A Study on Recycling Of Crumb Rubber and Low Density Polyethylene Blend on Stone Matrix Asphalt

Ganapathi Malarvizhi[1*], N.Senthil[1] and C.Kamaraj[2]

[1] Division Of Transportation Engineering, Department of Civil Engineering (CEG), Anna University, Chennai, India.
[2] Transportation Planning and Environment Division, CSIR-Central Road Research Institute, New Delhi, India.

Abstract- Stone Matrix Asphalt (SMA) is hot mixture asphalt consisting of a coarse aggregate skeleton and a higher binder content mortar. To minimize the pollution from waste tires and to improve the properties of SMA, Recycled Crumb Rubber (CR) plus Low Density Polyethylene (LDPE) flakes were used as additive using dry process as a research study. This research investigated the feasibility of using 15% and 30% CR+LDPE by weight of bitumen with 60/70 penetration grade bitumen for SMA. SMA mixture meeting the desired volumetric properties could be produced using the combination of 30% (Combined Combination with 30% CR and 70 % LDPE) by weight of the bitumen). No fiber was needed to prevent drain down when this rubber blend was used. Based on results of indirect tensile tests, unconfined compression test and variance analysis, it was observed that the addition of recycled CR+ LDPE using dry process could improve engineering properties of SMA mixtures, and the rubber content has a significant effect on long term performance.

Index Terms- Recycled crumb rubber, low density poly-ethylene flakes, dry process, properties.

I. Introduction

With the rapid development of the automobile industry and higher standard of living of people in India, the quantity of autos increased sharply, India is facing the environmental problem related to the disposal of large-scale waste tyres. The world generates about 1.5 billion waste tyres annually, 40 percent of them in emerging markets such as China, India, South Africa, South East Asia, South America and Eastern Europe. With more than 33 million vehicles added to the Indian Roads in the last three years. Now, In accordance with the statistic data, 80 million scrap tires were produced in 2002, and with 12% of growth rate every year, the total number of abandoned tires will be expected to reach 120 million in 2005 and 200 million in 2010[1]. How to deal with the huge number of waste tyres has become an urgent problem of environment in India.

The disposal of waste tyres in the world primarily has three ways to deal with such as landfill, burning and recycling. Recycled tire rubber applied to pavement may be the best way to reduce waste tyres in large quantities and, at the same time, improve some engineering properties of asphalt mixtures. Crumb rubber can be incorporate by a wet process or dry process. Wet process refers to modification of asphalt cement binder with 5-25wt% of fine tyre rubber Crumb Modifier (CRM) at an elevated temperature. The dry process includes mixing the rubber particles with aggregates prior to addition to asphalt. The main differences between the two processes consist in rubber particle size, rubber amount, rubber function, and incorporation facility [3]. Although the dry process presents some advantages in relation to the wet process, mainly concerning the costs involved and to the higher amount of rubber to be used, the research all over the world have concentrated mainly on the wet process. This choice may be explained by the irregular performance of some experiment sections built with the dry process, unlike the wet process, which has presented more satisfactory results [4].

Stone Matrix Asphalt (SMA) is hot mixture asphalt consisting of a coarse aggregate skeleton and a high binder content mortar. SMA was developed in Germany during the mid-1960s and it has been used in Europe for more than 20 years to provide better rutting resistance and to resist studied tyre wear [1]. Because of its success in Europe, some States, through the cooperation of the Federal Highway Administration, constructed SMA pavements in the United States in 1991 [2]. Since that time the use of SMA in the US has increased significantly. Japan has also started to use SMA paving mixtures as well with good success [3]. Recently, the Ministry of Communications in Saudi Arabia has introduced SMA in its road specifications. In the year 2006 and 2008, two experimental sections were constructed using both drum mix plant as well as batch mix plant in New Delhi, India [4].

SMA is a gap graded aggregate-asphalt hot mixture that maximizes the asphalt cement content and coarse aggregate fraction. This provides a stable stone-on-stone skeleton that is held together by a rich mixture of asphalt cement, filler, and stabilizing additive. The original purpose of SMA was to provide a mixture that offered maximum resistance to studded tire wear. SMA has also shown high resistance to plastic deformation under heavy traffic loads with high tire pressures, as well as good low temperature properties [2, 5]. The main concept of having a gap gradation of 100% crushed aggregates is to increase pavements through interlock and stone-to-stone contact. This mixture is designed to have 3-4% air voids, and relatively high asphalt content due to the high amount of voids in the mineral aggregate. The mixture contains high filler content (10% passing the 0.075-mm sieve), and typically contains a polymer in the asphalt cement, or fiber (cellulose or mineral) in the mixture to prevent drainage of the asphalt cement. This mixture has a surface appearance similar to that of an open graded friction course; however it has low in-place air voids similar to that of a dense graded HMA.

