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Laboratory Investigation Review of Stone Matrix Asphalt

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Abstract— The distress of pavements in the form of rutting as well as ultimate distortion due to heavy axle loading and the wear caused by studded tires is a serious threat. SMA as a surface mixture possesses good stability, durability and resistance to studded tires. This study aims to establish the design mix of SMA prepared using PMB 40 bitumen (polymer modified) and to investigate the properties of Stone Matrix Asphalt mixture through laboratory testing that will be helpful in understanding and describing the character of its performance. The methodology employed in the present study is the experimental method; it includes material testing, design mix and performance testing. Marshall Test has been adopted for determination of optimum binder content. This research is an endeavor for comparing the realization of characteristics of SMA mix with dense graded traditional HMA mix by conducting the laboratory experiments intended for dense graded traditional HMA mix. The results emphasize the usage of SMA mix especially on roads carrying a large volume of traffic.

Keywords: Stone matrix asphalt; Dense graded mixtures; Marshall Test; Rutting; Deformation; Polymer modified.

I. INTRODUCTION

SMA, a hot mixture, comprises of comparably a high amount of stone aggregates with large degree of binder content and filler. The motive behind containing a skip gradation of stone aggregates as 100%, is to enhance the stability of pavement by making stone-to-stone contact along with interlocking [1]. SMA was evolved in Germany during the 1960s; it has also been utilized effectively by numerous nations in the world as a bituminous course exceptionally resistant to rutting, for surfacing courses as well as binder courses [2]. The achievement in Europe has energized the U.S. to embrace the utilization of SMA compositions especially on heavily trafficked pavements like urban intersections as well as Interstates. In USA, the SMA innovation began a development in the mid 90s and has been generally utilized since [3, 4]. Japan has likewise begun to utilize SMA paving mixtures, as well, with good success. The greater part of the reports by the investigators appreciated the ability of SMA in withstanding against rutting or lasting deformity.

SMA is a skip graded mix with about 70-80 percent stone content, 6-7 percent of bitumen content, 8-12 % filler together with almost 0.3 percent fibers or similar modifier. The fibers else modifier check draining of binder during manufacture, hauling as well as laying. It is also difficult to meet the SMA gradation, especially for aggregate filler which is needed 8–11%, compared with the need for the asphaltic concrete (AC) mix ranging from 4% to 8%, and even then must be added by cement to comply with the gradation as needed in the specification. A general definition of SMA evolved by the SMA Technical Working Group is “A skip graded hot asphalt aggregate mixture which maximizes the binder content as well as coarse aggregate fraction. This gives a steady stone-on-stone skeleton which is kept in position by an affluent mix of bitumen, filler as well as stabilizing additive" [5, 6].

SMA provides increased durability, resistance to rutting, resistance to reflective cracking, good friction properties, improved aging properties, diminished traffic noise over HMA (Hot Mix Asphalt) [7]. In contrast to a uniformly-grade mix most of the voids in the CA in a Stone Matrix Asphalt mix are occupied by mineral filler along with binder. Potential issues with Stone Matrix Asphalt mix are bleeding as well as drainage. Fibers (cellulose and rock wool) are commonly used stabilizing additives [7, 8]. Different fibers such as jute, coconuts, sugarcane, wood, sisal, flax, elephant grass and palms etc. are investigated by various investigators [9, 10, 11, 12].

In India, fatigue or tensile cracking along wheel paths of vehicles are predominant on Indian roads as compared with other forms of distress. This happens basically because of accelerated thrust from heavy vehicles imposing a huge expenditure alone on maintenance of pavement. The present circumstance is additionally bothered by the customary utilization of delicate 80-100 bitumen that is having low shear strength. The Indian climate being hot wet in nature presents adverse conditions.

The objective of this study was to establish the design mix of SMA and to evolve the laboratory investigation qualities of SMA mixture that will be helpful in assessing and defining the performance characteristics. To ascertain the optimum bitumen content with respect to SMA mix with PMB-40 utilizing natural cellulose fibers in conformity of adopting Marshall design mix method and results would be compared with traditional HMA mixes. SMA design mix criterion specifically % VMA (voids in mineral aggregate), % VIM (air void content), % VCA (voids in coarse aggregate mix), TSR values (tensile strength ratio) and % bitumen drain off for SMA with PMB-40 and all these complied with the parameters of IRC:SP:79-2008 [2]. This study is an attempt to make a comparison, by exercising laboratory investigations established towards dense graded mix, the characteristics of SMA mix with the dense graded mix.

II. MATERIALS

2.1. Aggregate

Locally available crushed CA and FA as crusher dust of quartzite stone procured from crushers around Jaipur, Rajasthan, India. For design performance evaluation of SMA mix the grading of coarse as well as fine aggregates were investigated. The nominal maximum aggregate size of 12, 10, 6 mm, crusher dust and finely divided mineral matter i.e. hydrated lime as mineral filler (promotes anti-stripping properties by reducing moisture sensitivity) were blended after proportioning to conform the 13 mm (nominal maximum aggregate size) SMA gradation for wearing course with nominal layer thickness of 40 to 50 mm conforming to IRC:SP:79-2008 [2] is presented in Table 1. The gradation of SMA mix vs. Dense Grade Mix Gradation is depicted in Figure 1.

