A Sustainable Bituminous Pavement for Urban Arterial Road ï A Case Study

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ABSTRACT

Several factors such as ever increasing traffic volume and heavier axle loads, movement of slow moving vehicles, channelised traffic and excessive vehicle loading coupled with inadequate resources for maintenance and extreme climatic conditions in which flexible pavements operate in India are responsible for causing frequent and extensive deterioration of roads particularly in urban areas. To counter act this process and to minimize such damage, several measures viz. use of high performance mixes like Stone Matrix Asphalt (SMA), Porous Asphalt, Open Graded Frictional Course (OGFC) and Modified Bituminous Binders/ Mixes etc have been applied and found effective. Stone Matrix Asphalt (SMA) is a gap graded bituminous mixture that maximizes coarse aggregateœs content in the mix which provide better stone-on-stone contact. Additives are generally used in SMA mix to prevent draindown of binder. In the case study being reported upon, Delhi quartzite, Cellulose fibre and 60/70 penetration grade bitumen were used and both drum mix and batch mix types hot mix plants were used for production of SMA mixtures and draindown values, Hamburg wheel tracking test and tensile strength ratio (TSR) values were determined.

KEY WORDS: Stone Matrix Asphalt, Hamburg Wheel Tracking Tester, TSR, Bitumen and Aggregates.

1. INTRODUCTION

The growth and progress of any nation can be measured to a large extent by its socio-economic development which largely depends on the road network it has. Thus the development, maintenance and management of roads have always been serious concerns for road authorities. Flexible pavement is modeled as three layer structure and following three forms of pavement distress resulting from repeated (cyclic) applications of traffic loads are considered which relate to performance (Figure 1):

1. Vertical compressive strain at the top of sub-grade which can cause deformation in pavement layer resulting into permanent deformation (rutting) at the pavement surface.
2. Horizontal tensile strain (or stress) at the bottom of bituminous layer which can cause fracture (or fatigue cracking) of the bituminous layers.
3. Permanent deformation within the bituminous layer.

While the permanent deformation within bituminous layer can be controlled by meeting the mix design requirements, thicknesses of granular and bituminous layers are selected using the analytical design approach.

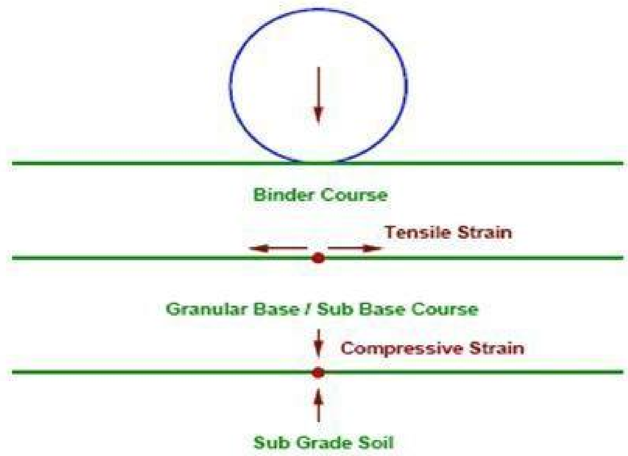

Figure 1: Critical Locations of Stress/ Strain in a Flexible Pavement

Several factors such as increasing traffic volume and heavier axle loads, movement of slow moving vehicles, channelised traffic movement and excessive vehicle loading coupled with inadequate resources for maintenance and extreme climatic conditions in which flexible pavements operate in India are responsible for causing frequent and extensive deterioration of roads particularly in urban areas. To counter act this process and to minimize such damage several measures viz. use of high performance mixes like Stone Matrix Asphalt (SMA), Porous Asphalt, Open Graded Frictional Course (OGFC) and Modified Bituminous Binders/ Mixes have been applied and found effective.

Stone Matrix Asphalt (SMA) is a widely used specification in many parts of the world. It is a gap graded bituminous mixture which has been proved to be durable and rut resistant with high skid resistance. In order to determine the suitability of SMA mixtures under Indian operating conditions, these mixtures were laid as wearing course on two different locations viz. (i) two major intersections in October 2006 and (ii) on one major urban arterial road in Delhi in October 2007.