In this research study, a dry processing of Crumb Rubber (CR) and Low Density Polyethylene (LDPE) blend were used as additive for SMA mixture was investigated. The main purpose of this research was to determine the effects of incorporating CR + LDPE waste on the engineering properties of SMA. The volumetric and mechanical properties of SMA that include various percentages of CR+LDPE were calculated and assessed with laboratory tests. The outcomes were statistically analyzed and determination of the significance at certain confidence limits was performed with single factor variance analysis (ANOVA).

II. Test Materials And Testing Program

2.1 Materials

The materials that have been used in this study are crushed blue granite stone for coarse aggregate and fine aggregate, hydrated lime as mineral filler with SMA13 grading as per Indian specification IRC-SP: 79-2008. Table 1 displays the selected grading of the aggregate and Table 2 shows its properties. The bitumen used for this study was 60/70 penetration grade. The physicochemical properties of the used bitumen are available in Table 3. Table 4 presents the specific gravities of the materials. In this study, the size of CR was below 30 mesh (0.600 mm) and LDPE flakes of 16MA400 grade injection molding grade film was used as additive in SMA mixture, its appearance is shown in Fig.1a-b.

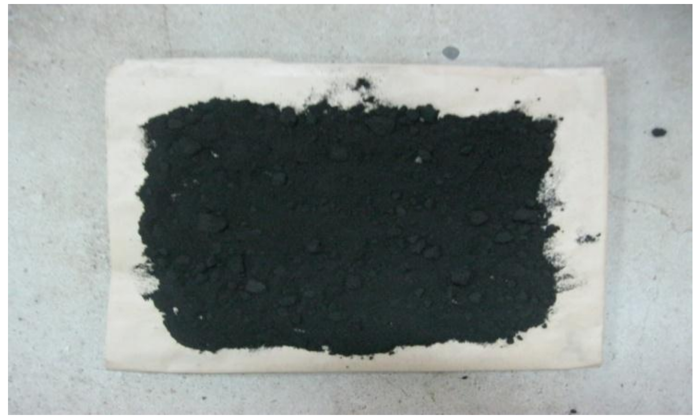

Fig. 1 a: Appearance of crumb rubber powder

Fig. 1 b: Appearance of LDPE flakes

Table 1 Gradations and Gradation Limits used for the study

Sieve Size (mm)	Adopted Gradation	Specification Limits
19	100	100
13.2	98	90 -100
9.5	73	50 – 75
4.75	22	20 -28
2.36	20	16 – 24
1.18	18	13 – 21
0.6	15	12 -18
0.3	13	10 – 20
0.075	9	8 – 12