2.2. Fiber

Earlier investigations recommend the inclusion of Fibers, as a stabilizing agent, are to reduce the drainage of the bitumen material during mixing, hauling and placing operations. In the current investigation natural cellulose fibers added at the amount of 0.3 % by weight of mix, are used as stabilizing agent.

2.3. Asphalt cement

The bitumen employed for fiber stabilized SMA was PMB - 40 (Polymer Modified Bitumen) conforming to the IRC (Indian Roads Congress) Specification IRC:SP:53 [13]. The outcome of laboratory investigations is enumerated in Table 2.

Table 1: Details for Blending of Aggregates done for 13mm SMA

S. No.	**IS Sieve Size mm**	**C.A. 12mm**		**C.A. 10mm**		**F.A. 6mm**		**Stone Dust**		**Filler**		**Combined Grading obtained**	**Required Grading IRC SP-79**
		% passing	**34%**	**% passing**	**34%**	**% passing**	**10%**	**% passing**	**20%**	**% passing**	**2%**		
1.	19	100.00	34.00	100.00	34.00	100.00	10.00	100.00	20.00	100.00	2.00	100.00	100
2.	13.2	98.67	33.55	99.40	33.80	100.00	10.00	100.00	20.00	100.00	2.00	99.35	90-100
3.	9.5	58.27	19.81	62.90	21.39	100.00	10.00	100.00	20.00	100.00	2.00	73.20	50-75
4.	4.75	0.16	0.05	0.23	0.08	60.50	6.05	98.90	19.78	100.00	2.00	27.96	20-28
5.	2.36	-	-	-	-	8.95	0.89	81.70	16.34	100.00	2.00	19.23	16-24

6.	1.18	-	-	-	-	4.55	0.45	57.60	11.52	100.00	2.00	13.97	13-21
7.	0.600	-	-	-	-	2.75	0.27	49.60	9.92	100.00	2.00	12.19	12-18
8.	0.300	-	-	-	-	1.75	0.17	39.70	7.94	98.00	1.96	10.07	10-20
9.	0.075	-	-	-	-	1.00	0.10	21.10	3.82	94.10	1.88	6.20	8-12

Recommended Blend: CA 12mm CA 10mm FA 6mm SD Filler
34% 34% 10% 20% 2%

Note : The combined grading of the coarse aggregate, fine aggregate and mineral filler (including hydrated lime)
shall be within the limits shown in Table-3.

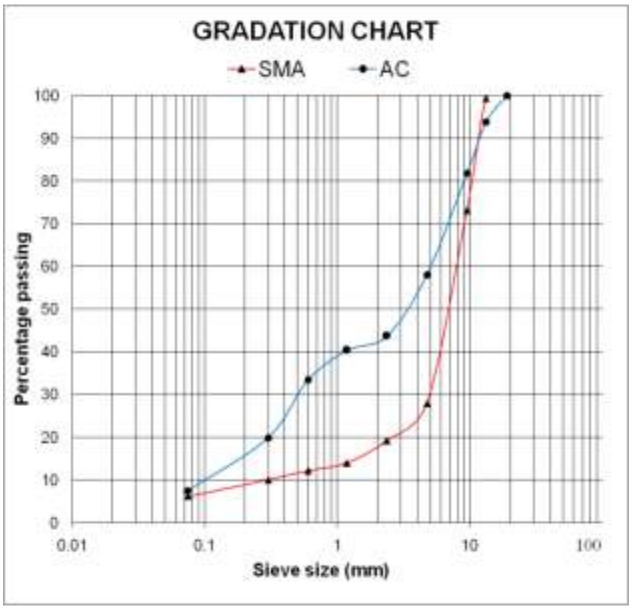


Fig. 1: SMA vs. Dense Grade Mix Gradation Curve

Table 2: Result of Experiments conducted on asphalt cement (PMB-40)

Experiment	**Procedure**	**Unit**	**Value**
Penetration (25 °C)	IS:1203-1978	0.1 mm	45
Specific Gravity (25 °C)	ASTM D-70		1.03
Ductility (27 °C)	IS:1208-1978	cm	92
Flash Point	IS:1209-1978	°C	265
Softening Point	IS:1205-1978	°C	65

III. METHODOLOGY

Laboratory experiments are entertained as a part of methodology. The investigation program includes testing of material and evolving mix design through conducting other various basic tests. The design of mix and testing conforms to American standards, AASHTO M 325 [14], AI MS-2 [15], ASTM C 29[16], D 2041 [17] etc.

