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Experimental Study on Stone Matrix Asphalt using Polymers

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Abstract

Increased traffic volume and upkeep necessitates effective and long-lasting pavements that control pavement distress. A great deal of research is being done “on Stone Mastic Asphalt (SMA), which provides a long-lasting surface course. Many attempts have been made to stabilize SMA mixes using synthetic fibers and polymers with varying degrees of success. Waste disposal is now a major concern for an environmentally friendly, long-term environment. Polymers such as Polyvinyl Chloride (PVC), Polyethylene (PE), and Styrene Butadiene Rubber (SBR) are used as an additive in this study to improve the interfacial adhesion between aggregates and binder by reducing drainage at high temperatures during storage, transportation, placement, and compaction. As a binder, VG 30 grade bitumen is employed. Marshall Stability Test is used to acquire Stability, Flow, and Optimum Binder Content (OBC), and Drain Down Test is used to gain Optimum Additive Content (OAC) in this experimental study. PVC, with a stability of 0.4 percent, was found to be the most stable of these polymers.

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

I. Introduction

The nation's road network is critical to its economic development, trade, and social cohesion. Only the quality of road networks determines transport and safety for both people and commodities. The fact that the population is growing every day has a direct impact on travel demand. In India, there are 79,243 kilometers of National Highways connecting all major cities and state capitals, as well as 1, 31,899 kilometers of State Highways connecting National Highways and significant towns and state district headquarters. Pavements in poor conditions cause vehicle wear and tear, as well as damage. The cost of travel is directly influenced by road conditions, including vehicle operations, traffic delays, and crash-related charges.

Bitumen mixtures are used in pavements to improve structural strength, provide better subsurface drainage, and give surface friction, particularly in wet circumstances. The main issue in our country is rutting caused by big axle loads, low speeds, and numerous start/stop spots. For this reason the SMA is adopted. Due to the crystalline structure of this SMA, the load is directly carried by coarse aggregate, resulting in extended durability and enhanced serviceability. The SMA Mix was designed according to the Indian Road Congress (IRC SP 79: 2008). Fibers or polymers are now commonly employed as stabilizing additives in SMA. Polymers are divided into five classes, each of which has its own set of characteristics. Thermoplastics: (Polyethylene, Polyvinyl Chloride, Poly Propylene, Ethylene Vinyl Acetate)

A. Natural And Synthetic Rubbers: (Styrene Butadiene Rubber, Poly Butadiene, Poly Isoprene, Butyl Rubber,Crumb Rubber)
B. Thermoplastic Rubbers: (Styrene Butadiene Styrene, Styrene Isoprene, EPDM)
C. Epoxy Resins
D. Mixed Systems

In this research the impact of polymers as additive in SMA and their role in volumetric and drain downcharacters 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.

2. Literature Review

In the 1980's federal and state highway officials in the United States recognized the need to design stiffer, more rut resistant pavements. As a result, American professionals participated in the European Asphalt Study Tour in 1990, where SMA pavements were investigated. This was the first concerted effort to figure out how to use SMA.[14] The objectives of GDOT's first SMA research project, No. 9102, were (1) to evaluate the performance of SMA asphalt under the stresses of heavy truck loadings, and (2) to compare the performance of SMA to the performance of conventional GDOT mixes.

In 1991, various combinations of SMA and standard mixes were placed in a 2.5-mile, high traffic volume test section on Interstate 85 northeast of Atlanta. SMA was evaluated as both an intermediate and surface course. The location on I-85 in northeast Georgia was selected due to its average daily traffic (ADT) of 35,000, including 40% trucks. This traffic roughly equals 2 million equivalent single axle loads (ESALs) per year.[1] Bradely et.al. (2004) studied Utilization of waste fibres in stone matrix asphalt mixtures. They used carpet, tire and polyester fibres to improve the strength and stability of mixture compared to cellulose fibre.

They found no difference in moisture susceptibility and permanent deformation in SMA mix containing waste fibres as compared to SMA mix containing cellulose or mineral fibre. Kamaraj C., G. Kumar, G. Sharma, P.K. Jain and K.V. Babu (2004) carried laboratory study using natural rubber powder with 80/100 bitumen in SMA by wet process as well as dense graded bituminous mix with cellulose fibre and stone dust and lime stone as filler and found its suitability as SMA mix through various tests.

