International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 6 Ver V || June 2018 || PP 45-52

Properties of Stone Matrix Asphalt Using Carbon Fiber and Glass Fiber

K. Karunakar[1],Dr.P.Sravana[2],K.Govind Goud[3], T.Sowjanya[4],
[1]Asst.Professor, CMRIT college Hyderabad
[2]Professor, Center for Transportation Engineering JNTUH college of Engineering, Hyderabad
[3]Asst.Professor, MGIT college Hyderabad
[4]Asst.Professor,CMRIT college Hyderabad
Corresponding Auther: K. Karunakar

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 glass, carbon fibers will be added to the SMA mixes and its properties will be evaluated. Since, the carbon fibers are easily available in India, 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 (carbon and Glass) 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. On the basis of above tests conclusions will be drawn accordingly fiber is to be selected.*

Keywords*: Glass Fiber; Carbon Fiber; Marshal Stability; Drain Down;*

Date of Submission: 09-06-2018 Date of acceptance: 25-06-2018

I. Introduction

India being the second largest growing economy country in the world, in par with other developed activities, road infrastructure is developing at a very fast rate. Large scale road infrastructure development projects like National Highway Development Project (NHDP) and Pradhan Manthri Gram Sadak yojna (PMGSY) are in progress. The spurt in the growth of traffic and overloading of vehicles decreases the life span of roads laid with conventional bituminous mixes. The spurt in the growth of traffic and overloading of vehicles decreases the life span of roads laid with conventional bituminous mixes. This also leads to the reduction in the riding quality resulting in exorbitant vehicle operating cost and frequently maintenance interventions due to premature failure of pavements. Providing durable roads has always been a problem for a country like India with varied climate, terrain conditions, rainfall intensities and soil characteristics. A good amount of research is going on all over the country in this field to solve the problems associated with pavements. It is observed that Stone Matrix Asphalt is an ideal mixture for long lasting Indian Highways.

Objectives

To investigate the performance of Stone Matrix Asphalt (SMA), with the usage of Carbon fiber and Glass fiber under the influence of change in nominal maximum aggregate sizes based on Indian specifications. The lists of objectives are stated below.

- Camparision of drain down results at varying finer contents with 7% bitumen at 160C and 170C temperature.
- Comparision of stability,flow and volumetric properties of SMA mixes, VG30, Carbon fiber and Glass fiber by using marshall methods.

Finally to understand the effect of significant changes in characteristics of the mixes due to Carbon fiber and Glass fiber in SMA mixtures.

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. Mtaining 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

II. Materials

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 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 (**Brown 1992**).

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 and gradation curve was also shown as in Fig 3.2.

Table 2.1 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	20 mm	2.654	IS 2386 Part III	2.5 minimum
Gravity	10 mm	2.656		
	Stone Dust	2.676		
Water	20 mm	0.104	IS 2386 Part III	2% maximum
absorption	10mm	0.095		
	Stone Dust	0.798		

Table 2.2 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 2.1 SMA grain size distribution curve for the MoRT&H,2009,Indian specification

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 draindown. 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 (**Dallas et al. 2006**),

- 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
- Aggregate with slight clay content is not desirable, lime act as an effective material reducing plasticity characteristics

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 2.3.

Table 2.3 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

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, Carbon fiber and Glass fiber chosen.

Carbon Fiber

Carbon Fibre, not surprisingly, is made of carbon crystals aligned in a long axis. These honeycomb shaped crystals organize themselves in long flattened ribbons as shwn in Fig 2.2. This crystal alignment makes the fiber strong. In turn these ribbons align themselves within long fibers. The fiber shape is the original shape of the material used to produce the Carbon fiber. I don't know of any process where fibers are shaped AFTER carbonizing. These fibers (containing flat ribbons of carbon crystals) in turn are bundled in large numbers and are woven, made into felt, twisted or as bundled without twisting. This is referred to as Roving. Carbon fiber is also offered as chopped strands and powder. In order to modify the characteristics of the lay up, other materials are sometimes added such as glass fibers, Kevlar or Aluminium. Carbon fiber is rarely used as it. Rather it is imbedded in a matrix. In mastmaking and boat building we usually think of epoxy or polyester resins, but carbon fiber is also used as reinforcement for thermoplastics, concrete or ceramics.

Fig 2.2: Physical appearance of carbon used in the study

Glass fiber

Glass fibers have a high tensile modulus, i.e., about 60 GPA, an elongation of 3-4%, and elastic recovery of 100%. These fibers will not burn, but become soft at 815°C and exhibit decreased stability at Temperatures above 315°C. In addition, glass fibers do not absorb water, but are brittle and sensitive to surface damage. Adding glass fibers into asphalt mixtures enhances material strength and fatigue characteristics as well as improving ductility.

