An Experimental Study on SMA Mixes by Using Carbon Fibre and Glass Fibre

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***Abstract*—India being the second largest growing economy country in the world, in part with other developed activities, road infrastructure is developing at a very fast rate. 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. As India is a tropical country so a layer to resist the temperature changes must be designed. Thus, research has to make to improve the surface layer characteristics to attain durable pavements. The lifespan has an inverse relationship over vehicle loadings. Thus, we engineers need to implement a cost-effective alternate for the positive effect on the maintenance aspect and resistance to distresses induced in the pavements; one of mixture which fulfills these criteria is SMA.**

In the present study 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 has investigated .Comparison of drain down results at varying finer contents with 7% bitumen at 160^{0}C and 170^{0}C temperature and comparison of stability, flow and volumetric properties of SMA mixes, VG30, Carbon fiber and Glass fiber by using Marshall Methods has done.

***Keywords*— SMA, VG, Carbon Fibre, Glass Fibre, Marshal Properties.**

I. INTRODUCTION

A. General

India being the second largest growing economy country in the world, in part 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. 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.

As India is a tropical country so a layer to resist the temperature changes must be designed. Thus, research has to make to improve the surface layer characteristics to attain durable pavements. The advancement of innovative technologies makes it possible to construct pavements with long life there by postponing the maintenance activities. One of the asphalt mixture which had proved it's resistance to pavement distress is the Stone matrix asphalt (SMA), which was originally familiarized by the Europeans during 1960's and also, due to its action towards severe axle loading conditions its known as the rut-resistive asphalt mixture.

B. Types of Asphalt surfacing

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

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

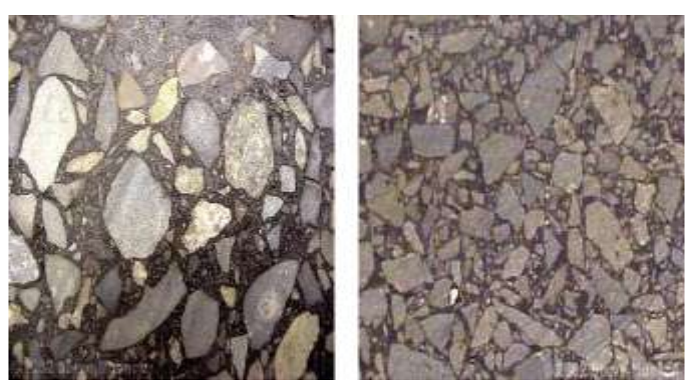


Fig 1 (a) Dense graded asphalt (b) Stone Matrix Asphalt

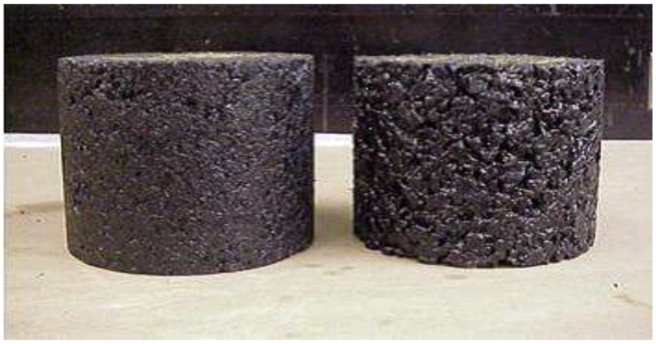


Fig 2 Dense-Graded HMA (left) vs. SMA (right)

The Stone matrix asphalt (SMA) or the "Split mastix asphalt" which was familiar in Germany during 1960's. A German engineer Dr. Zichner who is manager of Central Laboratory for Road Construction at the Strabag Bau AG was its designer. So, during these sixties the tendency in surface courses in Germany was to use "gussasphalt" (mastic asphalt) and also the asphaltic concrete having low coarse aggregate fractions, higher air voids and low bitumen content making its performance degrade especially with studded tyres in winter as seen in Fig 1.2. Due to the poor mix qualities the wearing courses were not able to resist these studded tyres effecting the pavement service period. During 1975, use of studded tires was stopped, and due to high pavement rehabilitation measures, need for advanced surface mixes which could resist the studded tyres was introduced. Dr.Zichner during his course proposed that, blend of coarse aggregate bear the dynamic shattering or crushing so, the durability of pavements can be modified by increasing the proportions of stone quantity and content of mastic and binders. 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.

