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Experimental Study on Stone Matrix Asphalt Using Polymers

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ABSTRACT : *The increased traffic volume and maintenance requires efficient and durable pavements which regulates the pavement distress. A lot of research work is going on the Stone Mastic Asphalt (SMA) provides a durable surface course. Many successful attempts are made to stabilize SMA mixtures with synthetic fibres and polymers. Now a day's waste disposal is the main issue for an eco friendly sustainable environment. In this research work polymers like Polyvinyl Chloride (PVC), Polyethylene (PE) and Styrene Butadiene Rubber (SBR) are used as an additive to reduce the drainage at high temperatures during storage, transportation, placement and compaction to improve the interfacial adhesion between aggregates and binder. Bitumen VG 30 grade is used as a binder. This experimental research is carried out by Marshall Stability Test to obtain Stability, Flow and Optimum Binder Content (OBC), Drain down test is carried out to get the Optimum Additive Content (OAC) .Out of these polymers the maximum stability was obtained for PVC at 0.4 %.*

Keywords : *Stone Mastic Asphalt (SMA), Polyvinyl Chloride (PVC), Polyethylene (PE), Styrene Butadiene Rubber (SBR), Marshall Stability Test, Drain down Test.*

I. Introduction

Road network plays a crucial role in the nation's economic development, trade and social integration. The travelling and safety for both people and goods depends upon quality of road networks only. As the population is increasing daily it directly affects the travel demand. India has 79,243 Km of National Highways connecting all major cities and state capitals and 1, 31,899 Km of State Highways connecting National Highways and major towns, district headquarters of states. If the pavements are in bad condition they cause vehicle wear, tear and damage. The road condition has direct impact on travel cost from vehicle operations, traffic delays and crash related expenses.

The bitumen mixtures used in the pavements to enhance the structural strength, providing better drainage at subsurface and provides surface friction especially in wet conditions. In our country the major problem associated with heavy axle loads with low speed and many start/stop points which cause rutting. For this reason the SMA is adopted. In this SMA load is directly carried by coarse aggregate due to crystalline structure which results in long durability with better serviceability. As per Indian road congress (IRC SP 79: 2008) the SMA mix was designed. Now a day's fibers or polymers are used as stabilizing additives in SMA. Different kinds of polymers are classified into five groups they are

A. Thermoplastics: (Polyethylene, Polyvinyl Chloride, Poly Propylene, Ethylene Vinyl Acetate)
B. Natural And Synthetic Rubbers: (Styrene Butadiene Rubber, Poly Butadiene, Poly Isoprene, Butyl Rubber, Crumb Rubber)
C. Thermoplastic Rubbers: (Styrene Butadiene Styrene, Styrene Isoprene, EPDM)
D. Epoxy Resins
E. Mixed Systems

In this research the impact of polymers as additive in SMA and their role in volumetric and drain down characters of mixture is proposed.

The objectives are

i. To find the Suitability of Polymers as a Stabilizer for Stone Matrix Asphalt.
ii. To evaluate the Stability, Flow value and Volumetric properties of SMA mixes using Polymers.
iii. To determine the OBC by conducting Marshall Stability Test.
iv. To study the drain down characteristics of Stone Matrix Asphalt for modified and unmodified samples.

II. Materials

Stone Mastic asphalt (SMA), otherwise known as Stone Matrix Asphalt / Split Mastic Asphalt, was developed in Germany in the mid of 1960's and it has spread throughout Europe and across the world in 1980's and 1990's respectively. The components of SMA consist of coarse aggregates, fine aggregates, filler, binder and additives. SMA is a gap-graded mixture with 70-80% coarse aggregate of the total mass. The high percent of coarse aggregates are used to carry heavy loads by giving stone-on-stone structure to prevent permanent deformation and provides durability. The remaining fine aggregates, filler and bitumen binder helps to bond the stone structure. The additives like polymers are used as a stabilizer to protect the mastic in the mixture. They control the moisture, stiffen the mastic and finally regulate the bitumen drain down.