IV. SPECIMEN PREPARATION AND TESTING

The mix was designed in the testing lab by preparing specimens as per the Marshall procedure (50 blows) with five separate asphalt contents ranging from 5.5% to 7.5% with an increment of 0.5%, four specimens were set up at every binder content. The samples prepared for SMA mix at different asphalt contents are shown in Figure 2. Three samples from each trial asphalt contents were compacted using a compactive effort of fifty blows on every side and employed to ascertain the volumetric characteristics of Marshall samples. The fourth sample was to be employed to ascertain the theoretical maximum specific gravity (G_{mm}) as per ASTM D 2041 [17]. For other tests at least 3 specimens were set up for every combination of variables and tested. The aggregates as well as fibers were dry mixed before adding the bitumen. The temperatures for mixing as well as compaction were 160°C and 150°C, respectively.

. The SMA mix was designed employing AASHTO MP8 [18] and AASHTO PP41 [19]. The SMA mix shall be compacted using compactive effort of 50 blows on every side employing the Marshall method as per the Asphalt Institute MS-2 (Sixth edition) [15]. Marshall test parameters like stability as well as flow values have been usually determined for information purpose but not employed for acceptance [6]. The optimum bitumen content is decided to produce approx. 4% air voids as well as a lowest VMA of 17 percent in conformity with IRC:SP:79-2008 [2].

All the mix designs for SMA construction have been performed using the 50 blows Marshall hammer. Even though these mixtures are used on heavy duty roads, 75 blows compaction need not be employed since it will contribute in much wearing out of the aggregate and will not happen in a considerable gain in density, over and above achieved with 50 blows. SMA mixes have a tendency with ease of compaction to the required density on highways than the compaction effort needed for traditional HMA mixes. The air voids has been typically around 4.0 percent in laboratory compacted samples considering the SMA mixes and approximately 5-6 percent initially in-place.

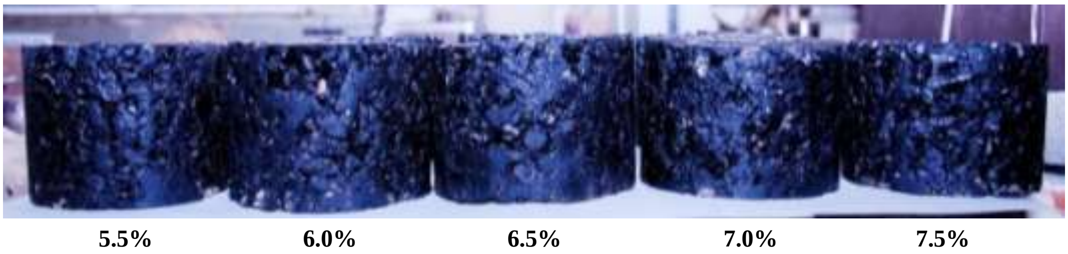


Fig. 2 : SMA Samples prepared for Marshall Test at different bitumen content

V. EXPERIMENTAL PROGRAMME

5.1. SMA Mix Design

Ascertaining the Optimum Binder Content

The optimum binder content was ascertained by corresponding to the design air voids, Va, of 4.0%. The rest of mix properties should meet those specified in Table 3. A good starting point for the design of mix is 6.0% bitumen content by weight of mix. The mix was designed in thetesting lab by preparing specimens as per the Marshall Procedure (50 blows) with binder contents ranging from 5.5% to 7.5% with an increment of 0.5%, 3 specimens were set up at every binder content.

Table 3: Mix design obtained for 13mm SMA: 40-50mm Thick

S. No.	Mix Design Criterion	Mix design SMA	Specification according to IRC SP-79
1.	Optimum Binder Content (PMB – Grade 40 Bitumen) By wt of total mix %	6.76	5.8 Min.
2.	Air Void Content (V_a) %	4.00	4.0

3.	Cellulose Fibers % (By wt. of total mix)	0.3	0.3 min.
4.	Voids in Mineral Aggregates (VMA) %	20.83	17 min.
5.	VCA mix % VCA_{DRC} %	39.00 41.00	$VCA_{mix} < CA_{drC}$
6.	Asphalt drain down %	0.14	0.30 max
7.	Tensile Strength Ratio (TSR) %	87.8	85 min

It may be noted that for SMA, the Marshall stability and flow values may be misleading and are usually determined for information purpose but not employed for acceptamce. A basic deviation among SMA and open graded mix is the less air void content (approx. 4%) in the SMA mix, while open graded courses may contain in excess of twenty percent air void content.

The Optimum Binder Content was ascertained by testing the samples for Bulk density, Air voids, VMA, Stability and Flow Values using the Marshall method described in the Asphalt Institute MS-02 (Sixth edition) [15]. Design Sheet of Marshal Test obtained for design of 13mm SMA : 40-50 mm thick is summarised in Table 4. Final outcomes of Marshall Experiment obtained for design of 13mm SMA : 40-50mm thick is summarised in table 5. Plots of SMA mix design derived by Marshall Test Procedure (AI, MS-02) [15] is shown in Figure 3.

For Test Results and plots of Marshall experiment to the corresponding 4% air voids, the Optimum Binder Content was ascertained as 7.25% by the weight of aggregates and 6.76% by weight of mix. For Optimum Binder Content ascertained as 6.76% by weight of mix, at 4% air voids, the rest of mix characteristics as per Table-3 were ascertained and found in order. To assure the scientific efficacy of the test, we deem sufficient to investigate at least three specimens per sample group and the tabulated results are average of three specimens.