Detailed laboratory investigations were carried out to design SMA using Delhi quartzite of 20 mm and 10 mm nominal sized stone aggregates, stone dust, hydrated lime (as filler) and 60/70 penetration grade paving bitumen. Cellulose fibers in the form of pellets were also used as stabilizing additive in SMA mixture. Marshall method of mix design was adopted, wherein the optimum binder content was calculated based on the criterion of 4% air voids in the mix and voids in mineral aggregates at minimum 17 percent. The laboratory performance tests like Indirect Tensile Strength (for water sensitivity), Draindown and Hamburg Wheel Tracking (for rutting) tests were conducted on SMA mixtures. Deflection tests with Falling weight deflectometer and Roughness measurements in terms of International Roughness Index (IRI) were also carried out on these test sections.

The experiences gained during construction, quality control exercised while laying SMA, and problems faced during the dosing of stabilizing additive in the drum/ batch types hot mix plants etc are also discussed herewith in the paper.

2 LITERATURE REVIEW

SMA is a gap graded hot mix which contains 70-80 per cent coarse aggregate of the total stone content, 6-7 per cent of bituminous binder, 8-12 per cent of filler (cement/lime) and about 0.3 to 0.5 per cent of stabilizing additive (fibre) or other modifier (MOR 01). The higher amount of coarse aggregate in SMA mixture provides stone-on-stone contact between coarse aggregateôs particles, while higher binder content in mortar adds to the durability of mix (BRO 97, BRO 95). The stabilizing additive acts to hold bituminous binder in the mixture at the high temperature during production and placement of mix and eventually reduces the draindown of binder (STU 94).

Scherocman (SCH 91) suggested that the gradation should have 30 percent aggregate passing 4.75 mm sieve, 20 percent passing 2.36 mm sieve and 10 percent passing 0.075 mm sieve. Staurt et al (STU 95) stated that aggregates passing 4.75 mm and 2.36 mm sieves sizes control the degree of gap and coarse aggregate content, while material passing 0.075 mm sieve controls optimum binder content in a SMA mix. Brown and Mallick (BRO 97, BRO 95) suggested use of dry-rodded unit weight apparatus (AASHTO T19) to determine the extent of stone-on-stone contact existing in SMA mixture. Stuart and Mogawer [STU 95] suggested (i) minimum tensile strength ratio (TSR) of 80 per cent and (ii) maximum allowable rut depths (by Hamburg wheel tracking device) of 4 mm at 10,000 passes and 10 mm at 20,000 passes for design of SMA mixture and to qualify these meeting rut depth requirements.

3. EXPERIMENTAL WORK

As stated earlier, Delhi quartzite aggregates of different sizes (20 mm and 10 mm) along with crusher dust and lime as well as 60/70 bitumen conforming to IS 2386 and IS 73:1992 are used as ingredients. The test results on physical properties of binders and aggregates are as under:

I. Bitumen

Penetration at 25^0C (0.1 mm)	: 67
Viscosity at 60^0C (poise)	: 2600
Viscosity at 135^0C (cst)	: 410

II. ***Aggregate***

Aggregate Impact Value	: 18%
Polished Stone Value	: 60%

3.1 Gradation of Aggregate

Indian Roads Congress (IRC) specification is adopted for design of SMA mix under this study (IRC SP:78). The proportioning / blending of constituent aggregates were 20:60:10:10 in respect of 20mm, 10mm, stone dust and lime respectively. The adopted aggregate gradation of SMA mix is shown in Figure 2.

3.2 Stabilizing Additive

In this study, cellulose based additives in the form of pellets were used as stabilizing agent (GEN). Additive is a conventional cellulose fibre in pellet form with 3-dimensional network of $(C_6H_{10}O_5)_n$ molecules, where n=1000, which increases binder viscosity at high temperature and prevents draindown of binder from the mix.

