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Comparison of Stone Matrix Asphalt Mixtures Prepared in Marshall Compaction and Gyratory Compactor

Goutham Sarang[1], Mehnaz E[2] and A.U. Ravi Shankar[3]

[1,2,3]*Department of Civil Engineering, NITK Surathkal,*
Srinivasnagar Post, Mangalore, Karnataka, INDIA.

Abstract

Stone Matrix Asphalt (SMA) is a gap graded bituminous mixture with high concentration of coarse aggregates and high mastic content. In Marshall mix design, only 50 blows are given to compact SMA samples, compared to 75 blows in the case of conventional dense graded mixtures. This is due to the gap graded structure of SMA and the presence of higher concentration of coarse aggregates, which lead to the breakdown of aggregates if more compaction pressure is given. Nowadays field density of many bituminous pavements were found to be significantly higher than the laboratory design density due to rapidly increasing traffic loads with higher tyre pressures. Increasing Marshall compactive effort to obtain the increased density is not suitable since it increases the breakdown of aggregates, especially for mixtures like SMA. In such situations, gyratory compactor is a suitable option to prepare mixtures with higher density without causing severe aggregate breakdown.

In this investigation SMA mixtures were prepared by Marshall Compaction (MC) and also in Superpave Gyratory Compactor (SGC), and their performances in laboratory were compared. The mixtures were prepared using Viscosity Graded (VG)–30 bitumen and a chemical named Zycosoil was used as a stabilizing additive. Volumetric properties, Marshall characteristics, behaviour to moisture action etc. were determined in laboratory. From the results it is seen that gyratory compaction is the suitable method to prepare SMA mixtures.

Keywords: SMA; stone to stone contact; drain down;aggregate break down; Superpave Gyratory Compactor.

1. Introduction

Stone Matrix Asphalt (SMA) is a gap graded bituminous mixture with high concentration of coarse aggregates and higher mastic (bitumen and filler) content. The mix was found to be better rut resistant and durable than conventional dese graded mixtures and this prompted many countries in Europe and United States (US) to adopt this mixture (AASHTO, 1990). The coarse aggregate skeleton provides the mixture with stone to stone contact, giving strength and making it rut and skid resistant. The high binder content mortar, composed of fine aggregates, mineral filler, asphalt binder and stabilizing additive, adds durability to the mixture. The stabilizing additive acts to hold the asphalt binder in the mixture during the high temperatures of production and placement to prevent drain down (Brown et al 1997).

1.1 Compaction method

To prepare bituminous mixtures by Marshall Compaction (MC), a compactive effort of 75 blows are given on either sides of the specimen for dense graded mixtures, whereas it is only 50 blows in case of SMA. This is due to the gap graded structure and presence of higher concentration of coarse aggregates in SMA, which lead to severe aggregate breakdown for higher compactive effort. For any mix design procedure, the density obtained in the laboratory should be equivalent to the density attaining in the field. Field density is attained due to the primary compaction during construction period and secondary compaction caused by the running traffic. But the field density of many bituminous pavements were found to be significantly higher than the laboratory design density due to rapidly increasing traffic loads with higher tyre pressures. Increasing Marshall compactive effort to obtain the increased density is not suitable, since it increases the breakdown of aggregates. The concept of developing a bituminous mix design method in laboratory, which yields approximately the same density expected in field, without causing severe aggregate breakdown, led to the development of Gyratory Compactors. Various agencies like Texas Highway Department, U.S Army Corps of Engineers etc. developed different types of gyratory compactors (Philippi, 1957; McRae et al, 1958). In the present study Superpave Gyratory Compactor (SGC), with ram pressure of 600kPa, gyration rate 30 rpm and gyration angle of 1.25^0, was used.

1.2 Objectives

The objective of the present investigation was to prepare SMA mixtures with VG–30 bitumen and Zycosoil stabilizing additive by giving compaction using MC and SGC. The samples prepared in both methods were tested for volumetric properties, Marshall characteristics and moisture resistance and and the results were compared.