5.2. Ascertaining the Bulk Sp Gr. Related to compacted mix (G_{mb})

$$Gmb = \frac{\text{weight of specimen in air}}{\text{Volume of specimen}}$$

Test result of determination Bulk Sp Gr. related to compacted mix (G_{mb}) is summarized in Table 6. Three compacted specimens having optimum binder content were set up for SMA mixture. Further the experimental results to ascertain the Bulk specific gravity related to the CA (**G_{ca}**) as well as water absorption of CA are summarized in Table 7.

Table 4: Design Sheet of Marshal Test obtained for design of 13mm SMA : 40-50 mm thick
(As per Marshall method given in Asphalt Institute MS-02 Sixth edition)

Design of 13mm SMA

% of 12mm aggregates	34	Sp. Gr. of 12mm aggregates	2.66	Builk S.G. of total aggregates (G_{sb})	2.65
% of 10mm aggregates	34	Sp. Gr. of 10mm aggregates	2.66		
% of 6mm aggregates	10	Sp. Gr. of 6mm aggregates	2.65	Effective S.G. of aggregate (G_{se})	2.581
% of SD aggregates	20	Sp. Gr. of Stone Dust	2.60		
% of Filler used	2	Sp. Gr. of Bitumen PMB-40	1.03	Proving ring factor	276
% of Natural Cellulose Fibre	0.3	Sp. Gr. of Filler	2.80		

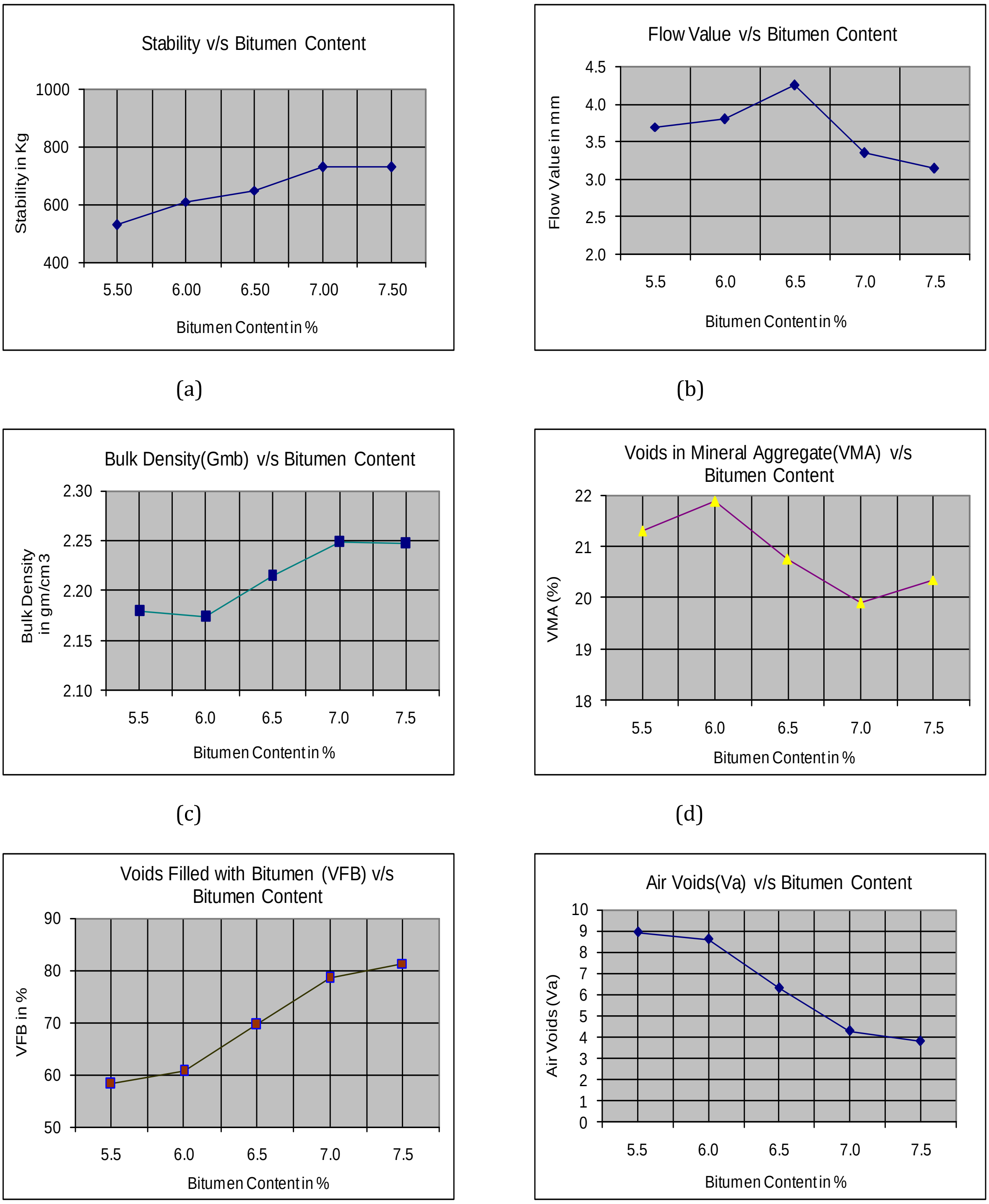
Specimen No.		A	B	C	D	E
% Asphalt content by wt. of aggregates		5.5	6.0	6.5	7.0	7.5
% Asphalt content by wt. of mix		5.21	5.66	6.10	6.54	6.98
Aggregate % by wt. of mix (Ps.)		94.79	94.34	93.90	93.46	93.02
Weights (grams)	in Air	1142.5	1146.5	1156.3	1160.00	1161.3
	In water	633.8	634.5	641.8	647.0	647.0
	SSD in air	1158.0	1162.0	1163.8	1162.8	1163.8
Volume of specimen, cc		524.5	528	522	516	517
Bulk density (G_{mb})		2.179	2.173	2.215	2.249	2.247
Max. S.G. of loose Mix, G_{mm}		2.393	2.378	2.364	2.350	2.336
% air voids (V_a)		8.931	8.601	6.301	4.283	3.798
% VMA		21.308	21.888	20.767	19.916	20.362
% VFB		58.139	60.704	69.663	78.558	81.389
Observed stability (Division)		2.00	2.30	2.40	2.70	2.65
Volume correction factor		0.96	0.96	0.98	0.98	1.00
Corrected Stability (in Kg.)		529	609	648	730	731
Flow value, mm		3.70	3.80	4.25	3.35	3.15

