IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 14-20
www.iosrjournals.org

Aggregate and Bitumen Modified with Chemicals for Stone Matrix Asphalt Mixtures

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ABSTRACT: *Stone Matrix Asphalt (SMA) is a gap graded bituminous mixture with comparatively higher concentration of coarse aggregates and binder mastic. The higher concentration of mastic (bitumen and filler) may cause drain down in these mixtures and to prevent it, suitable stabilizing additive is used. In this investigation, it was aimed to eliminate the use of additional stabilizing material, by modifying the aggregates and bitumen with suitable chemicals. Modification of aggregates was done by treating them with a chemical named Terrasil and bitumen modification was achieved by the addition of another chemical called Zycosoil. Effect of these chemicals was determined from testing the SMA mixtures for volumetric and Marshall properties, tensile strength and rutting behaviour. Samples were prepared in Superpave Gyratory Compactor (SGC) for testing. From the results it was observed that proper usage of these chemicals eliminates the necessity of stabilizing additive. Also it was seen that chemical treatment with aggregates is a better method to improve the overall performance of SMA mixtures compared to bitumen modification.*

Keywords –*Drain down, Stone Matrix Asphalt, Stone on stone contact, Superpave Gyratory Compactor, Terrasil, Zycosoil.*

I. INTRODUCTION

Stone Matrix Asphalt (SMA) is a gap graded hot mix asphalt developed in Germany during the 1960's to resist the excessive damage caused by studded tires. Compared to other conventional bituminous mixtures, SMA has higher concentration of coarse aggregates, bitumen and filler. In SMA, stone to stone contact is developed between each coarse aggregate to form a coarse aggregate skeleton and the load transfer is carried out through this skeleton [1, 2]. The high volume of coarse aggregates is the reason of strength of SMA whereas the binder content provides durability. Better rut resistance and durability of SMA compared to conventional dense graded mixtures leads to the growth of this mixture in many countries in Europe, United States (US) etc. [3].

The higher mastic content may lead to the drain down of bitumen and fines from the mixture during the elevated temperatures of production, transport, laying and compaction. To prevent this generally a suitable stabilizing additive is added in the mixture, which acts to hold the mastic materials [4, 5]. Studies have shown that bituminous binders subjected to suitable modification, if used in SMA can prevent drain down and improve the mixture performance. Punith et al.[6]observed that PG 64-22 modified with Crumb Rubber (CR) helps the SMA mixtures to meet the drain down requirements. Styrene-butadiene-styrene (SBS) and starch (ST) modified asphalt binders improved the performance of SMA and SBS was observed to be better than ST [7]. There are some commercially available additives, which can be used to treat aggregates with an intention to improve the properties of bituminous mixtures. Aggregates treated with such materials can be used for SMA mix preparation to prevent drain down without any other stabilizing additive.

The primary objective of this investigation was to prepare SMA mixtures without any additional stabilizing material, by modifying the aggregates and bitumen with suitable chemicals. Modification of aggregates was done by treating them with a chemical named Terrasil and bitumen modification was achieved by the addition of another chemical called Zycosoil. Here two types of mixtures, one with modified bitumen and the other with treated aggregates, were prepared in SGC. It is also aimed to compare the laboratory performance of these mixtures by conducting the volumetric and Marshall tests, Indirect Tensile Strength (ITS) test, rutting test and moisture susceptibility test.

II. MATERIALS USED

For preparing SMA mixtures, VG – 30 bitumen and crushed granite aggregates from nearby quarry were used. Quarry dust and lime were used as mineral filler and were used 8% and 2% respectively, by weight of total aggregates. The properties of bitumen and aggregates are tested IS method and the results are presented in Table 1 and 2.

Table 1.Properties of VG – 30 Bitumen

Property Tested	Results
Penetration (100 gram, 5 seconds at 25 ^{0}C) (1/10th of mm)	66
Softening Point (Ring & Ball Apparatus) (^{0}C)	53
Ductility at 27 ^{0}C (5 cm /minute pull) (cm)	>100
Specific Gravity	1.01
Flash Point (^{0}C)	249
Fire Point (^{0}C)	275
Absolute Viscosity at 60 ^{0}C (Poise)	2675
Kinematic Viscosity at 135 ^{0}C (cSt)	410

Table 2.Properties of Aggregates

Property	Test	Results	MoRTH Specifications
Strength	Los Angeles Abrasion Value	15.6%	25% maximum
Water Absorption	Water Absorption	0.84%	2% maximum
Specific Gravity	Specific Gravity Test	2.7	-
Particle shape	Combined Flakiness and Elongation Index	27.8%	30% maximum

Commercially available chemicals, named Zycosoil and Terrasil, were also used for this study. Zycosoil was used to modify the conventional bitumen and Terrasil was used to treat normal aggregates. The properties of these materials are presented in Tables 3 and 4.