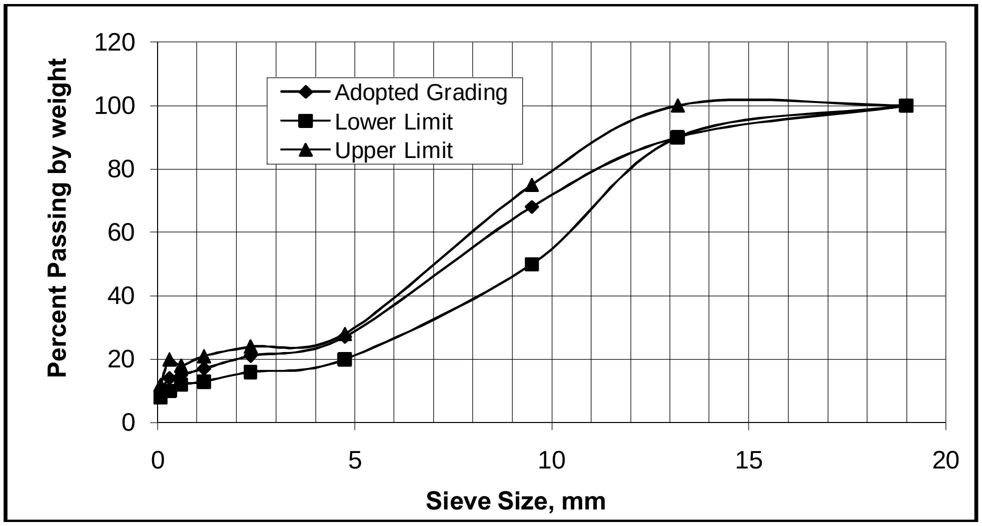

Figure 2: Adopted Aggregate Gradation of SMA Mix

3.3 Determination of Voids in Coarse Aggregate (Dry Rodded Method)

The voids in coarse aggregate (VCA) are determined by compacting aggregates using dry-rodded technique according to AASHTO T-19. This value is used in determining stone-on-stone contact and is calculated as follows:

$$VCA_{DRC} = [(G_{sb} Y_w - Y_s)/ G_{sb} Y_w] *100 \qquad .... \qquad (1)$$

Where, G_{sb} = bulk specific gravity of coarse aggregate; Y_w = density of water (kg/m^3); Y_s = unit weight of aggregate in dry- rodded condition (kg/m^3).

The value of VCA_{DRC} for coarse aggregate fraction was found to be 46.27%.

3.4 Design of SMA Mix by Marshall Method

Marshall method for design of SMA mix was performed to determine the optimum binder content (OBC) of SMA Mix. The mix was designed by using 50 blows used in Marshall Method (STU 94, STU 95, MON 94, MON 95). The mixing and compaction temperatures targeted were 175ºC and 143ºC respectively. SMA mixtures were prepared using 60/70 penetration grade bitumen with stabilizing additive at the rate of 0.3 percent. The samples were tested for (a) bulk specific gravity (G_{mb}) as per AASHTO: T-166, (b) the maximum theoretical special gravity (G_{mm}) as per AASHTO: T-9, (c) the percent air voids (V_a), (d) voids in mineral aggregate (VMA) and (e) voids in coarse aggregate in mix (VCA_{MIX}) which were calculated using following relationships:

$$\text{Voids in Mineral Aggregate, } VMA = 100- ((G_{mb}/G_{sb})*P_s) \qquad ..... \qquad (2)$$

$$\text{Percent Air Voids, } V_a = 100*(1-G_{mb}/G_{mm}) \qquad ..... \qquad (3)$$

$$\text{Voids in Coarse Aggregate, Mix, } VCA_{MIX} = 100 - ((G_{mb}/G_{ca})*P_{CA}) \qquad .... \qquad (4)$$

Where, P_s= Percent of aggregate in mixture; P_{CA}= Percent coarse aggregate in the total mixture; G_{mb}= Bulk specific gravity of compacted mixture; G_{mm}= Theoretical maximum density of mixture; G_{sb}= Bulk specific gravity of total aggregate; and G_{ca}= Bulk specific gravity of coarse aggregate fraction.

OBC for SMA mix has been estimated at which the air voids (V_a), and minimum voids in mineral aggregates (VMA) are 4 and 17 percent respectively. Volumetric analyses of SMA mixtures at various binder contents are presented in Table 1.

Table-1: Volumetric Properties of SMA Mixtures at Optimum Binder Content

Properties	**Value Obtained**
Fibre by Wt. of mix, percent	0.3
Optimum Binder Content by Wt. of Agg, percent	6.5
Optimum Binder Content by Wt. of Mix, percent	6.1
Bulk Specific Gravity of Compacted Mixture, Gmb	2.269
Air Voids, percent	3.94
VMA, percent	20.12
VCA_{DRC}, percent	46.00
VCA_{mix}, percent	38
Drain Down, percent	0.18
TSR, percent	84

3.5 Draindown

The test developed by Schulenburg Institute in Germany is adopted for finding out draindown characteristics of SMA mixture (STU 94). The draindown (D_n) was calculated as:

$$D_n\text{, percent} = 100 \times \frac{\text{(Weight of Initial Sample - Weight of Final Sample)}}{\text{Weight of Initial Sample}}$$

3.6 Resistance to Rutting

Rutting is the key factor for design of SMA mix. Rutting characteristic of SMA mix was investigated using Hamburg Wheel Tracking Device (HWTD) as reported elsewhere (KAN 01). The specimens (slabs) were prepared and tested at 45ºC with reciprocating load repetitions for 20,000 passes or until 20 mm impression on the slab surface occurred. The results obtained are presented in Figure 3.