Fig 3 A typical studded snow tyre

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

C. Difference Between SMA and Conventional Mixes

SMA is successfully used by many countries in the world as highly rut resistant bituminous course, both for binder (intermediate) and wearing course. The major difference between conventional mixes and SMA is in its structural skeleton .The SMA has high percent about 70-80 percent of coarse aggregate in the mix .This increases the interlocking of the aggregates and provides better stone to stone contact which serves as load carrying mechanism in SMA and hence provides better rut resistance and durability. On the other hand, conventional mixes contain about 40-60 percent coarse aggregate. They does have stone to stone contact, but it often means the larger grains essentially float in a matrix composed of smaller particles, filler and asphalt content .The stability of the mix is primarily controlled by the cohesion and internal friction of the matrix which supports the coarse aggregates.

The second difference lies in the binder content which lies between 5-6 percent for conventional mixes. Below this the mix becomes highly unstable. Above this percent will lead to abrupt drop of stability because the binder fills all the available voids and the extra binder makes the aggregates to float in binder matrix. The SMA uses very high percent of binder > 6.5 percent which is attributed to filling of more amount of voids present in it, due to high coarse aggregate skeleton. The high bitumen content contributes to the longevity of the pavements.

The third difference is the use of stabilizing additives in SMA which is attributed to the filling up of large no of voids in SMA so as to reduce the drain down due to presence of high bitumen content. 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.

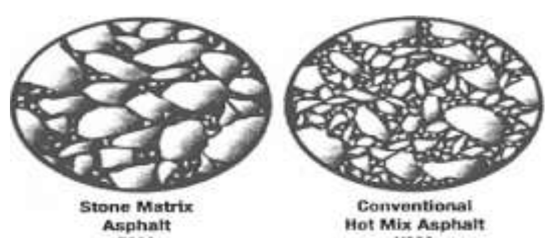


Fig 4, Stone Matrix Asphalt SMA & Conventional Hot Mix Aphalt

D. Coarse Aggregate Skeleton

Stone matrix asphalt refers to coarse aggregate- sand group with porous asphalt typically closest to straight coarse aggregate form. A coarse aggregate skeleton is a structure of grains with the suitable sizes resting against each other to interlock, whose structural requirements converge when proper mechanical resistance was provided by the blend of aggregates to withstand the vehicular loadings. The SMA basically consist coarse aggregate (skeleton) and mastic (fine aggregate, filler, stabilizer and bituminous binder).

Presently they are changes in the vehicular tyre structures along with increment in the axle loadings and traffic volumes necessitate the strong coarse skeleton. To explain the concept of SMA mineral skeleton imagine a box structure as shown in Fig 4 where the coarse grains are loaded to make it a perfect dense mix.

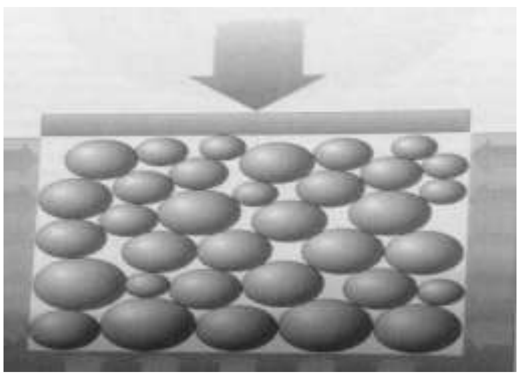


Fig 5 Vertically loaded grains in a box

Now, apply load over the skeleton to obtain a structure with high compressive strength where we can observe a distinct uninterrupted contact between the grains which is desirable for strong resistant and durable mix. If we observe the Fig 5 it shows the load transfer which happens in flexible pavement i.e. the grain to grain load distribution which is required skeleton.