Punith V.S., Sridhar R., Bose Sunil, Kumar K.K., Veeraragavan A (2004) did a comparative study of SMA with asphalt concrete mix utilizing reclaimed polythene in the form of LDPE carry bags as stabilizing agent (3 mm size and 0.4%) .The test results indicated that the mix properties of both SMA and AC mixture are getting enhanced by the addition of reclaimed polythene as stabilizer showing better rut resistance, resistance to moisture damage, rutting, creep and aging.[7] ~ 15 ~ Muniandy R., Huat, B.B.K. (2006) used Cellulose oil palm fiber (COPF) and found fibermodified binder showed improved rheological properties when cellulose fibers were preblended in PG64-22 binder with fiber proportions of 0.2%,0.4%,0.6%,0.8 %and 1.0% by weight of aggregates. It showed that the PG64-22 binder can be modified and raised to PG70- 22 grade. The Cellulose oil palm fiber (COPF) was found to improve the diameteral fatigue performance of SMA deign mix. The fatigue life increased to a maximum at a fiber content of about 0.6%, whilst the tensile stress and stiffness also showed a similar trend in performance. The initial strains of the mix were lowest at a fiber content of 0.6%.

Kumar Pawan, Chandra Satish and Bose Sunil (2007) tried to use an indigenous fiber in SMA Mix by taking low viscosity binder coated jute fiber instead of the traditionally used fibers and compared the result with the imported cellulose fiber, using 60/70 grade bitumen and found optimum fiber percentage as 0.3% of the mixture. Jute fiber showed equivalent results to imported patented fibers as indicated by Marshall stability test, permanent deformation test and fatigue life test. Aging index of the mix prepared with jute fiber showed better result than patented fiber.[12]In the 1980's federal and state highway officials in the United States recognized the need to design stiffer, more rut resistant pavements. As a result, American professionals participated in the European Asphalt Study Tour in 1990, where SMA pavements were investigated. This was the first concerted effort to figure out how to use SMA.[14] The objectives of GDOT's first SMA research project, No. 9102, were (1) to evaluate the performance of SMA asphalt under the stresses of heavy truck loadings, and (2) to compare the performance of SMA to the performance of conventional GDOT mixes. In 1991, various combinations of SMA and standard mixes were placed in a 2.5-mile, high traffic volume test section on Interstate 85 northeast of Atlanta. SMA was evaluated as both an intermediate and surface course. The location on I-85 in northeast Georgia was selected due to its average daily traffic (ADT) of 35,000, including 40% trucks.

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3. Materials

The main issue in our country is rutting, which is caused by big axle loads, low speeds, and numerous start/stop spots. As a result, the SMA is implemented. Because of the crystalline structure of this SMA, the load is transmitted directly by coarse aggregate, resulting in extended durability and enhanced serviceability. The SMA mix was established in accordance with the Indian Road Congress (IRC SP 79: 2008). As stabilizing additives in SMA, fibers or polymers are now commonly employed. Polymers are divided into five classes, each of which has its own classification system.

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 belongings of the sums are embodied 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"**

Filler

"Filler is the material that passes through a 0.075 mm sieve. Fillers include rock dust, Portland cement, and hydrated lime. Filler accounts for 8 to 12 percent of the total aggregates in the mixture. The filler acts as a stiffener for the rich binder, allowing the mastic to keep its shape. Filler has a specific gravity of 2.32.

Bitumen

As a binder, VG 30 bitumen was employed. This binder aids in the covering of aggregates and additives with a thick layer. The bitumen for the experiments was purchased from HPCL in Visakhapatnam, Andhra Pradesh, India. The bitumen's physical properties are listed 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"

Additives

"The additives stiffen the mastic and improve the characteristics of the bitumen at low and high temperatures. The material was obtained from Visakhapatnam's Lotus Chemicals. Polyvinyl Chloride (PVC), Polyethylene (PE), and Styrene Butadiene Rubber (SBR) are among the polymers used. In polymerization, the simplest components, known as monomers, are joined together to produce long molecular chains known as 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 = 2.60N/mm^2

Density = 1.38g/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.