3.7 Resistance to Moisture Damage

Resistance to moisture damage of SMA mix was determined by using AASHTO: T-283 method. The indirect tensile strength (ITS) of specimen was calculated using the formula as given below.

$$\sigma_x = 2P/(\pi DT) \quad \ldots\ldots \quad (5)$$

Where, P = load at failure, kg; D = Mean diameter of specimen, cm; T = Mean height of specimen, cm; σ_x = Indirect tensile strength, kg/cm^2.

Indirect tensile strength ratio (TSR), which is a measure of water sensitivity, is calculated using the following formula.

$$\text{TSR, per cent} = 100 \times (S_2/S_1) \quad \ldots\ldots \quad (6)$$

Where, S2= Average tensile strength of conditioned Marshall specimens

S1=Averagetensile strength of unconditioned Marshall specimens

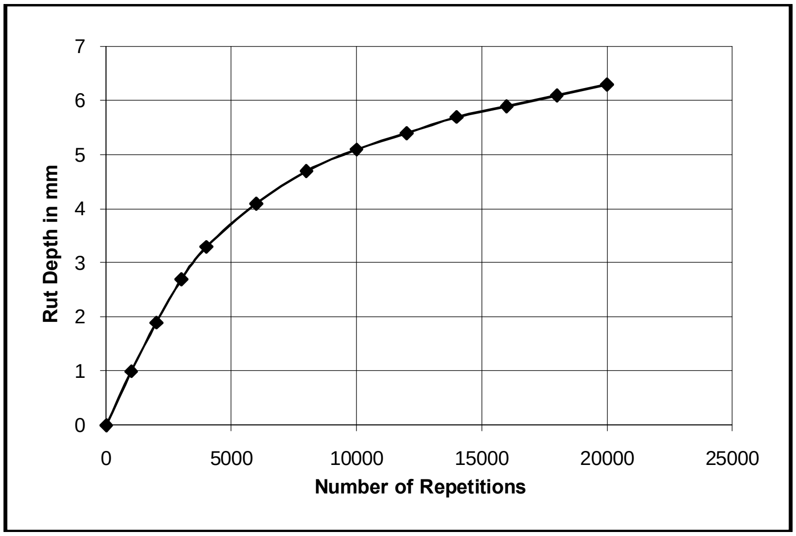

Figure- 3 Rutting Potential of SMA Mixes

4 FIELD TRIALS ON PRODUCTION AND CONSTRUCTION OF SMA MIXTURE

4.1 General

Production of SMA is similar to production of standard hot mix asphalt (HMA). SMA was used for the first time India on October 2006 and laid as wearing course during construction of Major Intersection using Drum mix plant. The distribution of fibre could not be done properly due to non availability of distribution system in the hot mix plant and several alternate arrangements were made to ensure proper distribution of fibre. The various problems encountered during production of SMA mixture under this trial are already discussed by Sharma et.al (Sharma 08). Photos- 1 and 2 present various activities/ process in production of SMA mix.

Another trail was taken up by CRRI in October 2007 on use of SMA on Dr.Zakir Hussain Marg which is a major urban arterial road which connects south and north bound traffic in Delhi. In this trial a batch type hot mix plant was used for production of SMA mixture.

4.2 Plant Calibration and Feeding of Aggregates/ Mineral Filler

Different proportions (20:60:10:10) of constituent materials are entered into the control panel. The feeding of different sizes of aggregates from the bins was done according to the proportion entered in control panel in the aggregates collector, as shown in Photos 3 & 4. After the final proportion was achieved, the entire aggregates were discharged to the aggregate drier.

4.3 Feeding of Stabilizing Additive

The dried aggregates were again delivered to the hot mix drum. Once hot aggregates entered into the drum, the gate was opened and the pre-weighed stabilizing additive was added and gate closed. The drum was rotated with additional time of about 5-15 seconds to ensure even distribution of stabilizing additive into hot aggregates. The process of feeding of stabilizing additive shown from Photos 5 to 8.