When these contact points were replaced by a filler particles results in a discontinuous load transfer potentially weakening the structure. Thus the skeleton shows the significance of skillful compaction for proper arrangement of interlocking and grains no crushing of coarser particles take place practically these grains are separated by finer quantities of filler, sand and thin binder film where the final packing takes place under the influence of traffic and temperature effects. Thus, more stable a skeleton was less susceptible the deformations in the pavements. In case of softening of binder due to higher temperatures the layer need to be effected by distresses for a proper blending of aggregates.

To study this significance of coarse aggregate composite in the present study Indian gradations referred from MORT&H specifications.

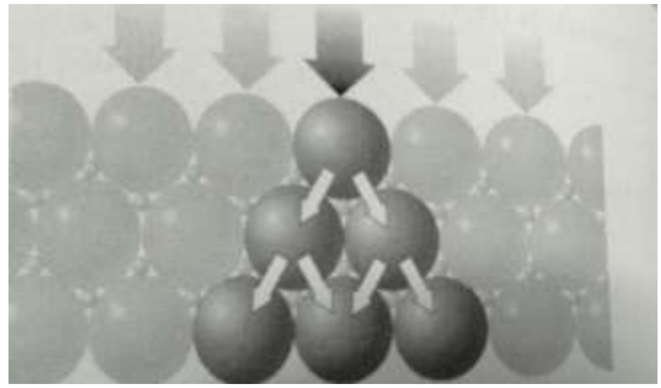


Fig 6: Load distribution in case of uniform load

E. Stone Matrix Asphalt (SMA)

The lifespan has an inverse relationship over vehicle loadings. Thus, we engineers need to implement a cost-effective alternate for the positive effect on the maintenance aspect and resistance to distresses induced in the pavements; one of mixture which fulfills these criteria is SMA.

It was originally introduced in Europe during early 1960's which recently emerging in USA due to its application under severe loadings provided by strong interlocking of aggregate structure through stone-on-stone contact .SMA is a discontinuous or gap-graded mixture which acquires its group action by the skeleton of coarse aggregate. It act as a permanent deformation resistant, durable surfacing coarse under more repetitive traffic loading. SMA has been used in Europe, Canada, United States, and as a durable asphalt surfacing option for local streets and highways. SMA has more coarse aggregate fraction that interlocks to form a stone to stone skeleton that resists pavement distresses. The mixture was filled with mastic of bitumen and filler to which fibers are added to provide adequate stability of bitumen and to prevent drain down during transport and placement. Typical SMA composition consists of 70−80 % coarse aggregate, 8−12 % filler, 6.0−7.0 % binder, and 0.2-0.5 % fiber to arrest the drain down effect.

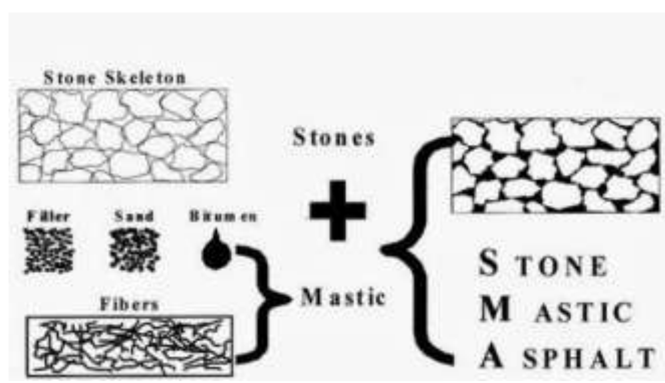


Fig 7: Division of SMA into basic components

F. Concept of Stone Matrix asphalt

To provide high rut resistant asphalt mixture proper volumetric properties need to be maintained for promoting the proper aggregate packing. The mixtures derived are based on following principles