4. Methods

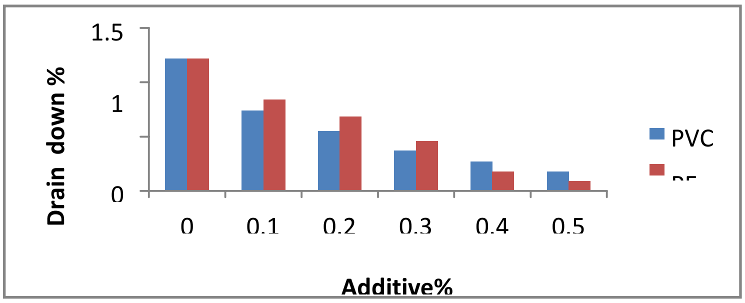
Using these materials SMA mixtures are prepared, analysis is carried out by drain down and marshal methods.

Drain down test

SMA mixture drain down should not exceed 0.3 percent of the total weight of the mixture (AASHTO T305). For SMA mixtures, the drain down test is more important than for ordinary dense-graded mixtures. For modified and unmodified samples, a sample of 1000gm aggregates and 7% bitumen is obtained. The Optimum Additive Content (OAC) is calculated using the Drain down test.

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

The performance of modified and unmodified samples differs in certain ways. The drain down in the unaltered scenario is 1.22 percent, which indicates it is (> 0.3 percent) and so unsuitable. The sample is incremented in proper proportionate of additive to regulate the drain down in order to acquire the appropriate percentage of additive. The additive content in the samples ranges from 0.1 to 0.5 percent. Because the OAC is less than 0.3 percent (AASHTO T305) at 0.4 percent, it was chosen as the best addition for polyvinyl chloride and polyethylene. Figure 2", illustrates the drain down values.

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

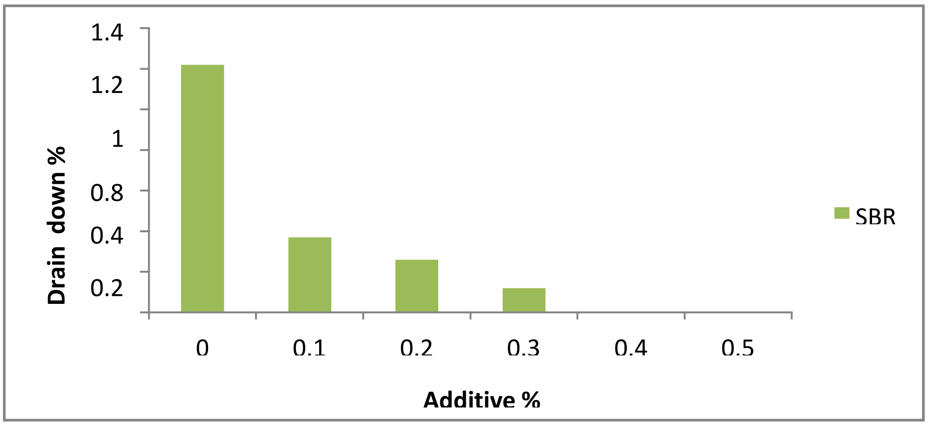


Fig. 3. Variation of Drain down with Styrene Butadiene Rubber

"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 inFig.3.

Marshall Method

Marshall Mix Designs comprises 1200g of aggregate consisting of various aggregate fractions, which was pre-heated to 175-190°C as previously calculated. The plain/modified bitumen was heated to 121-138°C, and the first trial bitumen content was added to a prepared steel bowl. At a temperature of around 154°C, the mixture was completely combined. In a preheated Marshall mould, the mixture was compressed by blowing 50 times on each face of the specimen.