Photo 1: Distribution of Stabilizing Additive in Drum Mix Plant

Photo 2: Sieve Analysis to find out Fibres in Dry Aggregate

Photo 3 : Feeder Bin

Photo 4: Aggregate Collector

Photo 5: Piston for Gate Opening

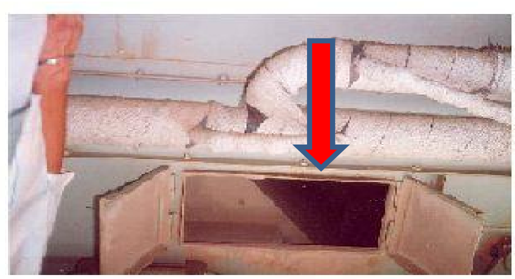

Photo 6: Gate Opening

Photo 7: Stabilizing Additive

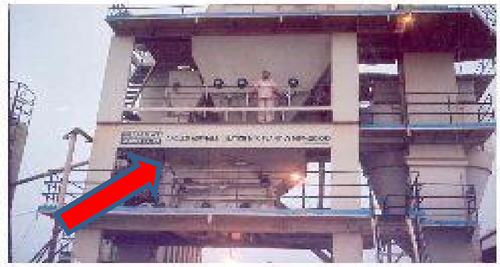

Photo 8: Aggregate Mixing Plant

4.4 Addition of Lime/Liquid Bitumen

The next step was to add lime and bituminous binder to the aggregates for production of SMA mix. The stabilizing additive was evenly distributed into aggregates and the required quantity of lime was added into the aggregate mix (Photos 9 & 10). Liquid bitumen was then added to get the final recipe of SMA mix.

Photo 9: Lime Silo

Photo 10: Final Recipe of SMA Mix

4.5 Transportation of Mix:

The trial sections were constructed during the night time at both the intersections and on the main urban arterial road, because of heavy traffic plying on these sections during the day time. Since the construction site was about 60-70 kms away from the hot mix plant, the trucks were covered with tirpal to avoid loss of temperature during the transportation of mix to construction site. The mix arrived at the paving site at a temperature of approximately 140°C to 150°C.

4.6 Paving

In addition to the continuous paver movements, SMA mixture was delivered into the paver and the speed of augers was kept turning 85-90 percent of time. This helped in ensuring the slowest possible speed for augers. The high auger speed can be a possible cause to shear the mortar from coarse aggregate thus causing fat spots onto the pavement surface.

4.7 Rolling

The densification of SMA mixture should be accomplished as quickly as possible. For this reason, the rollers are operated immediately behind the paver. Two steel-wheeled rollers weighing 9 tonnes were used while compacting SMA mixtures. Roller speed did not exceed 5 km/hr and the dry rolling continued towards the paver. Six to eight passes of breakdown rollers were given to achieve the desired density. Pneumatic- tyred rollers are not recommended for use on SMA, since, the rubber tyres tend to pick up the mortar and cause surface defects.

4.8 Finishing

Additional aggregate chips of size 1-3 mm were applied over the hot surface at the rate of 1-2Kg / m^2 immediately after the compaction of SMA mix and before the opening of road to traffic. Traffic was allowed after the surface got cooled down to the ambient temperature. Typical view of the finished surface of SMA achieved on the trial section is shown in Photo 11.

Photo 11: Final Texture of Newly Laid Surface of SMA

5. CONCLUSIONS

Based on the experiences gained through the field trials carried out under this study, the following major conclusions are drawn:

- SMA mixes designed with available aggregates showed good stone-on-stone contacts.
- The criterion of 17 percent voids in mineral aggregate and 3 percent air voids in the mix were fulfilled as SMA mix design requirements.
- Hamburg wheel tracking test results indicate that SMA with stabilizing additives under evaluation is less susceptible to plastic deformation. The rut depth of SMA was found to be less than 4 mm at 45^0C as compared to about 15 mm in case of conventional BC mixes. Thus, SMA mix contributed towards resistance to permanent deformation under heavy traffic conditions.
- TSR value is found to be in the range of 90-95 percent which is more than 80 percent as specified for conventional bituminous mixes at optimum designed conditions. Hence, SMA mixes with stabilizing agent are found to be having more resistance to moisture susceptibility.
- The draindown values of SMA mixes investigated are in the range of 0.02 to 0.2 percent against the stipulated value of 0.3 percent. Hence, use of stabilizing agent reduced the draindown of SMA mixes at hot storage and during transportation.
- In view of improved performance properties of SMA mixes modified with stabilizing additive, it may be concluded that SMA is suitable for roads subjected to heavy traffic and wet weather conditions.

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