Glass fiber reinforced asphalt concrete can improve the stability and the deformability of the asphalt concrete without increasing the bitumen content of AC mixtures; this behavior will be useful in preventing rutting and bleeding at high temperatures during the hot season. Moreover, with the new developments in production, glass fiber reinforced bituminous mixtures can be cost competitive as compared to modified binders as shown in Fig 2.3.

Many other laboratory studies have been conducted to evaluate cracking resistance of glass fiber grid based reinforcement systems under traffic loading or thermal loading, particularly at Texas A&M University (Lytton, 1988), Delft University (de Bondt, 1999a) and University of Nottingham (Brown et al., 2001). These studies indicated that glass fiber grid reinforcement performed significantly better than any other type of geosynthetic, as well as unreinforced systems, due to the very high stiffness of the glass fibers.

Fig 2.3 Physical appearance of Glass used in the study

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. The durability factor requires more binder in SMA mixes.

Table 2.4 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

III. Performance tests

- **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 ±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.

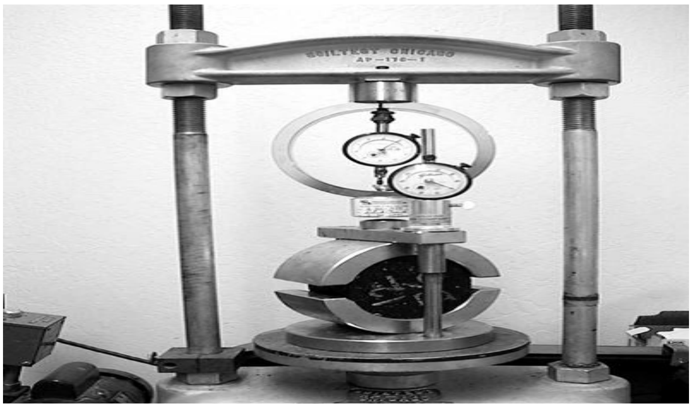

Figure 3.1 Marshall Test Setup

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

Fig 3.2 : SMA samples

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.

3.2 Drain down of binder

The loose asphalt mixtures are prepared for the draindown 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 no fiber and trail contents of 0.2%, 0.3% and 0.4% coir 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 gradations are tabulated below in Table 4.1 and compared in the Fig 4.1.

Table 3.1: Draindown values of SMA mix (Carbon fiber)

Fiber Content %	Draindown %		
	Draindown at 160°C	Draindown at 170°C	MoRT&H Specification
0.2	0.3262	0.3524	0.3 Maximum
0.3	0.196	0.214	
0.4	0.0365	0.0921	

Table 3.2: Draindown values of SMA mix (Glass fiber)

Fiber Content %	Draindown %		
	Draindown at 160°C	Draindown at 170°C	MoRT&H Specification
0.2	0.345	0.485	0.3 Maximum
0.3	0.1912	0.2095	
0.4	0.0194	0.0456	

Fig 3.3 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 0.0365% - 0.3524%. For the case of maximum binder content (7%) when there is 0.2% there's more drain down of 0.485% in case of Glass fiber ,while the lowest of 0.345% was observed in the case of Carbon 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 0.1912% - 0.214% 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.

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 0.1789% - 0.02019%, again concluding that Coir fiber has the draindown within the limits we can use for design.

Hence its evident here that coir fiber is providing significant stabilization as compared to mixes with no 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.

IV. Carbon reinforced SMA mix design

SMA specimens were prepared in SGC by using 100 gyrations. 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

4.1 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 4.1 : Comparison of Stability and Flow in SMA mixes

4.2 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 5.26 – 3..70% in Carbon fiber and 5.22 – 3.30% for Glass 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 6.605% and 6.55 % in Carbon fiber and Glass 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 4.2 & 4.3. 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 4.1: Properties of SMA samples prepared using Carbon fiber

Property	**Bitumen content (by weight of aggregate)**			
Nominal aggregate size of 19 mm , Indian SMA	**5.5%**	**6.00%**	**6.50%**	**7.00%**
Marshall stability (Kgs)	1053	1076.4	1186.4	1042
Flow Value (mm)	2.42	2.81	3.10	3.43
Bulk density (gm/cc)	2.34	2.35	2.35	2.34
Volume of voids Vv (%)	5.26	4.47	4.08	3.70
Voids in Mineral Aggregate VMA (%)	24.57	24.60	24.96	25.63
Void filled with bitumen VFB (%)	78	81	83	85
Marshall Quotient (Kgs/mm)	435.12	383.06	382.70	303.79
VCA Mix	24.37	24.41	24.76	25.43
VCA Mix/ VCA Dry	0.67	0.67	0.68	0.70
Optimum Bitumen content (%)	**6.605%**			