2.1 Aggregates

The strength, toughness and rut resistance of SMA depends mostly on aggregates. Before using the aggregates, they should be tested to check the suitability. The aggregate were obtained from Rapaka (a small village, 10 Km. away from Rajam). The physical properties of the aggregates are represented in Table I.

Table I. Physical properties of Coarse Aggregates

PROPERTY	*TEST*	*TEST METHOD*	*RESULTS OBTAINED*	*RECOMMENDED VALUES*
STRENGTH	Crushing Value	IS:2386 (IV)	25.3%	**30% maximum**
	Aggregate Impact Value	IS:2386 (IV)	17.7%	**30% maximum**
	Los Angeles Abrasion Test	IS:2386 (IV)	18%	**30% maximum**
SPECIFIC GRAVITY	Specific Gravity Test	IS:2386 (III)	2.65	**2.6-2.8**
WATER ABSORPTION	Water Absorption	IS:2386 (III)	0.5%	**2% maximum**
PARTICLE SHAPE	Combined Flakiness and Elongation Index	IS:2386 (I)	26.7%	**30% maximum**

2.2 Filler

The material that passing through 0.075 mm sieve is called filler. Rock dust, Portland cement, hydrated lime is used as fillers. The filler occupies 8 to 12 % of total aggregates of mixture. The filler essentially stiffening the rich binder and makes the mastic to hold. The specific gravity of filler is 2.32

2.3 Bitumen

Bitumen of VG 30 grade used as a binder. This binder helps to provide a thick layer coating to aggregates and additives. The bitumen used for conducting the tests was obtained from HPCL, Visakhapatnam, Andhra Pradesh, India. The physical properties of the bitumen are represented in Table II.

Table II. Physical properties of (VG-30) Bitumen

TEST	*TEST METHOD*	*RESULT OBTAINED*	*RECOMMENDED VALUE*
PENETRATION	IS:1202-1978	63	50-70
SOFTENING POINT	IS:1205-1978	49	>47
DUCTILITY	IS:1208-1978	>100	>75

2.4 Additives

The additives are added to stiffen the mastic and enhance the bitumen properties at low and high temperatures. Material was collected from lotus chemicals Visakhapatnam The polymers Polyvinyl Chloride (PVC), Polyethylene (PE) and Styrene Butadiene Rubber (SBR) are used. The simplest units called monomer are linked together in the polymerization forms long molecular chains called polymers.

Fig.1. Polymers SBR, PVC & PE respectively

Polyethylene: Poly Ethylene was then cleaned properly and shredded to form the size of the particle 2-3 mm for the preparation of the recycled polyethylene.

Physical properties

Specific gravity = 0.94

Melting temperature = 115˚C

Polyvinyl chloride: thermoplastic material has widely been used in construction works for being cheap, durable and easy workability.

Physical properties

Tensile strength = $2.60 N/mm^2$

Density = $1.38 g/cm^3$

Specific gravity = 1.25

Styrene butadiene rubber: The advantage of SBR is that the rubber particles are extremely small and regular which can easily disperse in bitumen and mixed uniformly throughout the material and form a reinforcing network structure.

III. Methods

Using these materials SMA mixtures are prepared, analysis is carried out by drain down and marshal methods.

3.1 Drain down test

The Drain down of SMA mixtures should not exceed 0.3% by weight of the mixture (AASHTO T305). Drain down test is more significant for SMA mixtures than for conventional dense-graded mixtures. The sample of 1000gm of aggregates and bitumen of 7% is taken for modified and unmodified samples. From the Drain down test Optimum Additive Content (OAC) is calculated.