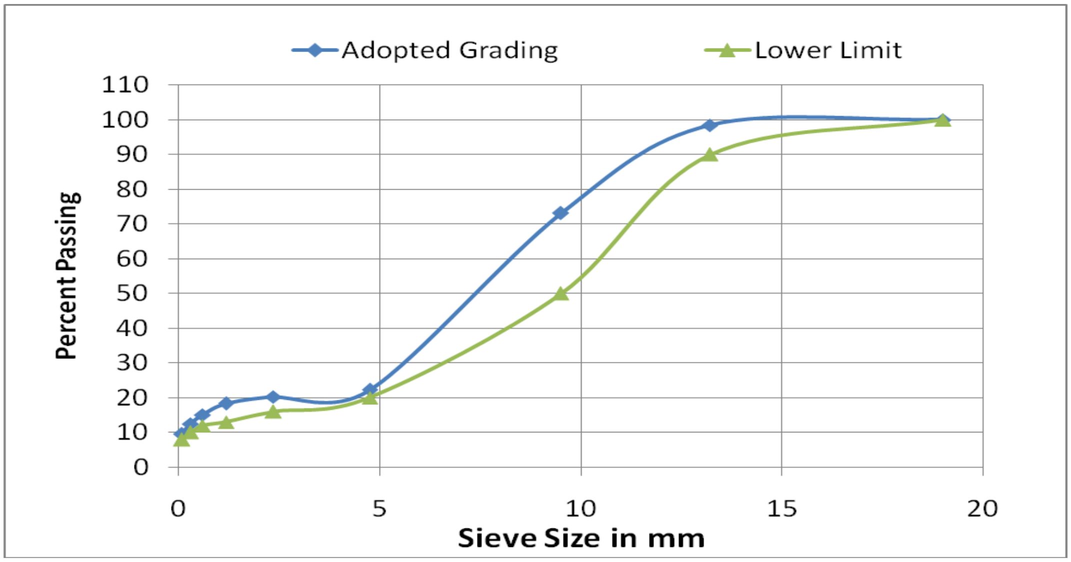

Fig.2: Aggregate gradation curves.

Table 2 Physical properties of crushed aggregate

Property	Test	Method	Specification	Test results
Cleanliness	Grain Size Analysis	IS:2386 (P-1)	< 2% passing 0.075 mm sieve	1%
Particle Shape	Flakiness index Elongation Index	IS:2386 (P-1)	<12% < 18%	10% 15%
Strength	Los Angeles Abrasion Value	IS:2386 (P-4)	< 25%	22%
	Aggregate Impact Value	IS:2386 (P-4)	< 18%	14.7%
Water Absorption	Water Absorption	IS:2386 (P-3)	< 2%	1.7%
Specific gravity	Specific gravity	IS:2386 (P-1)	-	2.85

Table 3 The results of tests performed on bitumen

S.NO	Properties	Test Method	Units	Permissible Values	Test Results
1	Specific Gravity test	IS 1202 - 1978	-	-	1.02
2	Penetration at 25 ^{O}C	IS 1203 - 1978	0.1mm	60 – 70	64
3	Softening Point	IS 1205 - 1978	OC	55	55
4	Ductility	IS 1208 - 1978	cm	Min. 50	76

Table 4 Specific gravities of materials (g/cm^3)

S.NO	Materials	Specific gravity (g/cm^3)
1	Coarse aggregate	2.85
2	Fine aggregate	2.7
3	Bitumen	1.02
4	CR	1.25
5	LDPE	0.95

2.2 Marshal Mix Design

The Marshall Mix design procedure as specified in ASTM D1559 was used in this study. Laboratory mixing and compaction temperature for all mixtures were selected according to viscosity criteria. Two rubber contents were considered (15% and 30% by weight of bitumen) in dry process. In dry process, the additives were blended with the aggregate before adding bitumen. In order to fabricate the samples, the stages were followed:

1) Before adding aggregate to the mixture, it was heated to 200ºC for a period of approximately 2h. The weight of aggregate for each sample was 1100g.
2) The CR+LDPE blends were introduced at the rate of 15% and 30% respectively.
3) After the addition of additive, the blending time of aggregate was prolonged 10-20 s to disperse rubber evenly.
4) The combination of aggregate, bitumen and filler was mixed at a temperature of 160±5 ºC for about 5 min.
5) The bitumen contents used in the mixture was varied at the rate of 5.5%, 6% and 6.5% by weight of aggregate. The selected bitumen was heated to 160 ºC for about 1 h prior to blending with the aggregate.
6) The Marshall compactor was used for the compaction stage of the process with 50 blows applied to both the faces of the sample at 150 ºC.
7) Samples were cooled at room temperature for a period of 12 h before de-molding.
8) The Optimum bitumen Content (OBC) was estimated at which the air voids (V_a), and the minimum voids in mineral aggregates (VMA) are 4 and 17 percent respectively.

2.3 Testing Program

After determining the OBC of each mixture, drain down tests were performed per AASHTO T 305 *determination of drain down characteristics in uncompacted asphalt mixtures*. Drain down was tested by placing the uncompacted mixture in a basket in an oven at the mixing temperature of the binder (162 ◦C) and at 177 ◦C per AASHTO T 305. The drain down was calculated as the percentage of binder that drained out of the basket compared to the original weight of the sample. Drain down was also tested at binder contents exceeding the OBC to determine the stabilizing capacity of fiber. Most states require that the drain down of SMA mixtures not exceed 0.3% by weight of the mixture. The binder contents used in this portion of the study started at 5.5% (by weight of mixture) and increased by 0.5% until a draindown of 0.3% was reached. The stabilizing capacity of fiber was determined as the binder content at which the draindown reached 0.3%.