Table 4.2: Properties of SMA samples prepared using Glass 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)	1008	1011.6	1024.2	1012.2
Flow Value (mm)	2.31	2.72	3.21	3.68
Bulk density (gm/cc)	2.36	2.36	2.37	2.37
Volume of voids Vv (%)	5.22	4.85	4.08	3.30
Voids in Mineral Aggregate VMA (%)	23.93	24.28	24.32	24.67
Void filled with bitumen VFB (%)	78	80	83	87
Marshall Quotient (Kgs/mm)	436.36	371.911	319.06	275.05
VCA Mix	23.73	24.08	24.12	24.48
VCA Mix/ VCA Dry	0.65	0.66	0.66	0.67
Optimum Bitumen content (%)	**6.55%**			

Table 3.5: Properties of SMA mixes at Optimum binder content

Property	**Type of Fiber**	
	Carbon	**Glass**
Bulk density (gm/cc)	2.3479	2.37
Voids in Mineral Aggregate VMA (%)	25.1007	24.3935
Void filled with bitumen VFB (%)	83.42	83.84
Marshall stability (Kgs)	1156.076	1021.68
Flow Value (mm)	3.1693	3.3088
Marshall Quotient (Kgs/mm)	366.1289	309.8179

Fig 4.3: Comparison of Volumetric properties in SMA mixes

V. Conclusions

The basic purpose of this study was to evaluate the use of Carbon fiber instead of Glass 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 6.605% and 6.55% for Carbon and Glass fiber respectively with 5.5% as minimum binder content to prevent fat spots. The binder content required was more in Carbon fiber.
- The percent draindown at OBC the range was 0.0021% -0.0648 %, concluding that Carbon fiber to be better then Glass fiber.
- The stability value at OBC and 0.3 % fiber content was 1156.076Kgs and 1021.68Kgs for the Carbon and Glass respectively i.e., almost 11.625% increase in stability as compared to Carbon. The flow values are 3.1693mm and 3.3087mm for Carbon and Glass fiber respectively as prescribed standards in range of 2 - 4 mm.

- Hence by adding the Carbon 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.

Scope For Further Research

- To check the feasibility of SMA mixes using carbon 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 German.
- To observe the special effect over the fatigue strength adopting the modified bitumen's like CRMB, PMB etc.
- Influence over the carbon fiber with different dimensions (Length and Diameter) and content in the mix.

References

[1]. Ahmed, M.A., Attia, M.I.E. (2013). "Impact of aggregate gradation and type on Hot mix asphalt rutting in Egypt." Engineering research and applications,3(4), 2249-2258.
[2]. Beena, K.S., Bindu, C.S. (2011). "Coir fiber as a stabilizing Additive in Stone Matrix Asphalt."International Journal of Earth sciences and engineering,4(1), 165-177.
[3]. Brown, E., & Cooley, L. (1999). "Designing Stone Matrix Asphalt mixtures for Rut resistant Pavements." NCHRP Report 425, National Cooperative Highway Research Program,Transportation research Board,Washington, D.C; USA.
[4]. Chen, JS.,Lin, KY.(2005). "Mechanism and behaviour of bitumen strength reinforcement using fibers". Material Sciences,40, 87-95.
[5]. Dallas, N.L.,Jon, A.E. (2006). "The Benefits of Hydrated lime in Hot mix asphalt". National Lime association,Arlington,United States.
[6]. Do Vale, A.,Casgranade, M., Soares, J. (2013). "Behaviour of natural fiber in Stone matrix asphalt mixturesusing two design methods." Materials in Civil engineering,26(3), 457-465.
[7]. Hejazi, S.M.,Abtahi, S.M.,Sheikhzadeh, M.,Semnani, D. (2008). "Introducing two simple models for predicting fiber-reinforced asphalt concrete behavior during longitudinal loads." Applied Polymer Science, 109(5), 2872-2881
[8]. Mahrez, A., Karim, M.R. (2010). "Fatigue characterictics of stone matrix asphalt mix reinforced with fiber glass." Physical Sciences,5(12), 1840-1847

K. Karunakar "Properties of Stone Matrix Asphalt Using Carbon Fiber and Glass Fiber "International Journal of Engineering Science Invention (IJESI), vol. 07, no. 06, 2018, pp 45-52