G. Merits of SMA

The development of SMA application was started during early 1990's around Europe, which further renowned since 1991 in USA for heavy-traffic roads. The significant growth was further pronounced in North America, Australia, New Zealand and China. It was used in India for heavier axle loads especially when overloading occurs. During nineties AASHTO European Asphalt study contributed in German asphalt mix technology known as "split mastic asphalt" to provide a durable and rut resistant surface coarse mix .The English version is "stone mastic asphalt" and whereas for American adaption its named as "stone matrix asphalt"

H. Objectives for the Study

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

I. Scope of the Project

Previous studies have been focused on finding the optimal fiber contents and specifications, evaluation of engineering properties when modifications for aggregate or the fiber has been made. As, alterations in the particle size distribution will influence the void ratio and load size dispersion of aggregates ,in the present study the influence of changes in fibers over the properties of asphalt mixture has been studied. The scope of the present study covers, methodology to determine the engineering properties of SMA mixtures using the Carbon fiber and Glass fiber by means of the laboratory procedures.

In order to ensure the suitable Carbon and Glass content, using the drain-down test results experiments are carried out choosing constant fiber content.

II. MATERIALS AND METHODOLOGY

A. General

The present research study is focused on the gap-graded hot asphalt mix called the Stone matrix asphalt (SMA), which is designed to maximize the resistance against the permanent deformations using the stone-on-stone aggregate skeleton. The volumetric properties of an asphalt mix depend on the kind of gradation adopted. It is difficult to achieve the exact mid gradation from a quarry having wide size range in aggregates. Hence it's essential to study the characteristics of SMA over changes in gradation based on the fatigue and rutting characteristics. For this study, aggregate gradation namely MoRT&H, 2009 gradation having the nominal aggregate size of 16mm and 13.2mm respectively are chosen. To overcome the problem of drain down the natural stabilizer which is biodegradable, abundantly, economically available coir fiber is chosen using the mechanical tests of samples its feasibility was verified. Using the conventional binder VG-30 samples prepared with varying contents 5.5%- 7.0% (by weight of mineral aggregate) and with fixed fiber content of 0.3% (by weight of mix). The Marshall mix design procedure with aid of Super pave gyratory compaction for the significant air void percentage was used to optimize asphalt content for both type of gradations. The optimum binder content are found at 3-4% air voids. The Table 3.1 and Table 3.2, mentions the guidelines for SMA mix design requirements as per IRC:SP:53-2008 and MoRT&H,2009 respectively, based on these, design of SMA mixtures is carried out.

Table 1. SMA mix requirements as per (MoRTH-2009 and IRC:SP:53-2008)

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

B. Materials

1. Aggregate

The aggregate (both Coarse and fine) used in this study was brought from the quarry. These aggregates used in SMA should be highly durable, strong and tough to resist heavy loads

a. 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.

b. 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.

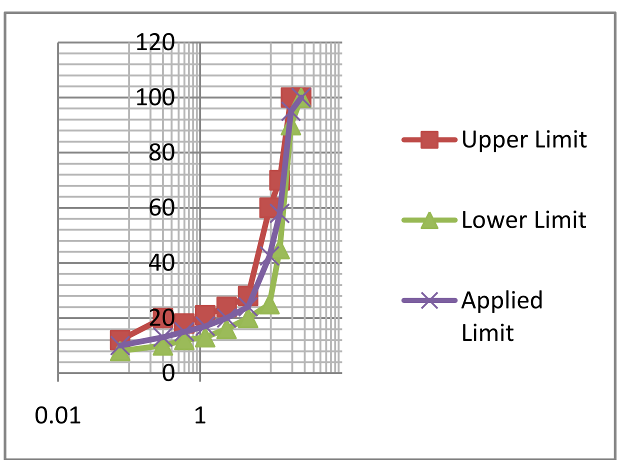
c. Aggregate gradation: The aggregate gradations is mainly based on the MoRT&H, 2009 specifications. The MoRT&H gradation i.e., the Indian gradation having the nominal maximum aggregate size of 19mm has been described in Table 3.3 and gradation curve was also shown as in Fig 3.2.