Moisture susceptibility was conducted by comparing the indirect tensile strength (ITS) of three 100mmdiameter×63.5mmtall specimens conditioned in 60±1 ◦C water for 24 h to the ITS of three specimens, of the same dimensions, dry conditioned at 25±1 ◦C (modified ASTM D 4867). The ITS specimens were compacted to 6–8% air voids with a Marshall hammer. Each specimen was loaded to failure and the following parameters were evaluated:

1. Indirect tensile strength (ITS):

$$ITS = 2P_{max}/\pi td, \quad (1)$$

where *P*max is peak load (N), *t* the average height of specimen (mm) and *d* the diameter of specimen (mm).

1. Tensile strength ratio (TSR):

$$TSR\,(\%) = \frac{ITS_{wet}}{ITS_{dry}} \times 100, \quad (2)$$

The unconfined compression tests were performed using a 15-ton capacity universal testing machine in a room temperature of around 25º C. Test specimens 2.5 inches thick and 4 inches diameter were placed on the lower fixed plate of the testing machine. Load was applied with a uniform rate of 2 mm/min on the circular face of the testing samples until failure occurred. The maximum load to failure was recorded and hence the compressive strength was calculated.

The compressive strength can be calculated using the following expression;

1. Unconfined Compressive strength (UCS):
2.

$$\sigma_c = \frac{4P_{max}}{\pi D^2} \quad (3)$$

where, σ_c = Unconfined Compressive Strength, P_{max} = Maximum applied compressive load , and D = Diameter of the specimen.

III. Results And Discussion

3.1 Bulk Specific Gravity

The volumetric properties of the samples were determined and the test results of the samples with various combinations and relations were presented below. The Bulk Density for the various combinations of the Crumb Rubber and LDPE as additive in the SMA Mix was shown in the Table 5 and Fig.2 (a) and 2(b). The Bulk Density varies from 2.31 to 2.36 for the various combinations of the Crumb Rubber and LDPE.

Table 5 Relationship between Bulk Density Vs Binder Content

Additive	15%			30%		
Binder Content, %	5.5	6	6.5	5.5	6	6.5
Control	2.341	2.328	2.315	2.341	2.328	2.315
70C+ 30L	2.354	2.341	2.328	2.351	2.337	2.329
50C +50L	2.360	2.345	2.332	2.358	2.346	2.332
30C +70L	2.360	2.346	2.335	2.360	2.347	2.335

Note: 70C = 70% of Crumb Rubber by weight of bitumen in SMA Mix; 30L = 30% of LDPE by weight of bitumen in SMA Mix.