Table 5: Final Outcomes of Marshall Experiment obtained for design of 13mm SMA : 40-50mm thick

% Asphalt content by wt. of aggregates	Bulk density (G_{mb})	% AIR VOIDS (V_a)	% VMA	% VFB	Flow value (mm)	Corrected stability (kg)	MQ kN/mm
5.5	2.179	8.931	21.308	58.139	3.70	529	1.43
6.0	2.173	8.601	21.888	60.704	3.80	609	1.61
6.5	2.215	6.301	20.767	69.663	4.25	648	1.53
7.0	2.249	4.283	19.916	78.558	3.35	730	2.18
7.5	2.247	3.798	20.362	81.389	3.15	731	2.32

Table 6 : Ascertainment of Bulk Sp Gr. of Compacted Mix (G_{mb})

% Asphalt content by wt. of aggregates	% Asphalt content by wt. of mix	Aggregate % by wt. of mix (Ps)	Weights (grams)			Volume of specimen cc	Bulk density (G_{mb})
			In air	In water	SSD in air		
7.25	6.76	93.24	1158	646	1161	515	2.25



(a) (b)

(c) (d)

(e) (f) **OBC at 4% air voids – 7.25% by wt. of Aggregates**

-- 6.76% by wt. of Mix.

Fig. 3 : Plots of SMA mix design derived by Marshall Test Procedure (AI, MS-02)

Table 7 : Determination of Bulk specific gravity of the coarse aggregate (G_{ca}) and water absorption ofcoarse aggregate

Observation	**I**	**II**	**Average**
Weight of Standard Aggregate + Basket in water A_1 (g)			
Weight of Basket A_2 (g)			
Weight in g of Saturated Specimen in Water A = (A_1 – A_2)	802.0	1291.0	
Weight in g of Saturated Surface Dried Specimen in Air (SSD) B	1441.0	2065.0	
Weight in g of Oven Dried Specimen in Air C	1436.0	2058.0	
Specific gravity on Oven Dried basis $\frac{C}{B-A}$	2.66	2.66	2.66
Specific gravity on saturated surface dry basis $\frac{B}{B-A}$	2.67	2.67	2.67
Apparent Specific gravity $\frac{C}{C-A}$	2.69	2.68	2.69
Water Absorption gravity $\frac{B-C}{C}x100$	0.35	0.34	0.35 <2% O.K.

5.3. Ascertaining the Voids within the CA (VCA)

Wash the CA and determine its Dry Rodded Unit Weight in conformity with ASTM C 29 [16]. Calculate the dry-rodded VCA of the CA fraction by the following equation.

$$\mathbf{VCA_{DRC} = [(G_{ca}\, Y_w - Y_S)/G_{ca}\, Y_w]*100}$$

Where,
VCA_{DRC} = voids in the CA in the dry-rodded condition,
G_{ca} = bulk specific gravity of the CA = 2.66,
Y_w = unit weight of water (998 kg/m^3),
And Y_s = unit weight of CA fraction in dry-rodded condition (kg/m^3) = 1570

$$VCA_{DRC} = \left[\frac{2.66x998-1570}{2.66x998}\right]x100$$
$$= 41\%$$

5.4. Selection of Gradation for the Mix Design

Compact the specimens, remove from the moulds, and allow to cool. Determine the bulk specific gravity, $\mathbf{G_{mb}}$ of the specimens (AASHTO T 166) [20]. The uncompacted mixture samples are employed to ascertain the theoretical maximum specific gravity, $\mathbf{G_{mm}}$ (ASTM D 2041) [17], three uncompacted specimens having optimum binder content were set up for SMA mixture. Using $\mathbf{G_{mb}}$ and $\mathbf{G_{mm}}$ the % air voids (V_a), VMA, and VCA mix are calculated by the following formulae:
Voids within Mineral Aggregate,