Table 2: Physical properties of the aggregate

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

Table 3: 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



Graph 1. SMA grain size distribution curve for the MoRT&H,2009, Indian specification

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.

3. Stabilizer

SMA mixtures have the problem of drain down 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.

a. 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. This crystal alignment makes the fiber strong. In turn these ribbons align themselves within long fibers.

b. 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.

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 5: 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

Flash Point and fire point, 0C	IS 1209-1978	265	Min 220
		295	

5 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.

6 Method of fiber addition

The method of fiber distribution in the SMA mix influences the bind between fiber and mastic which further influence the strength and volumetric properties of mix. So, fabrication of samples was made using the dry process i.e., the fibers are added to the mix before the binder or bitumen is added.

7 Loose mix preparation

- Initially from the pocket of aggregates of each desired sieve size obtained from the sieve analysis, are used to prepare a mix of standard weight based on the aggregate gradation.
- The coir fiber are cut to length of range 10-20 mm, as much larger than this will spoil the homogeneity are added to the mix for aggregate and with higher bitumen content (7.0%) so that the feasibility of the mix is suitable for any desired optimum binder obtained from analysis.
- A comparison analysis is to be made with trail of 0.2% - 0.4 %, for both coir fiber and Cellulose fiber using drain down test then optimal fiber need to be calculated.

8 Drain Down Test

Drain down 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 3.6. 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 drain down 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).

Binder drain down test is more significant for SMA mixtures the test developed for this purpose by AASHTO T305 (2000) is anticipated to simulate conditions that the mixture is likely to encounter during transportation and placing. The test was verified for both fibers (coir fiber and cellulose fiber).

Fig 8: 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 1600C.
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,

$$Draindown\ (\%) = 100 * \frac{(D-C)}{(B-A)}$$

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)

9 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, SMA mixtures. Test specimens were prepared in Super pave 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 Super pave 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 behaviour 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 levelling 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.

Fig 9 : 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.

10. Volumetric properties

Theoretical Maximum Specific Gravity

Loose SMA mixtures were prepared to determine their theoretical maximum specific gravity (G_{mm}) values. Test was conducted as per ASTM D 2041.

1. The SMA mixture was prepared using oven-dry aggregates, and placed in a pan and the particles of mix were separated by hand, taking care to avoid fracturing the aggregate, so that the fine aggregate portion were not larger than about 6 mm. The sample was cooled to room temperature.
2. The sample was placed directly into a cylindrical container and net mass (mass of sample only) weighed and was designated as A.
3. Sufficient water was added at a temperature of approximately 25°C to cover the sample completely. The cover was placed on the container.
4. The container was placed with the sample and water, and agitation was started immediately to remove entrapped air by gradually increasing the vacuum pressure (by vacuum pump) for 2 min until the residual pressure manometer read 3.7 ± 0.3kPa, vacuum and agitation was continued for 15 ± 2 min.
5. The vacuum pressure was gradually released using the bleeder valve and the weighing in water was done. For determining the weight in water, the container and contents were suspended in water for 10 ± 1 min, and then the mass was determined. The mass of the container and sample under water was designated as C.

The maximum specific gravity of the sample was calculated as follows:

$$G_{mm} = \frac{(A)}{[A-(C-B)]} \qquad 3.2$$

where:

G_{mm} = Maximum specific gravity of the mixture,
A = Mass of dry sample in air, g,
B = Mass of bowl under water, g, and
C = Mass of bowl and sample under water, g.