Bitumen concentration of 5.5 percent, 6 percent, 6.5 percent, and 7 percent weight of dry mix were used to make the specimens. SMA13mm grading was used to create the bituminous mixture for the Marshall Test samples, 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"

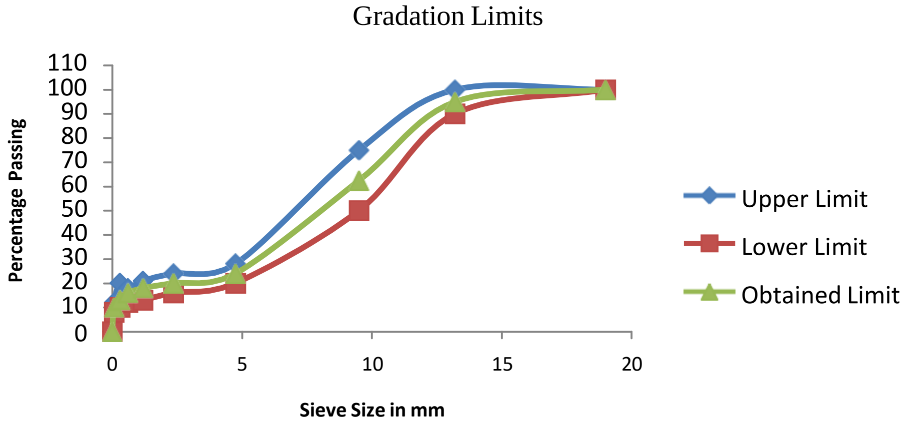


Fig. 4. Gradation Curve for SMA13mm IRC-SP: 79-2008

5. Analysis & Results

To evaluate the stability and flow parameters, "the Marshall Stability test was performed on the prepared specimens according to ASTM D 1559. The Marshall Test parameters were determined and shown.

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"

For various bitumen proportions, graphs are drawn with the Marshall test characteristics along the Y-axis and bitumen content along the X-axis in the Fig.5-9.

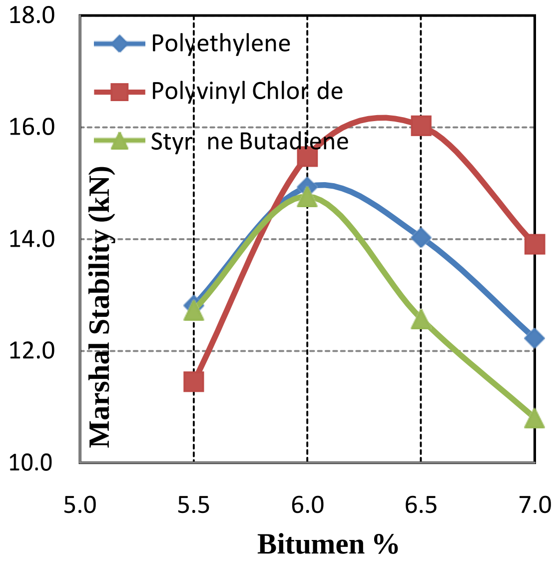
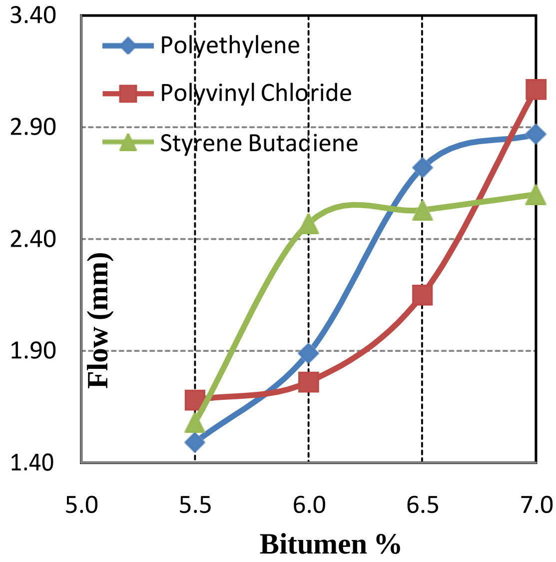


Fig. 5. Marshall Stability Vs Bitumen content



"**Fig. 6.** Flow Vs Bitumen content"