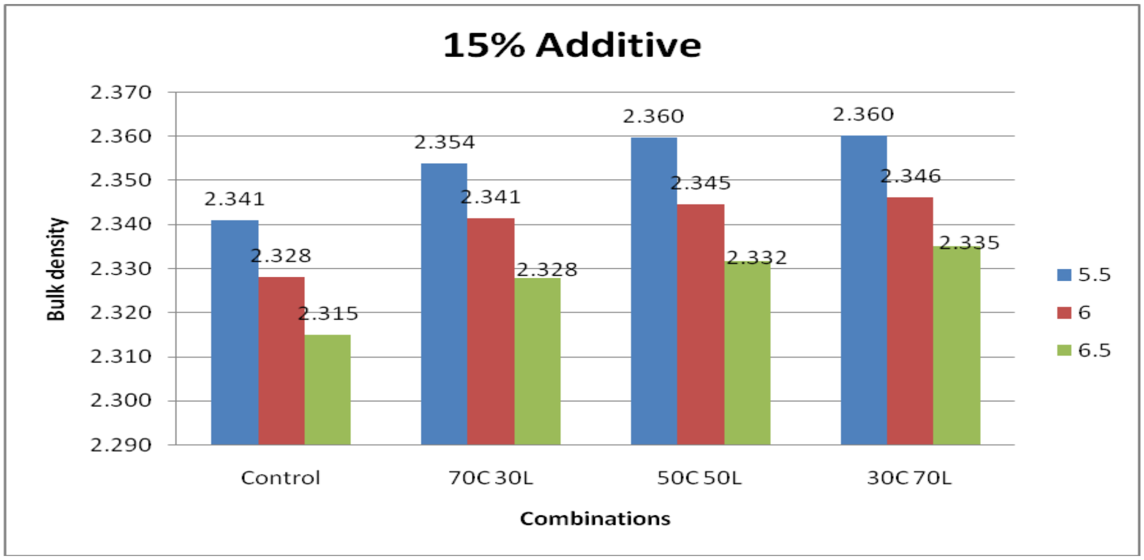

Fig.2(a) : Bulk Density for SMA with 15% Additive

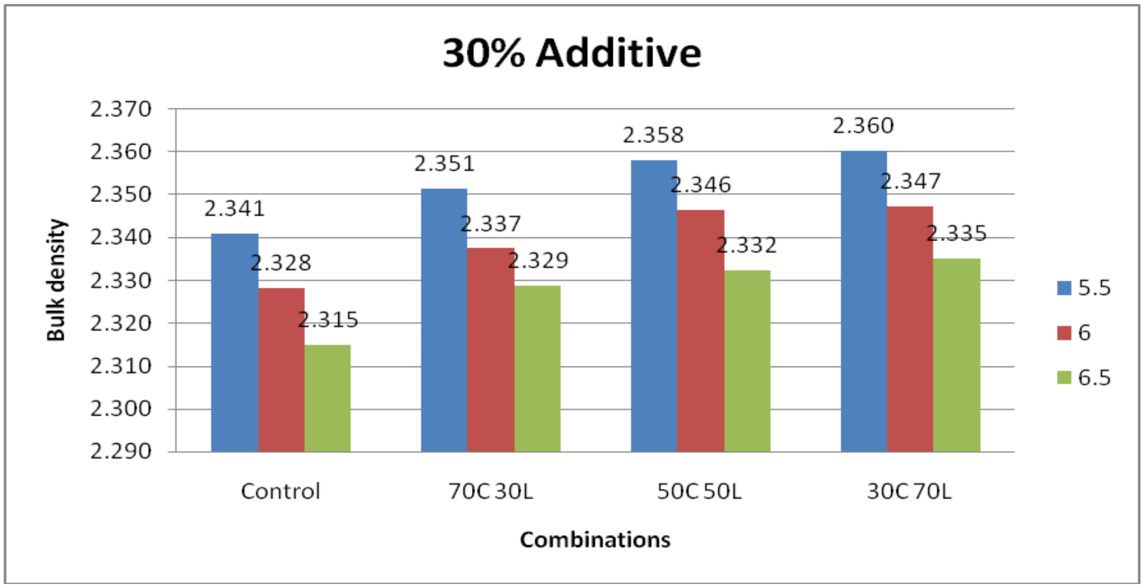

Fig.2(b): Bulk Density for SMA with 30% Additive

3.2 Air Voids

The air voids V_A is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. The variation of V_A with various combinations is shown in the Table 6, Fig. 3(a) and 3(b). The Air voids vary from 3.8% - 4.8 % for the various dosages of the Crumb Rubber and LDPE. As per specification requirement, 3% - 5 % Air Voids is given as the Mix Design parameters.

Table 6 Relationship between Air Voids Vs Binder Content

Additive	**15%**			**30%**		
Binder Content, %	5.5	6	6.5	5.5	6	6.5
Control	5.22	4.97	4.74	5.22	4.97	4.74
70C +30L	4.70	4.43	4.20	4.80	4.59	4.16
50C +50L	4.46	4.30	4.04	4.53	4.23	4.02
30C +70L	4.45	4.23	3.71	4.45	4.19	3.90