Table 3.Technical specifications of Zycosoil

Property	Result
Colour	Clear to pale yellow
Solid content	41 ± 2 %
Solvent	Ethylene glycol
Flash Point	80^{0}C
Viscosity at 25^{0}C	200-800 cps
Solubility	Forms clear solution in water and soluble in asphalt

Table 4. Technical specifications of Terrasil

Property	Description
Appearance	Pale yellow liquid
Solid content	68±2%
Viscosity at 25^{0}C	20-100cps
Specific gravity	1.01g/ml
Solubility	Forms clear solution in water
Flash Point	Flammable 12^{0}C

III. EXPERIMENTAL INVESTIGATIONS

The aggregate gradation adopted for this study is as per Indian Roads Congress (IRC SP – 79) and is shown in Fig. 1.SMA mixtures were prepared according to Marshall method of mix design for bitumen contents 5.0, 5.5, 6.0, 6.5 and 7 % by weight of aggregates. For mixes with aggregate treatment with Terrasil conventional VG – 30 bitumen without any modification was used and in the case of mixes with Zycosoil modified bitumen, natural aggregates without any treatment was used. Compaction of mixture was done in SGC by providing 100 gyrations for each sample.

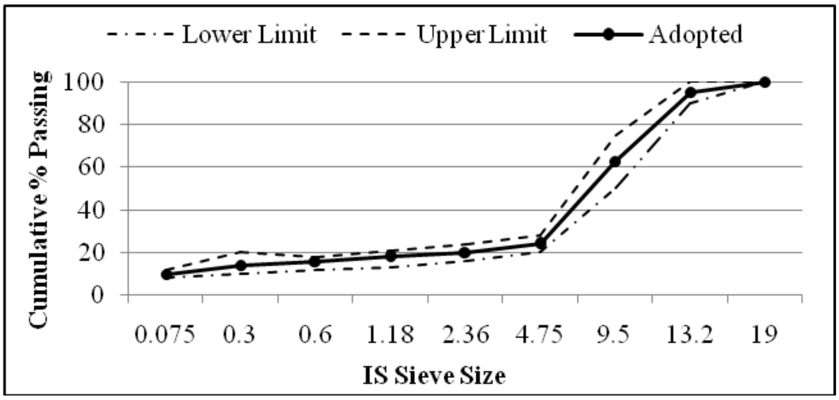

Figure 1. Aggregate Gradation Curve for SMA

For aggregate modification, first 1g of concentrated Terrasil was diluted in 5 litres of water and this solution was added to aggregates (greater than 0.3mm) at 4% by weight of aggregates. After treatment the aggregated were dried in air. To modify bitumen, Zycosoil was diluted in methanol (in the ratio 1:10) and this diluted solution was added with bitumen in the ratio of 1:100 (1g solution to 100g bitumen).

3.1 Drain Down

Drain down test was conducted as per ASTM D 6390 on loose SMA mixtures with and without modifier. Drain down was observed to be about 0.380% for SMA without any modifier whereas it was 0.240% and 0.192% for mix with modified bitumen and treated aggregates respectively. This showed that mixes with treated aggregates with conventional bitumen and mixes with modified bitumen with normal aggregates satisfy drain down criteria without any stabilizer materials. It was also seen that, aggregate modification is the better method to control drain down compared to the use of modified bitumen.

3.2 Volumetric and Marshall Properties

ASTM D 2041 procedure was used to determine maximum theoretical specific gravity (GMM) of loose SMA mixtures with modified bitumen and treated aggregates. Bulk density, air voids, Voids in Mineral Aggregate (VMA), Voids Filled with Bitumen (VFB) etc. were calculated. Bulk density and was GMM in the range of 2.32 – 2.34 g/cc and 2.47 – 2.41 g/cc respectively for both mixtures. The air void was between 3.2 – 6.3 % and VFB was in the range 64 – 85 %. Minimum VMA required for SMA with the present aggregate gradation is 17% and that was satisfying for all the samples. Marshall stability and flow of each sample was determined as per ASTM D 6927. Stability was in the range 11 – 16 kN and flow was between 2.5 and 3.5mm.