Table III. Drain down values for different percentages of PVC and PE

ADDITIVE %	***0***	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***
Polyvinyl Chloride %	1.22	0.74	0.55	0.37	0.27	0.18
Poly Ethylene %	1.22	0.84	0.68	0.46	0.24	0.09

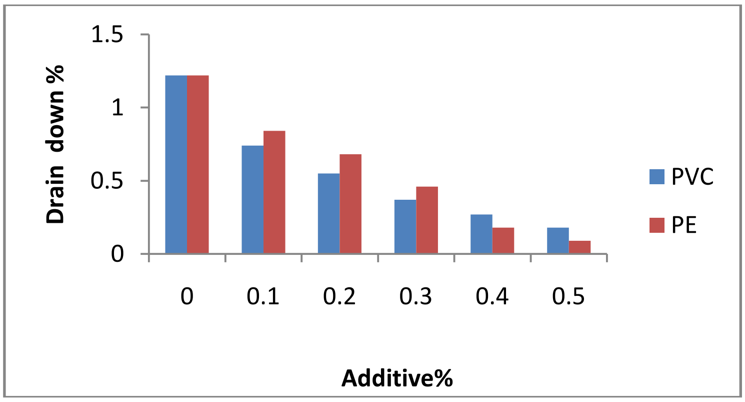

Fig. 2. Variation of Drain down with Polyvinyl Chloride and Polyethylene

There are some differences in the performance for modified and unmodified samples. In the unmodified case the drain down is 1.22% that means it is (> 0.3%)so it is not suitable. To obtain the suitable percentage of additive the sample is incremented in proper proportional of additive to regulate the drain down. The samples are done from 0.1 to 0.5 % of additives content. At 0.4 % the OAC is less than 0.3% (AASHTO T305) so it selected as optimum additive for polyvinyl chloride and polyethylene. The drain down values are represented in Fig.2

Table IV. Drain down values for different percentages of SBR

ADDITIVE %	*0*	*1*	*2*	*3*	*4*	*5*
STYRENE BUTADIENE RUBBER %	1.22	0.37	0.26	0.18	0	0

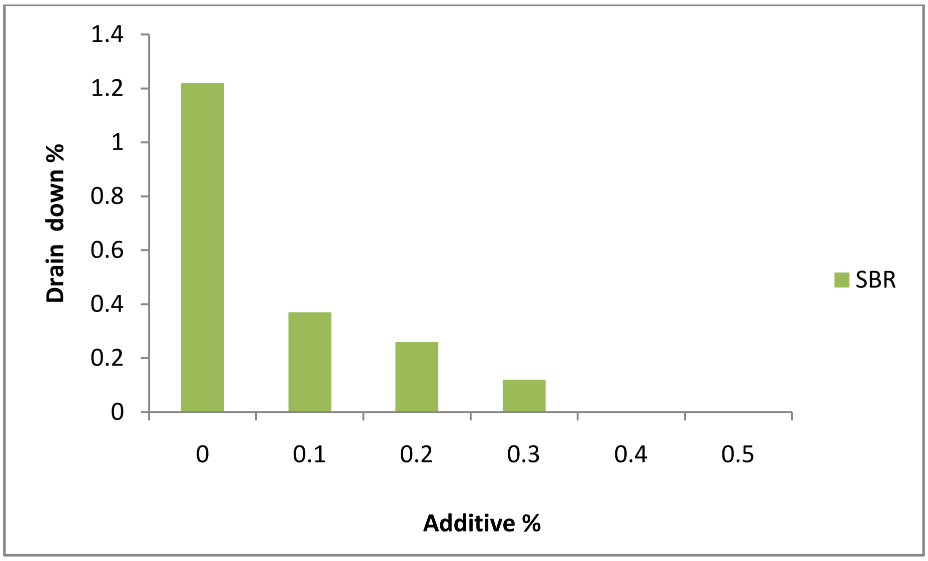

Fig. 3. Variation of Drain down with Styrene Butadiene Rubber

The sample is done from 1 to 5 % of additives content. At 2 % the OAC is less than 0.3% (AASHTO T305) so it selected as optimum additive content for Styrene Butadiene Rubber. Their drain down values are represented in Fig.3.