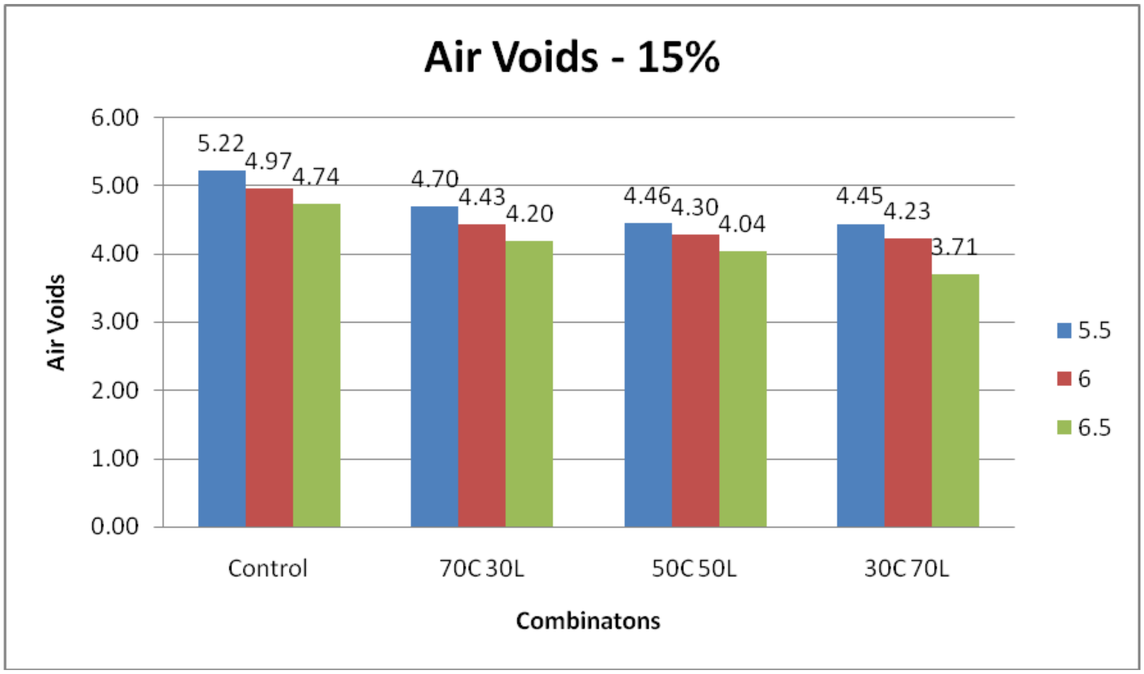

Fig.3(a): Relationship between Air Voids and Binder Content for SMA with 15% Additive

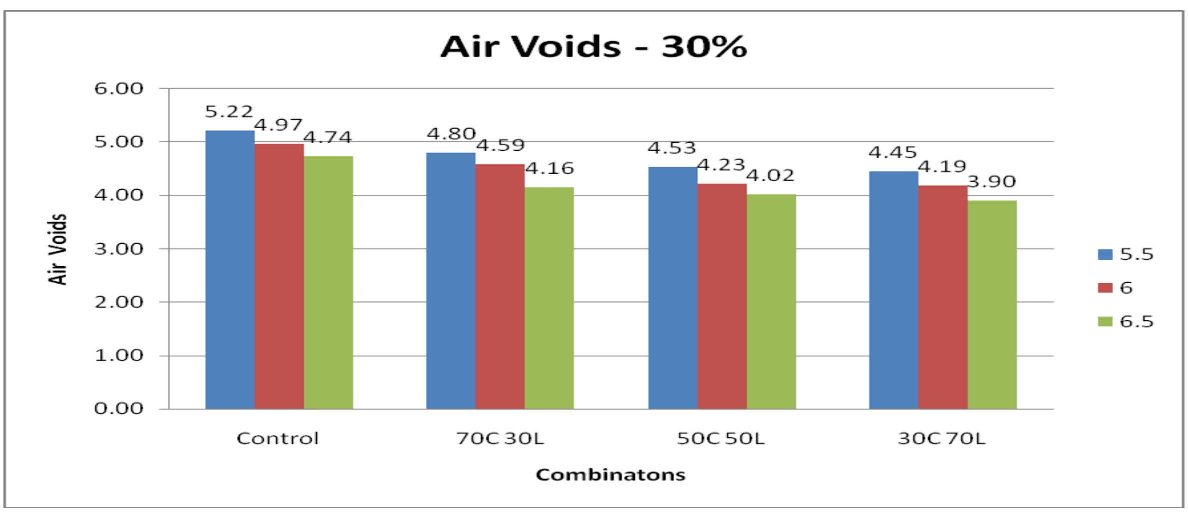

Fig.3(b): Relationship between Air Voids and Binder Content for SMA with 30% Additive

3.3 Voids in Mineral Aggregates

Voids in Mineral Aggregaes can defined as the intergranular space occupied by the asphalt and air in a compacted asphalt mixture. An increase in the dust proportion will generally decrease the VMA. The variation of VMA for the various combinations of the Crumb Rubber and LDPE as additive in the SMA mixes were shown in the Table 7, Fig. 4(a) and 4(b). The Air voids vary from 17 % to 20 % for the various dosages of the Crumb Rubber and LDPE. As per specification requirement, a minimum of 17 % of Voids in Mineral Aggregates has to be present in the mix as the Mix Design parameters.