To check the stone on stone contact in SMA mixtures, Brown and Cooley[8]suggested a simple method by calculating the Voids in Coarse Aggregates (VCA). It was determined only for aggregates in Dry Rodded Condition **(**VCA_{DRC}) and also for mixture (VCA_{MIX}) using the equations 1 and 2. For stone on stone contact to exists, the latter should be lesser. In this investigation, VCA_{DRC} was 39.85% and VCA_{MIX} was in the range 34.2 – 35.3 %, which ensures the stone on stone contact.

$$VCA_{DRC} = \frac{\left(G_{CA}Y_W - Y_S\right)}{G_{CA}Y_W} \times 100 \quad (1)$$

$$VCA_{MIX} = 100 - \left(\frac{G_{MB}}{G_{CA}} \times P_{CA}\right) \quad (2)$$

G_{CA} : bulk specific gravity of the coarse aggregate fraction
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) (Determined in accordance with ASTM C 29)
G_{MB} : Bulk specific gravity of compacted mixture
P_{CA} : Per cent coarse aggregate in the total mixture

Graphs between bitumen content and all these properties were plotted for both mixtures and the Optimum Bitumen Content (OBC) values for each mix were determined by taking the bitumen content corresponding to 4% air voids. It was found to be 6.295% for Zycosoil modified bitumen mixes and 6.255% for Terrasil treated aggregate mixes. The volumetric and Marshall properties of each mixture at corresponding OBCs are presented in Table 4.Even though the values are within the specified limits for both mixtures, from the table it can be observed that SMA mixture with chemically treated aggregates were performing slightly better than the other mixture.

Table 4. Properties of SMA mixtures with modified bitumen and treated aggregates

Property	**Modified Bitumen**	**Treated Aggregates**
OBC (%)	6.295	6.255
G_{MM} (g/cc)	2.429	2.433
G_{MB} (g/cc)	2.332	2.335
VMA (%)	17.83	19.37
VFB (%)	77.54	79.32
Marshall stability (kN)	15.18	15.86
Flow value (mm)	3.18	3.18
Marshall Quotient (kN/mm)	4.76	4.99
VCA_{MIX}	34.59	34.64
VCA_{MIX} / VCA_{DRC}	0.868	0.869

3.3 Indirect Tensile Strength

ITS testing is a method to measure the diametrical tensile strength of bituminous mixture specimens, according to AASHTO 283 specification. In this method tensile strength of compacted specimen is tested in normal conditions and also after subjecting accelerated weathering phenomenon. Accelerated weathering is provided by conditioning the specimens for one freeze and thaw cycle. The specimen is subjected for freezing at –15±3 ^{0}C and then keeping in hot water bath maintained at 60^{0}C for a duration of 24 hrs. The samples were tested for tensile strength as shown in Fig. 2. The ratio of ITS value of conditioned specimens to that of normal specimens is known as Tensile Strength Ratio (TSR), which is a measure of moisture resistance of bituminous mixtures.

Figure 2. ITS Testing Machine

The ITS test results for both mixtures are presented in Table 5. ITS values were comparatively higher in the case of samples with chemically treated aggregates for both normal and conditioned states. After accelerated weathering the tensile strength is getting reduced for both mixtures, and this reduction was more for mix with modified bitumen, which resulted in lesser TSR.

Table 5. ITS and TSR values of SMA Mixtures at OBC

SMA Mixture	**Indirect Tensile Strength (MPa)**		**TSR (%)**
	Normal	**Conditioned**	
Modified Bitumen	0.812	0.693	85.34
Treated Aggregates	0.809	0.721	89.12

3.4 Stripping

Boiling or stripping test was conducted as per ASTM D 3625 on loose hot mixtures with both modified bitumen and treated aggregates at their corresponding OBC values. Stripping was observed to be within limits for both mixtures, and was around 2 – 5 %.

3.3 Rutting behaviour

Rutting or permanent deformation is observed in pavements as a longitudinal depression along the wheel tracks. Rutting characteristic of SMA mixture was determined using Immersion Wheel Tracking Device (IWTD) shown in Fig. 3. SMA slabs with dimension 600mm x 200mm x 50mm were prepared at OBC and placed on the platform of this device. A wheel is attached, which moves along the slab to and fro and causes deformation on the specimen. The depth of deformation at the middle of the slab is recorded using two Linear Vertical Deflection Transducers (LVDT) fixed at the sides of the wheel [9, 10].

Figure 4. Immersion Wheel Tracking Device

SMA mixtures with Zycosoil modified bitumen and Terrasil treated aggregates were compacted in the mould to prepare the slabs for testing. Each slab was kept on the device and the wheel was moved above it for 10,000 passes. Rut depth was recorded at regular intervals, and the results are resented in Fig. 4. It is observed that after completion of 10,000 wheel passes, the rut depth was 7.1mm and 6mm for slab with modified bitumen and slab with treated aggregates respectively. For all wheel passes, slab with treated aggregates were having lesser deformations.