2. Materials Used

For this study, crushed granite aggregates from nearby local quarry and VG–30 bitumen were used. Hydrated lime was used as the mineral filler and a chemical named

Zycosoil (manufactured by Zydex Industries, Gujarat) was used to stabilize the mix. Properties of materials used are listed in Tables 1, 2 and 3.

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

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

3. Experimental Investigation

The aggregate gradation for SMA specified by MoRTH was adopted for this investigation and is shown in Fig. 1. SMA mixtures were prepared according to Marshall method of mix design specified by Asphalt Institute Manual Series (MS)–2. Loose SMA mixture with Zycosoil was prepared for bitumen contents 5.0, 5.5, 6.0, 6.5 and 7 % by weight of aggregates. Two types of compacting methods, by Marshall compactor and SGC, were adopted. For preparing the samples in MC, 50 blows were given on either sides of the specimen using Marshall hammer, whereas for compacting in SGC, 100 gyrations were provided for each sample.

For Zycosoil application, 0.1% of concentrated Zycosoil (by weight of bitumen) should be added with bitumen. But for better results, it can be diluted with some anhydrous alcohols such as methanol, ethanol or iso-propanol in the ratio of 1:10 (Zycosoil to alcohol) and 1g of this solution can be added with 100g of bitumen. In this study, methanol was used to dilute Zycosoil.

3.1 Drain Down

Drain down test was conducted as per ASTM D 6390 on loose SMA mixtures with and without Zycosoil.

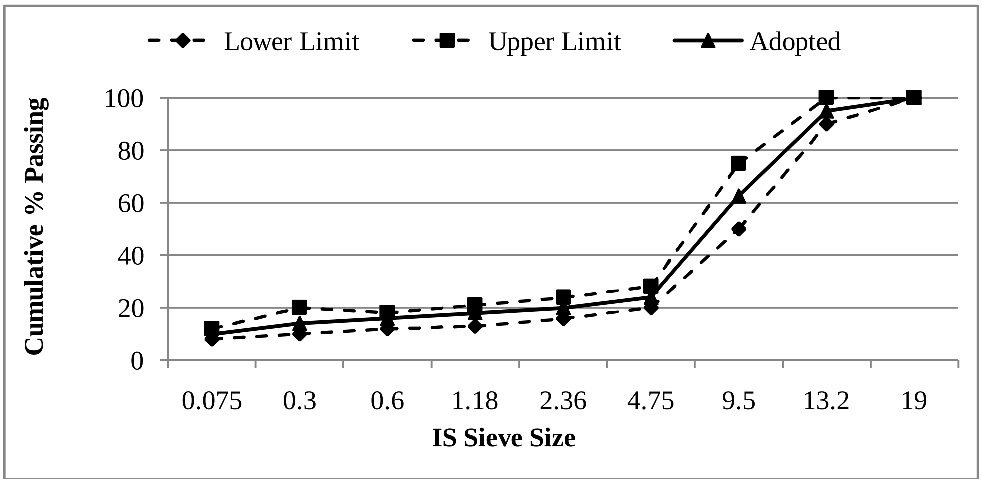

Figure 1: Aggregate Gradation Curve.

3.2 Volumetric and Marshall Properties

Theoretical maximum specific gravity (G_{MM}) of uncompacted loose SMA mixtures with Zycosoil was determined as per ASTM D 2041. After preparing the samples, their dimensions and weights were measured to determine the bulk specific gravity (G_{MB}), air voids (V_V), Voids in Mineral Aggregates (VMA), Voids Filled with Bitumen (VFB) etc. of compacted specimens. Both MC and SGC specimens were tested for conventional Marshall stability and flow as per ASTM D 6927. Voids in Coarse Aggregate (VCA) for aggregates in Dry Rodded Condition (VCA_{DRC}) and for mixture (VCA_{MIX}) were also calculated using the following equations (Brown and Cooley, 1999):

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

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

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} = Percent coarse aggregate in the total mixture.