3.2 Marshall Method

Marshall Mix Designs contains 1200g of the aggregate consisting of different aggregate fractions, as worked out earlier, was pre-heated to 175-190°C. The bitumen (plain/modified) was heated to 121-138°C and the first trial bitumen content was added to a preheated steel bowl. The mix was thoroughly mixed at mixing temperature about 154°C. The mix was compacted in a preheated Marshall mould by applying 50 blows on each face of the specimen.

Specimens were prepared at bitumen content 5.5%, 6%, 6.5% and 7% weight of dry mix. Bituminous mixture for the Marshall Test samples was designed as per SMA13mm grading as per Indian specification IRC-SP: 79-2008.Optimum Binder Content (OBC) was chosen at 4% of Air Voids. From the Thompson and filler equation is used to obtain maximum density gradation.

Table V. Gradations and Gradation Limits used for the study

Sieve Size (mm)	Upper Limit (mm)	Lower Limit (mm)	Obtained
19	100	100	100
13.2	100	90	95
9.5	75	50	62.5
4.75	28	20	24
2.36	24	16	20
1.18	21	13	18
0.600	18	12	16
0.300	20	10	13
0.075	12	8	10

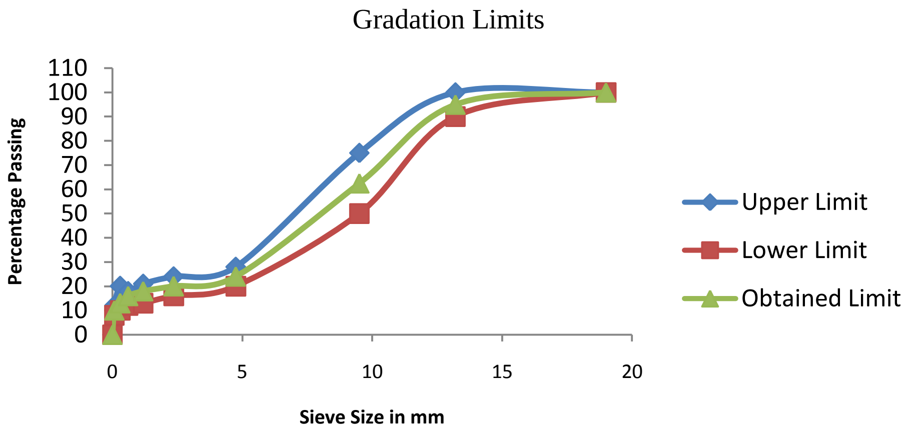

Fig. 4. Gradation Curve for SMA13mm IRC-SP: 79-2008

IV. Analysis & Results

The Marshall Stability test was conducted on the prepared specimens as per ASTM D 1559 to determine the stability and flow values. The Marshall Test properties such as bulk density, Volume of air voids, volume of bitumen, voids in Mineral aggregates were determined and shown in Table VI.

Table VI. Marshall Test Properties of Bituminous Concrete Mixes by using PVC, PE and SBR additives.

Additive	Theoretical Density (Gt) g/cc	Bulk Density (Gb) g/cc	Unit weight g/cc	Flow (F) mm	Marshall Stability (S) kN	Volume of Air Voids (Vv) %	Voids in Mineral Aggregates (VMA) %	Voids Filled with Bitumen (VFB) %
5.5% Bitumen								
0.4% PVC	2.44	2.315	22.710	1.68	11.45	5.39	17.77	69.52
0.4% PE	2.44	2.420	22.631	1.49	12.81	5.73	18.16	68.44
2% SBR	2.44	2.312	22.680	1.58	12.73	5.32	17.77	70.09

Additive	Theoretical Density (Gt) g/cc	Bulk Density (Gb) g/cc	Unit weight g/cc	Flow (F) mm	Marshall Stability (S) kN	Volume of Air Voids (Vv) %	Voids in Mineral Aggregates (VMA) %	Voids Filled with Bitumen (VFB) %
6% Bitumen								
0.4% PVC	2.42	2.319	22.769	1.76	15.48	4.27	17.93	76.16
0.4% PE	2.42	2.320	22.788	1.81	14.93	4.43	18.22	75.68
2% SBR	2.42	2.339	22.945	2.47	14.76	4.13	17.80	76.74