Table 7 Relationship between VMA Vs Binder Content

Additive	15%			30%		
Bitumen Content, %	5.5	6	6.5	5.5	6	6.5
Control	17.85	18.68	19.53	17.85	18.68	19.53
70C+ 30L	17.40	18.22	19.07	17.48	18.36	19.04
50C+ 50L	17.19	18.10	18.94	17.25	18.04	18.92
30C+ 70L	17.18	18.05	18.66	17.17	18.02	18.82

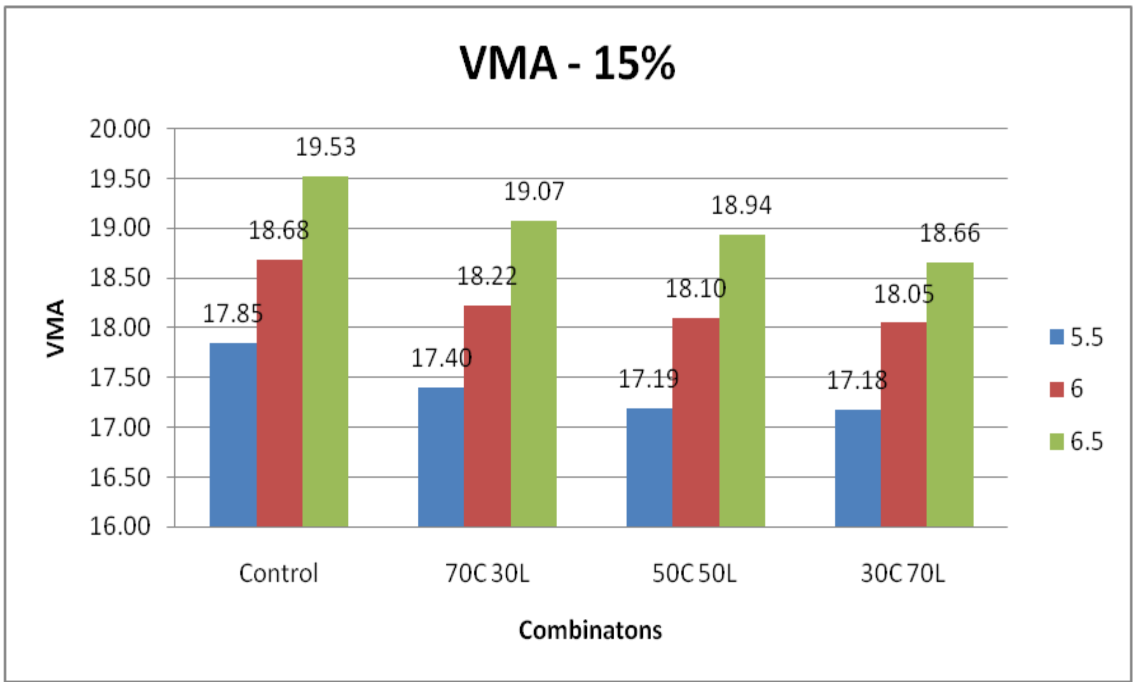

Fig.4(a): Relationship between VMA and Binder Content for SMA with 15% Additive

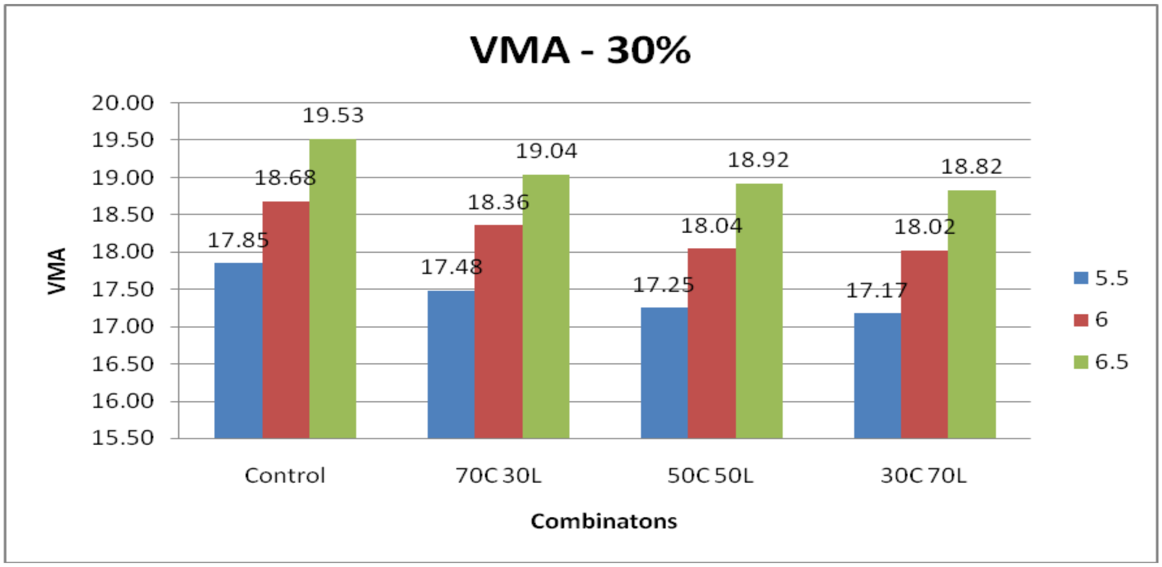

Fig.4(b): Relationship between VMA and Binder Content for SMA with 30% Additive

3.4 Voids in Coarse Aggregates

The variation of Voids in the Coarse Aggregates for Mix with different dosgae of additive in the SMA mixes were shown the Table 8, Figure 5(a) and 5(b). The VCA_{MIX} vary from 34 % to 36 % for the various dosages