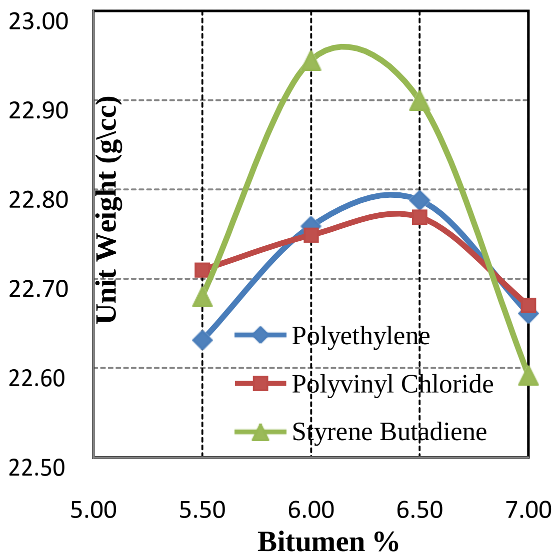


Fig. 7. Unit weight Vs Bitumen content

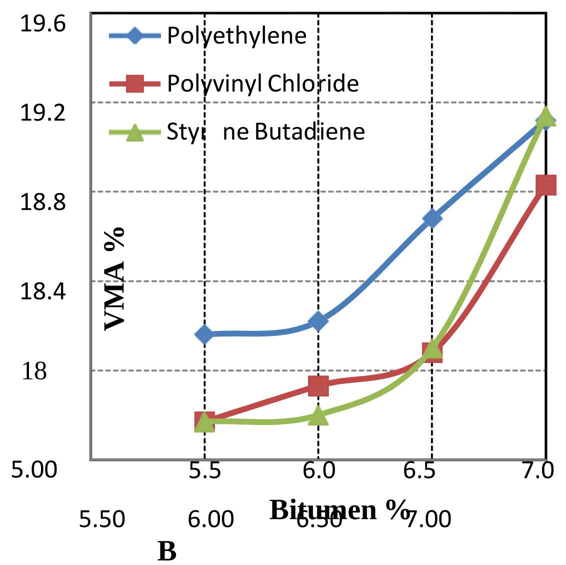


Fig. 8. Voids in Mineral Aggregate Vs Bitumen content

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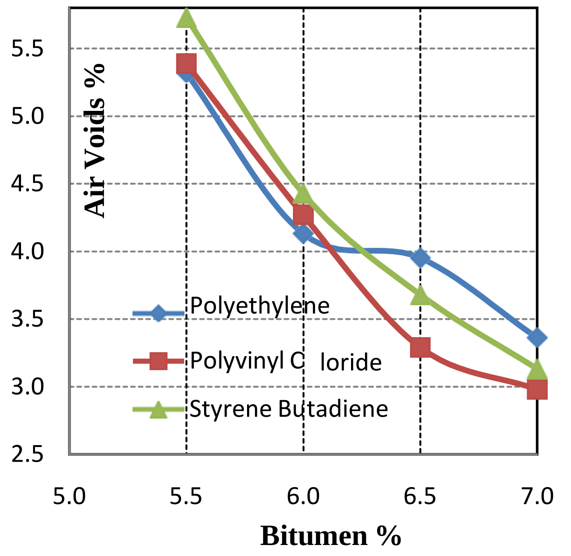

Fig. 9. Volume of Air Voids Vs Bitumen content

Goods such in place of Bulk Density, "Theoretical Density, Volume of Air Voids, Volume of Bitumen, VMA, VFB, Marshall Stability, and Flow values were studied using the aforementioned graphs for different additives in mix with variable are shown in Fig 5 to 9. All of these characteristics are indicative of how well a bituminous concrete mix performs in the field.

6. Conclusions

The following findings are reached based on observations and study of Drain down Test and Marshall Test attributes. At 0.4 percent (PVC) content, the Marshall Stability value reaches a maximum of 16.03kN, which is higher than SBR and PE. At 5.5 percent bitumen concentration, the bulk density is found to be the highest at 2.420 g/cc for (PE). The use of bitumen also results in a decrease in Air Voids, which is necessary for the pavement's strength and service life, as well as an increase in Flow and VFB. Bitumen drainage is lowered by 0.4 percent (PVC, PE) and 2 percent (PVC, PE) in the Drain down test (SBR). At 4% Air Voids, the best bitumen content is 6.27 percent (PE), 6.24 percent (SBR), and 6.11 percent" (SBR) (PVC).

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