The theoretical maximum density for SMA mixtures with 6% and 6.5% bitumen content by weight of aggregates were determined in the specified method and average of the two values were taken. The effective specific gravity of the aggregates was determined using the formula:

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$$

where,

G_{se} = Effective specific gravity of aggregates
G_{mm} = The Average Theoretical maximum specific gravity determined as per ASTM D2041
P_{mm} = Percentage by weight of total loose mixture
P_b = Asphalt content percentage by total weight of mixture
G_b = Specific Gravity of Asphalt

The G_{mm} of mixtures with different asphalt contents was then calculated as:

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$$

P_s = Aggregate content, per cent by total weight of mixture

The theoretical density of each mix was calculated by knowing the specific gravities of the different materials used. It was calculated from the equation (3.5)

$$G_t = \frac{100 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4} + \frac{W_b}{G_b}}$$

where,

W_1 = % by weight of coarse aggregates in total aggregate
W_2 = % by weight of fine aggregates in total aggregate
W_3 = % by weight of filler in total aggregate
W_4 = % by weight of lime in total aggregate
W_b = % by weight of bitumen of total aggregate
G_1 = Specific gravity of coarse aggregates
G_2 = Specific gravity of fine aggregates
G_3 = Specific gravity of filler
G_4 = Specific gravity of lime
G_b = Specific gravity of bitumen

The bulk density of each specimen is calculated from the equation

$$G_{mb} = \frac{W_a}{W_{ssd} - W_w}$$

where,

W_a = Weight in air
W_w = Weight in water
W_{ssd} = Saturated Surface Dry (SSD) weight

Voids in Total Mix (Vv)

Voids in total mix are the volume of small pockets of air between the coated aggregate particles throughout a compacted mix, expressed as a percentage of bulk volume of compacted mix.

$$V_v = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100\ \%$$

where,

G_{mm} = Theoretical maximum density
G_{mb} = Bulk specific gravity

Voids in Mineral Aggregates (VMA)

VMA is the volume of inter granular void space between the aggregate particles of the compacted paving mixture that includes the air voids and the volume of the asphalt not absorbed into the aggregates.

$$VMA = Vv + Vb$$

where,

V_v = Voids in Total Mix
V_b = Volume of bitumen
V_b = $Gmb \times \frac{P_b}{G_b}$
G_{mb} = Bulk specific gravity
P_b = Asphalt content percentage by total weight of mixture
G_b = Specific gravity of bitumen

Voids Filled with Bitumen (VFB)

VFB is the percentage of the volume of the air voids that is filled with bitumen.

$$VFB = \frac{VMA - V_v}{VMA} \times 100$$

Voids in the Coarse Aggregates (VCA)

The coarse aggregates were washed and the dry rodded unit weight was determined in accordance with ASTM C 29. A measure of known volume (about 10L) and weight was used for this experiment. The oven- dried coarse aggregates were filled up to 1/3 of the measure, levelled with finger and compacted by giving 25 strokes of the tamping rod evenly distributed over the surface. The remaining portion was also filled in the same manner and the weight of measure and aggregates was taken. The unit weight of coarse aggregates by the dry rodding procedure (Y_S) was calculated as:

$$Y_s = \frac{G - T}{V}$$

where,

Y_s = Unit weight of the coarse aggregate in dry rodded condition, kg/m^3
G = Mass of the measure plus aggregate, kg
T = Mass of the measure, kg
V = Volume of the measure, m^3

The dry rodded VCA of the coarse aggregate was calculated using the following equation:

$$VCA_{DRC} = \frac{G_{ca} Y_W - Y_s}{G_{ca} Y_W} \times 100$$

where,

VCA_{DRC}= Voids in the coarse aggregate in the dry rodded condition

G_{ca} = Bulk specific gravity of the coarse aggregate

Y_w = Unit weight of water (998 kg/m^3)

