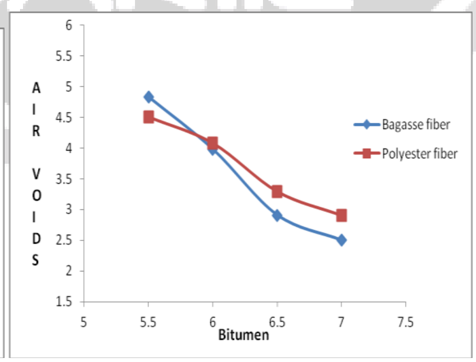
Table 4.4: Properties of SMA samples prepared using Polyester fiber

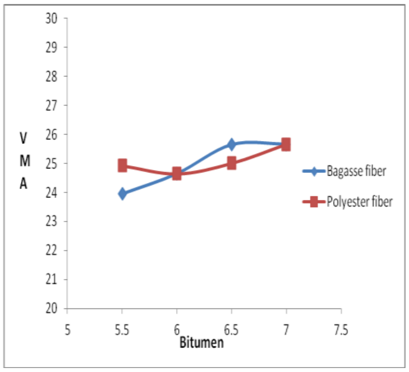
Property	Bitumen content (by weight of aggregate)			
Nominal aggregate size of 19 mm , Indian SMA	**5.50%**	**6.00%**	**6.50%**	**7.00%**
Marshall stability (Kgs)	962.6	1120.6	1030.6	1008
Flow Value (mm)	2.23	2.65	3.11	3.56
Bulk density (gm/cc)	2.33	2.35	2.35	2.34
Volume of voids Vv (%)	4.51	4.08	3.29	2.9
Voids in Mineral Aggregate VMA (%)	24.93	24.65	25.01	25.66
Void filled with bitumen VFB (%)	81.91	83.44	86.85	88.7
Marshall Quotient (Kgs/mm)	431.659	422.867	331.382	283.146
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 (%)	**6.05%**			

Table 4.5: Properties of SMA mixes at Optimum binder content

Property	Type of Fiber	
	Bagasse	**Polyester**
Bulk density (gm/cc)	2.366	2.35
Voids in Mineral Aggregate VMA (%)	24.374	24.686
Void filled with bitumen VFB (%)	83.29	83.78
Marshall stability (Kgs)	1166.248	1129.78
Flow Value (mm)	2.938	2.696
Marshall Quotient (Kgs/mm)	359.317	413.535







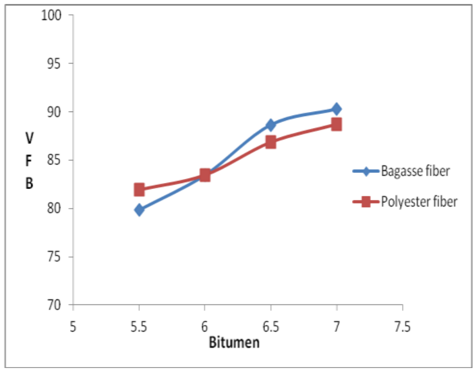


Fig 4.3: Comparison of Volumetric properties in SMA mixes

5.1 CONCLUSIONS

The basic purpose of this study was to evaluate the use of bagasse (sugarcane residue) fiber instead of polyester fiber. As the bagasse fiber is locally available material more over its cost is too less comparing with polyester fiber. Thus, the results of the use of 10-15mm length fibers 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 5.98% and 6.05% for Bagasse and Polyester fiber respectively with 5.5% as minimum binder content to prevent fat spots. The binder content required was more in Polyester fiber.
- The percent draindown at OBC the range was 0.1906% -0.0937 %, concluding that Polyester fiber to be better then Bagasse fiber.

The stability value at OBC and 0.3 % fiber content was 1166.24Kgs and 1129.78Kgs for the Bagasse and Polyester respectively i.e., almost 3.12% increase in stability as compared to Polyester. The flow values are 2.93mm and 2.69mm for Bagasse

- and Polyester fiber respectively as prescribed standards in range of 2 - 4 mm.
- Hence by adding the Bagasse 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 Bagasse fiber will be cost effectiveness rather then Polyester fiber.

5.2 SCOPE FOR FURTHER RESEARCH

- In the future performance of baggase fiber with grades of bitumen can also be tested and seen whether it can be used successfully or not.
- To study effect of fatigue, strength properties on performance of SMA and also for other HMAs and superpaves.
- Indirect tensile test of bituminous mixes can give us an idea about tensile strength of bituminous mixes.
- Repeated load testing can give us idea about the fatigue resistance of the specimen.
- Wheel tracking test can give us idea about the rut resistance of the specimen.
- Use of other fillers may result in better performance with baggase fiber. So it may also be evaluated in future.

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