Additive	Theoretical Density (Gt) g/cc	Bulk Density (Gb) g/cc	Unit weight g/cc	Flow (F) mm	Marshall Stability (S) kN	Volume of Air Voids (Vv) %	Voids in Mineral Aggregates (VMA) %	Voids Filled with Bitumen (VFB) %
6.5% Bitumen								
0.4% PVC	2.4	2.321	22.769	2.15	16.03	3.29	18.08	81.82
0.4% PE	2.4	2.323	22.788	2.72	14.03	3.68	18.68	81.94
2% SBR	2.4	2.335	22.901	2.53	12.57	3.95	18.10	81.53

Additive	Theoretical Density (Gt) g/cc	Bulk Density (Gb) g/cc	Unit weight g/cc	Flow (F) mm	Marshall Stability (S) kN	Volume of Air Voids (Vv) %	Voids in Mineral Aggregates (VMA) %	Voids Filled with Bitumen (VFB) %
7% Bitumen								
0.4% PVC	2.38	2.340	22.670	3.07	13.91	2.98	18.93	84.18
0.4% PE	2.38	2.310	22.661	2.87	12.23	3.13	19.12	83.62
2% SBR	2.38	2.303	22.592	2.60	10.89	3.36	19.14	82.70

Graphs are plotted taking Marshall test properties along Y-axis and bitumen content along X-axis for different proportions of bitumen which is as shown in the Fig.5-9.