Y_S = Unit weight of coarse aggregate fraction in dry-rodded condition (kg/m^3)

The VCA of the mixture is calculated using the following equation:

$$VCA_{MIX} = 100 - \left(\frac{G_{mb}}{G_{ca}} \times P_{ca}\right)$$

where,

G_{ca} = Bulk specific gravity of the coarse aggregate fraction

P_{ca} = Percent coarse aggregate in the total mixture

When $\frac{VCA_{MIX}}{VCA_{DRC}} < 1$, the stone on stone contact in the SMA mix is ensured.

C. 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.

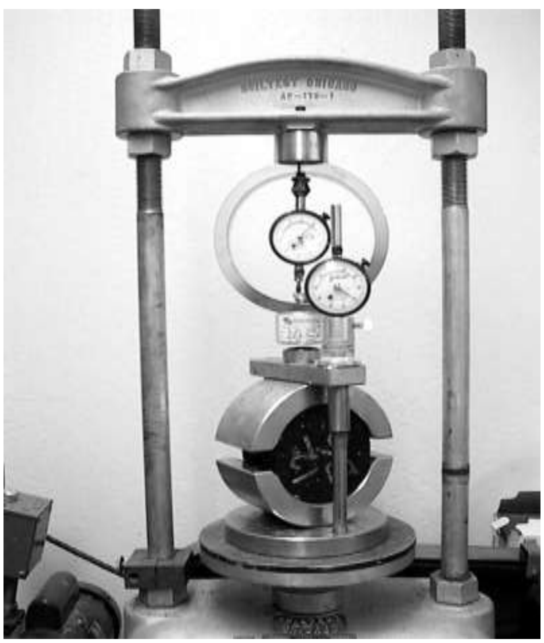


Figure 10: Marshall Test Setup

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

III. RESULTS AND DISCUSSIONS

A. 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 drain down test results. Maintaining the fiber length more than 20mm further increase air gap between aggregates degrade the mix behaviour . Later using the obtained optimal fiber quantity with constant length is used in the mixes of nominal aggregate sizes of 13.2 mm . The experiments carried out on SMA mixes mentioned in previous chapter, with the present mixes results and observations are discussed in this chapter.

B. Performance Tests

1 Draindown of binder

The loose asphalt mixtures are prepared for the draindown test. Either of the gradation Indian 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 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).

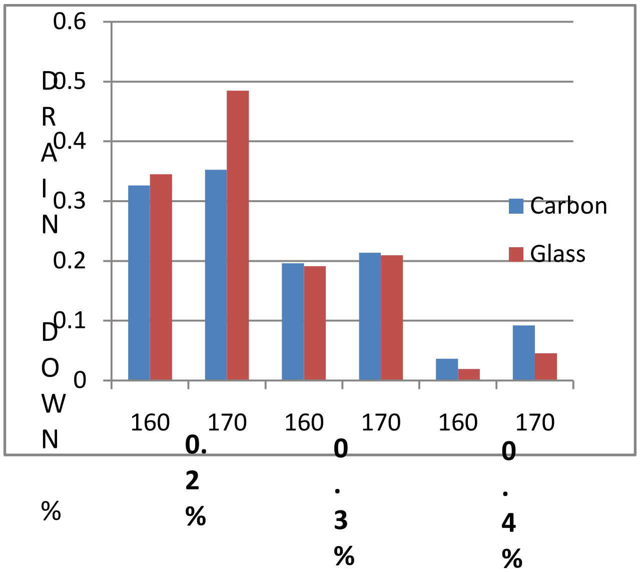
The draindown test for loose SMA mixes was performed using the basket drainage test as per ASTM D 6390 (2005). The results of the draindown are presented for both the maximum binder content of 7%, and also at the optimum binder contents obtained for the two gradations are tabulated below in Table 4.1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

Table 6: 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 7: 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	



Graph 2. 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 drain down 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 drain down.