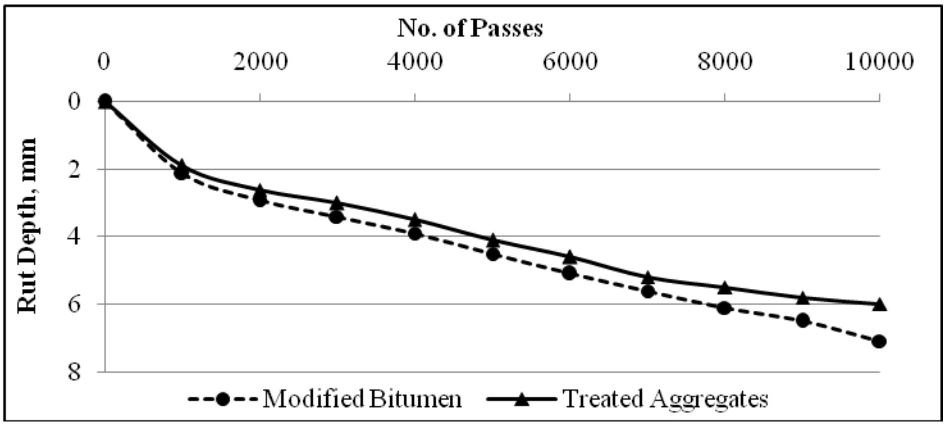

Figure 4.Rut Depths at different Wheel Passes

IV. CONCLUSION

The major conclusions drawn from the study are:

- Suitable chemicals be used to modify the conventional bitumen and to treat the normal aggregates in SMA, can control drain down of the mixture without any additional stabilizer material.
- In this study, SMA mixtures of chemically modified bitumen with normal aggregates and chemically treated aggregates and conventional bitumen were satisfied the drain down criteria.
- In a comparative study of SMA mixtures with modified bitumen and treated aggregates, it is observed that mix with treated aggregates is performing better than the other.
- Treated aggregate–SMA mixtures showed better volumetric and Marshall properties. OBC was reduced from 6.295% in the case of modified bitumen-mix to 6.255% for treated aggregate-mixture.
- Tensile strength and rutting resistance were better for mix with treated aggregate compared to that with modified bitumen. After 10000 wheel passes in IWTD, rut depths were 7.1 and 6.0 for slabs with modified bitumen and treated aggregates respectively.

- Even though stripping was almost same for both mixtures, the loss in tensile strength after accelerated weathering was more for SMA with modified bitumen, which was having a TSR of 85%, whereas it was 89% for treated aggregates-mixture.

REFERENCES

[1] E.R. Brown, and J.E. Haddock, A method to ensure stone-on-stone contact in Stone Matrix Asphalt paving mixtures, *NCAT Report 97-02*, NCAT, Auburn, Alabama, US, 1997.

[2] Y.F. Qiu, and K.M. Lum, Design and performance of Stone Mastic Asphalt, *Journal of Transportation Engineering, 132(12)*,ASCE, 2006, 956–963.

[3] AASHTO,*Report on the 1990 European asphalt tour*, AASHTO Report, Washington DC, US, 1990.

[4] E.R. Brown, J.E. Haddock, R.B. Mallick, and T.A. Lynn, Development of a mixture design procedure for Stone Matrix Asphalt." *Journal of Association of Asphalt Paving Technologists, 66*, 1977, 426–457.

[5] B.D. Prowell, D.E. Watson, G.C. Hurley, and E.R. Brown,Evaluation of Stone Matrix Asphalt (SMA) for airfield pavements,*Final Report, No: AAPTP 04-04*, Airfield Asphalt Pavement Technology Program, Auburn University, Alabama, US, 2009.

[6] V.S. Punith, F. Xiao, and S.N. Amirkhanian, Effects of lime content on moisture susceptibility of rubberized stone matrix asphalt mixtures using warm mix additives in terms of statistical analysis,Journal of Materials in Civil Engineering, 24(12), ASCE, 2012, 1431–1440.

[7] A. Al-Hadidy, and Y. Tan, Performance of the SMA mixes made with the various binders,*Construction and Building Materials, 25*, Elseveir, 2011, 3668–3673.

[8] E.R. Brown, and L.A. Cooley, Designing Stone Matrix Asphalt Mixtures for rut-resistant pavements". *Report No. 245, NCHRP*, Transportation Research Board, National Research Council, Washington, DC, US, 1999.

[9] K. Ganesh, H.S. Jagadeesh, and R. Sathyamurty, Design of Automatic Immersion Wheel Tracking Equipment to measure the rutting characteristics of bituminous mixes with plain and modified binders,*Highway Research Journal, 3, January-June*, Highway Research Board, IRC, 2010, 25–32.

[10] A.U.R. Shankar, K. Koushik, and G. Sarang, Performance studies on bituminous concrete mixes using waste plastics, *Highway Research Journal, 6 (1), January-June*, Highway Research Board, IRC, 2013, 1–11.