$VMA = 100 - [G_{mb}/G_{sb})^* P_s]$

Percent Air Voids,

$V_a = 100^* (1 - G_{mb}/G_{mm})$

Voids in CA mix,

$VCA_{mix} = 100 [(G_{mb}/G_{ca})^* P_{CA}]$

Where,

P_s = % of aggregate within mixture

P_{ca} = % CA within the complete mixture = $= 0.68 \times \frac{93.24}{100} = 0.634$

G_{mb} = Bulk specific gravity related to compacted mixture

G_{mm} = Theoretical maximum density related to the mixture

G_{sb} = Bulk specific gravity related to total aggregate, along with

G_{ca} = Bulk specific gravity related to the CA fraction.

The blend that surpasses the least VMA demand as well as possess a VCA_{mix} that is less than the VCA_{DRC} should be considered as the required mix design aggregate blend. To ensure stone-on-stone contact within the CA it is very essential that VCA_{mix} is less than VCA_{DRC}.

VCA_{mix} = 100 x $\left[\frac{2.25}{2.66}\right] x 0.634$

= 39%

$VCA_{DRC} > VCA_{mix}$ O.K.

5.5. Voids within the Mineral Aggregates

Calculate VMA in conformity with AI MS-02 [15], based on ASTM D 2726 [21].
Determination of voids within the Mineral aggregates (VMA) :

$$VMA = 100 - \left(\frac{Gmb}{Gsb}\right) x\ Ps$$

where,

VMA = Voidswith in Mineral aggregate,

P_s = % of agg. in mixture = 93.24%,

G_{mb} = Bulk specific gravity related to compacted mix = 2.25 g/cc, and

G_{sb} = Bulk specific gravity of total aggregate = 2.65 g/cc

$VMA = 100 - \left(\frac{2.25}{2.65}\right) x\ 93.24$ = 20.83%

> 17 (min.) O.K.

Effect of VMA : In the mix design lowest quantity of voids within the mineral aggregate is to be achieved. The aim behind is to provide sufficient room for the binder, so that it can furnish enough adherence to hold together the aggregate particles, besides bleeding when temperatures increase and the binder expands.

5.6. Percent air voids content within the mix (V_a)

% Asphalt content by wt. of mix = 6.76%

$Va = 100 \left(1 - \frac{Gmb}{Gmm}\right)$

Where,

G_{mb} = Bulk specific gravity related to the compacted mixture = 2.25

G_{mm} = Theoretical maximum density related to the mixture = 2.345

$Va = 100 \left(1 - \frac{2.25}{2.345}\right)$

= 100 (1-0.96)

= 4% O.K.

Effect related to Air Voids : It might be stressed upon that the Design Air Voids Content (4 percent) is the extent required following numerous years of traffic.

5.7. Indirect Tensile Strength (ITS) experiment

A tensile strength experiment was performed to ascertain the tensile strength data related to the SMA mix. The outcomes attained are an indication for the quality of materials utilised. The experiment includes laying the specimen between the the two steel loading strips across diameter within the Marshall testing machine. Apply load to the specimens diametrally at a vertical rate of 50mm per minute. A uniform tensile stress is generated along the vertical diametrical plane. Three compacted specimens having optimum binder content were set up for SMA mixture.

The tensile strength related to each specimen is calculated by following equation having SI units:
$St=2000\ P/\pi\ t\ d$
Where,
St = tensile strength, kPa
P = maximum load, N
T = specimen thickness, mm
d = specimen diameter, mm

5.8. Tensile Strength Ratio (TSR) experiment

Tensile Strength Ratio (TSR) was determined in conformity with AASHTO: T 283 [22]. This is the standard experimental procedure for obtaining the outcome related to moisture on the Bituminous concrete paving mixes. The outcome may be employed to forecast long term water susceptibility (stripping resistance) of bituminous mixtures. Six compacted specimens having optimum binder content were set up for SMA mixture, 3 to be investigated dry and 3 to be tested after partial saturation and moisture conditioning with a freeze-thaw cycle. Prepare the 6 specimens with a Marshall compactor so that they have air voids content of 7.0±0.5%. Divide them into two subsets. One set was tested dry by keeping at headroom temperature as well as then keeping in a 25°C±0.5°C water bath for 2 hours before conducting the indirect tensile strength experiment. Put the other set in a water bath kept at 60°C±1°C for 24 hour. The samples were removed from hot water bath and kept at a temperature maintained at 25°C±0.5°C for 2 hour. The indirect tensile strength related to the 3 dry and 3 conditioned Specimens at 25°C±0.5°C was ascertained by placing them into ITS test assembly and loading alongside the axis of the test specimen. The test assemly was put within the Marshall testing apparatus and the load recorded at failure. The TSR (an indicator of water susceptibility), is determined and test outcomes are shown in Table 8. When polymer modified asphalt binder is specified, a minimum tensile strength having value as 690 kPA and a minimum TSR of 85% shall be required.