3.3 Moisture Resistance

Resistance of SMA samples to moisture action was checked in two methods, using Tensile Strength Ratio (TSR) and Retained Marshall Stability (RMS). TSR was found out from the Indirect Tensile Strength (ITS) test conducted as per AASHTO T 283 (Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage) and RMS from the Marshall stability values of conditioned specimens as per CRD-C 652-95 (Standard Test Method for Measurement of Reduction in Marshall Stability of Bituminous Mixtures Caused by Immersion in Water).

3.3.1 Tensile Strength Ratio

Two sets of specimens were prepared in both MC and SGC at their respective OAC's. One set, called unconditioned specimens, was tested in the normal way and the other set was subjected to conditioning by one freeze and thaw cycle. The samples were kept in the mould and tested for tensile strength. The ratio between the ITS value of conditioned subset to that of unconditioned subset is known as TSR which is an assessment parameter for moisture susceptibility of asphalt mixtures.

3.3.2 Retained Marshall Stability

A set of specimens prepared from MC and SGC were kept in water bath maintained at 60^0C for 24 hours. These specimens are known as conditioned specimens and were tested for Marshall stability. The ratio of stability of conditioned specimens and conventional Marshall stability of similar specimens (with same bitumen content) is termed as RMS.

4. Results and Discussion

4.1 Drain Down

Drain down was observed to be about 0.380% for SMA without Zycosoil whereas it was 0.240% for mix with Zycosoil. This showed that Zycosoil can be used as a stabilizing additive to control drain down to keep it within the limit of 0.3% and hence further tests were conducted on mixes with Zycosoil.

4.2 Volumetric and Marshall Properties

The bitumen content corresponding to 4% air voids was calculated for both set of mixtures and was considered as the Optimum Binder/Bitumen Content (OBC). The volumetric properties and Marshall characteristics of samples prepared in MC and SGC, at their corresponding OBC are tabulated in Table 4. All properties were observed to be improved for SMA samples compacted in SGC. VCA_{DRC} was obtained as 39.85% and VCA_{MIX} was less than VCA_{DRC} for all samples. This ensures the presence of stone to stone contact between coarse aggregates in SMA mixtures.

Table 4: Properties of SMA samples prepared by MC and SGC.

Property	MC	SGC
OBC (%)	6.582	6.295
G_{MM} (g/cc)	2.420	2.429
G_{MB} (g/cc)	2.324	2.332
V_V (%)	3.96	4.00
VMA (%)	18.33	17.83
VFB (%)	78.41	77.54
Marshall stability (kN)	12.94	15.18
Flow value (mm)	3.38	3.18
Marshall Quotient (kN/mm)	3.82	4.76
VCA_{MIX}	34.99	34.59
VCA_{MIX} / VCA_{DRC}	0.878	0.868

4.3 Moisture Resistance

The test results of ITS and RMS are presented in Tables 5 and 6. It can be seen that SMA samples compacted in SGC acquires higher tensile strength and stability compared to the samples prepared by MC. Also the SGC samples are showing better moisture resistance by increased TSR and RMS values.

Table 5: ITS Test results.

Sample Preparation	ITS Conditioned (MPa)	ITS Unconditioned (MPa)	TSR (%)
MC	0.532	0.657	80.9
SGC	0.693	0.812	85.3

Table 6: Stability of Conditioned and Unconditioned SMA Samples.

Sample Preparation	Stability Conditioned (kN)	Stability Unconditioned (kN)	RMS (%)
MC	12.09	12.94	93.4
SGC	14.51	15.18	95.6

5. Conclusions

From the laboratory investigation it can be seen that, SMA samples compacted in SGC are showing better results than samples prepared by MC. The major conclusions drawn are the following:

- For SGC samples, OBC got reduced to 6.3% from 6.6% (of Marshall samples) and the bulk density at corresponding OBC increased from 2.32 to 2.33.
- In SGC method, conventional Marshall stability showed an increase of 17%, whereas it was 20% for stability of conditioned specimens.
- ITS value was observed as 24% and 30% higher for unconditioned and conditioned samples respectively, in the case of SGC preparation.
- Resistance to moisture was better for SGC samples with comparatively higher TSR and RMS values.
- Overall, it can be concluded that to prepare SMA samples, compaction in SGC is the more suitable than MC.

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