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 drain down 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 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 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.

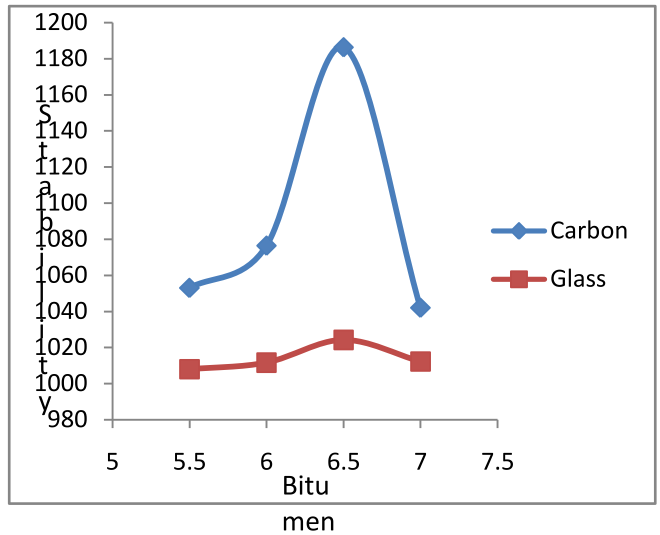
1. *Carbon reinforced SMA mix design*

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

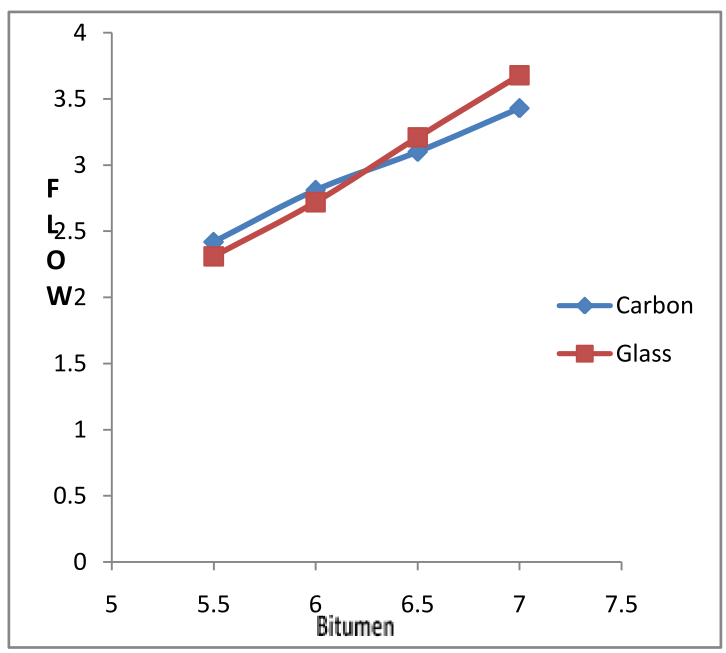
a. *Marshall Properties*

The Marshall stability first increases and then decrease with bitumen content, as initially when the bitumen holds aggregates in tight to carry the load, but when the voids are further filled by bitumen the load is instead carried by hydrostatic pressure through bitumen.

The comparison between the Marshall properties with two different binders are shown in Fig 4.2 and Fig 4.3.



Graph 3. Comparison of Stability graph in SMA mixes



Graph 4 : Comparison of Flow in SMA mixes

IV. CHAPTER

A. Conclusions

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

- The fiber content of 0.3% was found to be optimum satisfying the drain down 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 drain down 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. An average performance was observed from the rutting and fatigue evaluations.

B. Scope for Further Research

- To check the feasibility of SMA mixes using coir fiber by choosing different nominal aggregate sizes from the specifications such as in IRC:SP:2008, NAPA , NCHRP 425 especially adopted in United States and 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.

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