5.9. Schellenberg Binder Drainage Experiment

Draining of the loose SMA Mix was ascertained in line with the Schellenberg Binder Drainage Experiment which is ideal for evaluation of the mix stability. Cellulose fibers like stabilizer employed to check draining of the binder. Three uncompacted specimens having optimum binder content were set up for SMA mixture, poured in a beaker and weighed. The beaker having SMA sample is kept in an oven for 1 hour maintained at 170°C±1°C. After a lapse of one hour sample with beaker is took out of the oven as well as rapidly vacated the beaker sans any vibration or shaking. Weigh the beaker again to closest 0.1 gram. Determine the percent of bitumen draining as below:

Binder Draindown (%) = $100x\ (C\text{-}A)/(B\text{-}A)$

Where,
A= mass of the vacant beaker.
B= mass of the beaker and SMA mix
C= mass of the beaker with residue

In Table 3, the test outcome is summarized. The drainage test result obtained as 0.14% is less than the defined maximum drainage of 0.30% in IRC:SP:79-2008 [2]. If the mix is unable to fulfill this obligationt then the percent fibers should be increased to a level that reduces draindown to the acceptable limit.

Table 8 : Testing for moisture sensitivity of the mix (TSR test) : AA SHTO T 283

Sample no.		**TC-1** (dry subset)	**TC-2** (conditioned subset)
% BT (P_b)		6.76	6.76
No. of blows each face		15	15
Specimen thickness in mm (t) av		$\frac{68+66}{2}=67.0$	$\frac{68+67}{2}=67.5$
Weights (grams)	**in air**	1150	1131
	in water	640	631
	SSD in air	1170	1153
Volume of specimen cc		530	522
Bulk density (G_{mb})		2.17	2.17
Max. Sp. Gr. of loose mix (G_{mm})		2.35	2.35
% air voids Va		7.5	7.5
Max. Load in N (P)		4200	3600
$S_1 = \frac{2000P}{\pi t d}$		$\frac{2000 \text{ x } 7280}{3.14 \text{ x } 67 \text{ x } 100} = $ 692.1 kPa	
$S_2 = \frac{2000P}{\pi t d}$		$\frac{2000 \text{ x } 6440}{3.14 \text{ x } 67.5 \text{ x } 100} = 607.7$ kPa	
TSR = S_2 / S_1		$\frac{607.7}{692.1} \text{ x } 100$ = 87.8% > 85% O.K.	

S_1 = average tensile strength of the dry subset, kPa
S_2 = average tensile strength of the conditioned subset, kPa

5.10. Refusal Density of the trial specimen

Ascertained the Refusal Density of the trial specimen [23] and in Table 9, the outcomes are summarized. The refusal density is a computation of the respective state of compaction of the sample. Three compacted specimens having optimum binder content were set up for SMA mixture.

Significance of the Refusal Density Test

Refusal Density is the highest Density which is achieved by the compacted Bituminous mix. The Marshall compaction is continued till no additional densification of the specified samples is obtained. This state of maximum density is called the refusal density. The optimum is giving minimum 3 percent air voids content at the refusal density. It was obtained by compacting the Marshall mould by 300 blows on both sides of the trial specimen. Here 300 blows on the mould simulate the field condition where the compacted layer achieves after secondary compaction under heavily loaded traffic with higher tire pressures.

In Refusal Density mould we check that Air Voids Content should be at least 3%. If after secondary compaction of the road pavement layer in the field, the air voids content become less than 3%, then the pavement will fail by the plastic deformation. It has been observed that the mixes that ultimately consolidated to below the 3% air voids content can be susceptible to rutting & shoving when subjected to heavy traffic locations. Also such mixes are likely to evolve cracks because of movement of heavily loaded traffic, when the pavement element allows comparatively higher deflection value.

Minimum voids obligation achieved for a provided mixture must be so decided that would furnish enough room for required densification which may flourish below traffic movements and expansion of binder at higher temperature. In the absence of this, the binder bleeds upon the surface and cause skidding. Therefore, the goal of Refusal Density Design is to make secure such as at refusal still there is minimum 3 % voids content in the mix, as the deformation by plastic distortion takes place speedily as the air voids content reaches below 3 percent.

Table 9 : Testing for Refusal Density of the trial specimen

Sample no.		**TC-3**
% BT (P_b)		6.76
No. of blows each face		300
Weights (grams)	**in air**	1082
	in water	614
	SSD in air	1088
Volume of specimen cc		477
Bulk density (G_{mb})		2.27
Max. Sp. Gr. of loose mix (G_{mm})		2.345
% air voids V_a		3.2
Remarks		Not less than 3, OK

5.11 Determination of % voids filled with bitumen (VFB)

$$\mathrm{VFB} = \frac{100\ \mathrm{Vb}}{\mathrm{VMA}}$$

Where,

VFB = %t voids filled with bitumen
V_b = Volume of bitumen %
= VMA – V_a
VMA = Voids in Mineral Aggregate

The test data are summarized in Table 10. The principal outcome of VFB measure is to restrict highest extents of VMA and further highest levels of binder content. The low air voids might be very crucial in regard of persistent deformation, the VFB measure assists to evade those mixtures which would be prone to rutting in heavily trafficked pavement conditions.