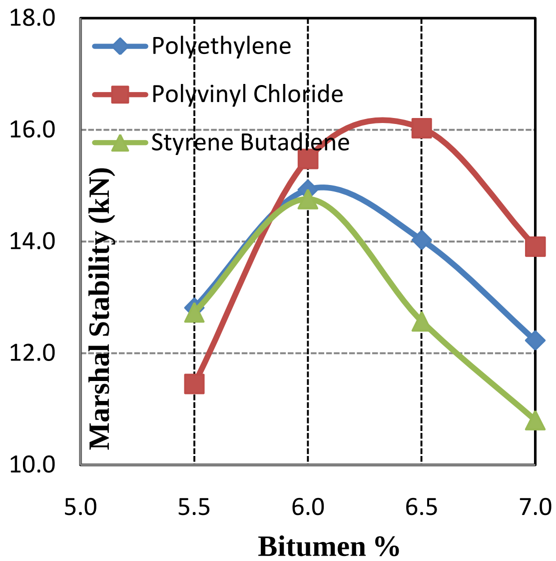

Fig. 5. Marshall Stability Vs Bitumen content

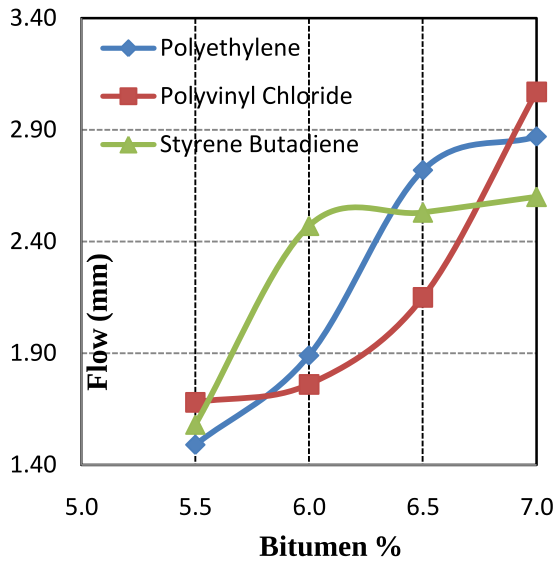

Fig. 6. Flow Vs Bitumen content

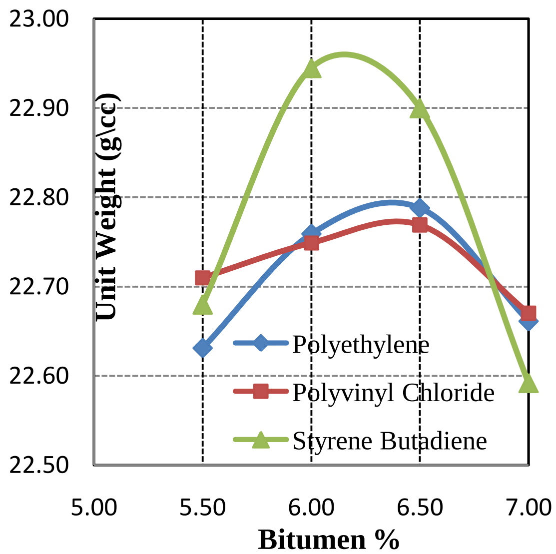

Fig. 7. Unit weight Vs Bitumen content

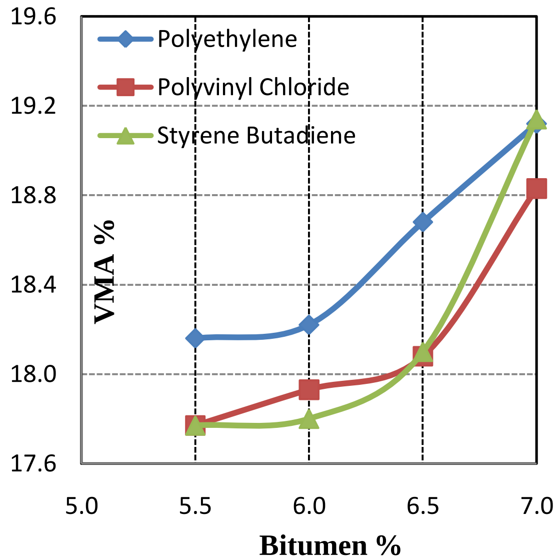

Fig. 8. Voids in Mineral Aggregate Vs Bitumen content

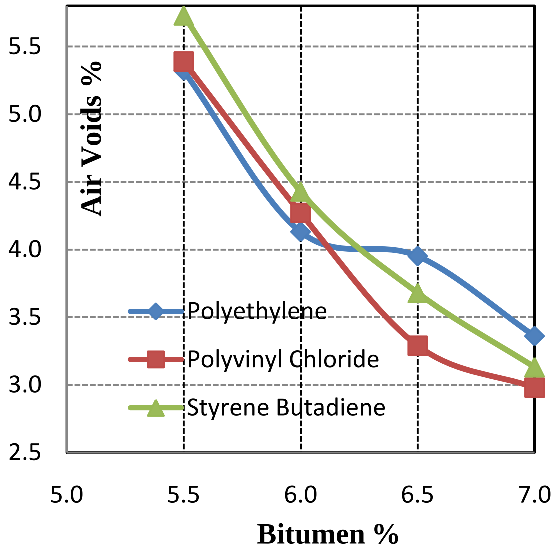

Fig. 9. Volume of Air Voids Vs Bitumen content

From the above graphs the properties such as Bulk Density, Theoretical Density, Volume of Air Voids, Volume of Bitumen, VMA, VFB, Marshall Stability and Flow values were analyzed for different additives in mix with varying are shown in Fig 5 to 9. All these properties are indicators of the performance of bituminous concrete mix in the field.

V. Conclusions

On the basis of observation and analysis of Drain down Test and Marshall Test properties, the following conclusions are drawn. The Marshall Stability value is found maximum of 16.03kN at 0.4% (PVC) content which is more than SBR and PE. The Bulk density is found maximum having 2.420 g/cc for (PE) at 5.5% bitumen content. It is also observed that Air Voids decrease, which is required for better strength and service life of the pavement and the Flow and VFB is increased by addition of bitumen. From the Drain down test the bitumen drainage gets reduced at 0.4% (PVC, PE) and 2% (SBR). The optimum bitumen content obtained at 4% Air Voids are 6.27% (PE), 6.24% (SBR) and 6.11% (PVC).

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