Table 10 : Calculation for % voids filled with bitumen (VFB)

% BT by wt. of mix (P_b)	6.76
% air voids V_a	4.0
VMA %	20.83
Volume of bitumen % V_b = VMA – V_a	20.63 – 4.0 = 16.83

$\text{VBF} = \frac{100\ \text{Vb}}{\text{VMA}}\%$	$100 \times \frac{16.83}{20.83}$ =80.79

VI. RESULTS AND DISCUSSIONS

6.1. SMA Mix Design

For Test Results and plots of Marshall Experiment to the corresponding 4% air voids, the Optimum Binder Content was ascertained as 7.25% by the weight of aggregates and 6.76% by weight of mixture (the design mix Marshall experiment specimen is shown in Figure 4). For Optimum Binder Content ascertained as 6.76% by weight of mix, at 4% air voids, the rest of mix characteristics as per table-4 were ascertained and found in order. The Mix Design Formula thus obtained is enumerated in Table-3. The tabulated results are average of three specimens. For the SMA mix the grading of aggregates appears relatively on the coarser faction on the chart in comparison to the dense graded mix (Figure 2). The design mix Marshall SMA test specimen and the corresponding HMA specimen are shown in Figure 5. Marshall stability and flow values are not at all suitable for the evaluation of stone mastic asphalt's deformation behaviour. The comparatively lower values of Marshall stabilities of SMA might be misleading in regard of distortion resistance in comparison to bituminous concrete.

Fig. 4 : SMA Specimen

(HMA) (SMA)

Fig. 5 : Marshall Specimen

6.2. Indirect Tensile Strength (ITS) experiment

The indirect tensile strength value of of the SMA mix specimen prepared at optimum binder content is summarized in Table 8, marked as dry subset. The test outcome also shows the air voids of mixtures prepared towards indirect tensile strength tests. The measure of indirect tensile strength obtained as 692.1 kPa is higher than the limiting minimum tensile strength of 690 kPA, when polymer modified asphalt binder is used.

6.3. Tensile Strength Ratio (TSR) experiment

Indirect tensile strength values and Marshall stability values for the pair of dry subset and conditioned subset are summarized in Table 8. TSR value is also presented in Table 8. The TSR value obtained as 87.8% is higher than a minimum TSR limiting value of 85% specified in IRC:SP:79-2008 [2], it indicates good retained stability about the design mix SMA obtained..

6.4. Schellenberg Binder Drainage experiment

The result of the experiment conducted is summarized in Table 3. Three uncompacted specimens having optimum binder content were set up for SMA mixture. The drainage value observed as 0.14% is satisfactory and in conformity with the limiting maximum value of 0.3% according to IRC:SP:79-2008 [2].

It indicates that cellulose fibers help to check the draining of binder while production, hauling as well as placement of the mix.

6.5. Refusal Density of the trial specimen

The experimental outcome obtained is summarized in Table 9. Three compacted specimens having optimum binder content were set up for SMA mixture. The percent air voids content about the design mixture obtained in this experiment as 3.2% is higher than the restricting value of 3% [23]. At refusal over-there is a still minimum three percent voids in the mix, as the deformation by plastic distortion takes place speedily as the air voids content reaches below 3 percent. From the current study it can be concluded that 300 blows of extended Marshall compaction can be considered as the refusal density about the gradation and variety of aggregate selected in the study as 3 % air voids was retained in the mixture. Research has proved that the risk of plastic failure in asphaltic concrete surfacing on severely loaded sites can be mininimized if percent air voids of at least 3%/ can be retained after secondary compaction by traffic.

VII. CONCLUSIONS

In the present study the design mix and test characteristics of SMA mix are investigated. The behaviour about cellulose fibers like a stabilizer is encouraging. The research outcome show that bituminous mixture SMA –PMB 40 with fibers satisfactorily accomplish the water susceptibility tests, binder drainage as well as refusal density test. Mix design considerations of SMA i.e. % air void, % VMA (voids in mineral aggregate), % VCA (voids in coarse aggregate mix), values were ascertained for SMA with PMB-40 and these were also in conformity with the specifications as per IRC:SP:79-2008[2].

SMA as a highly rut resistant bituminous course, can be used both for binder (intermediate) and wearing courses, for heavy traffic roads. Because of the newness of SMA technology use of modified binder & its higher binder content, use about cellulose fiber additives, the cost of SMA would be substantially higher & increase in cost over traditional dense graded mix is 20% to 25%. Even though SMA is more cost effective in comparison to dense graded HMA for high volume roads A future research is required for modification in the SMA mixture to make it more cost efficient and to get down the cost further lower without affecting its performance properties.

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