of the Crumb Rubber and LDPE. The Voids in the Coarse Aggregates under Dry Rodded Condition is found to be 48%. As per specification requirement, Voids in Mineral Aggregates for Mix is less than the Voids in Mineral Aggregates under Dry Rodded Condition as the Design Parameter. This shows the presence of the better Stone on stone contact in the mix.

Table 8 Relationship between VCA Vs Binder Content

Additive	**15%**			**30%**		
Binder Content, %	5.5	6	6.5	5.5	6	6.5
Control	35.02	35.37	35.74	35.02	35.37	35.74
70C+ 30L	34.66	35.01	35.38	34.73	35.11	35.35
50C +50L	34.49	34.91	35.27	34.54	34.86	35.26
30C+ 70L	34.49	34.87	35.05	34.48	34.84	35.18

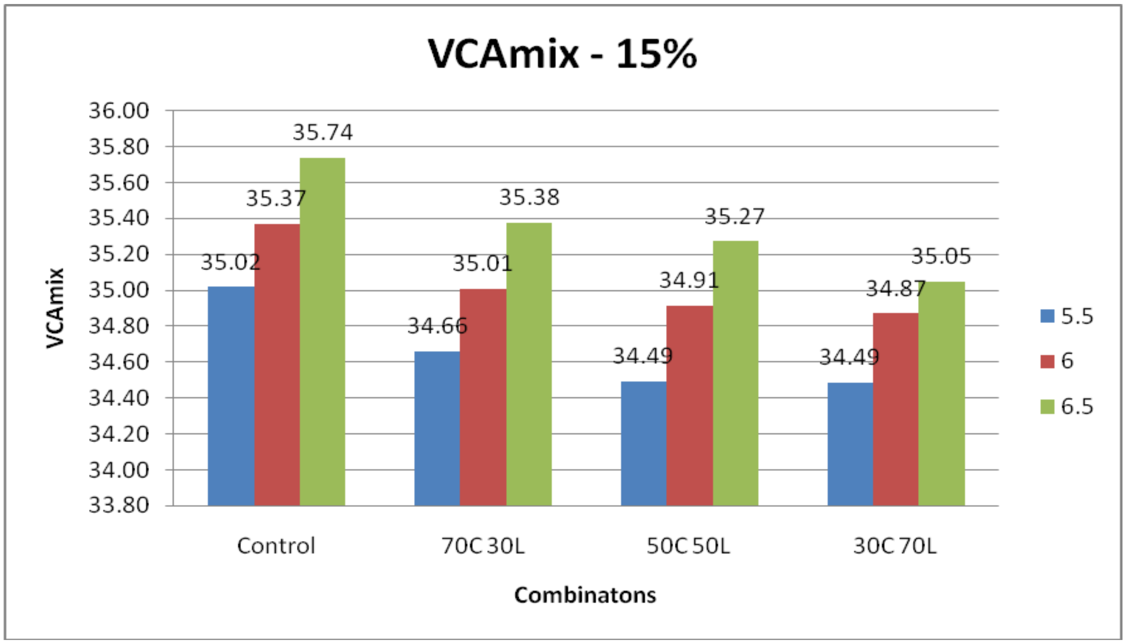

Fig 5(a): Relationship between VCA_{MIX} and Binder Content for SMA with 15% Additive

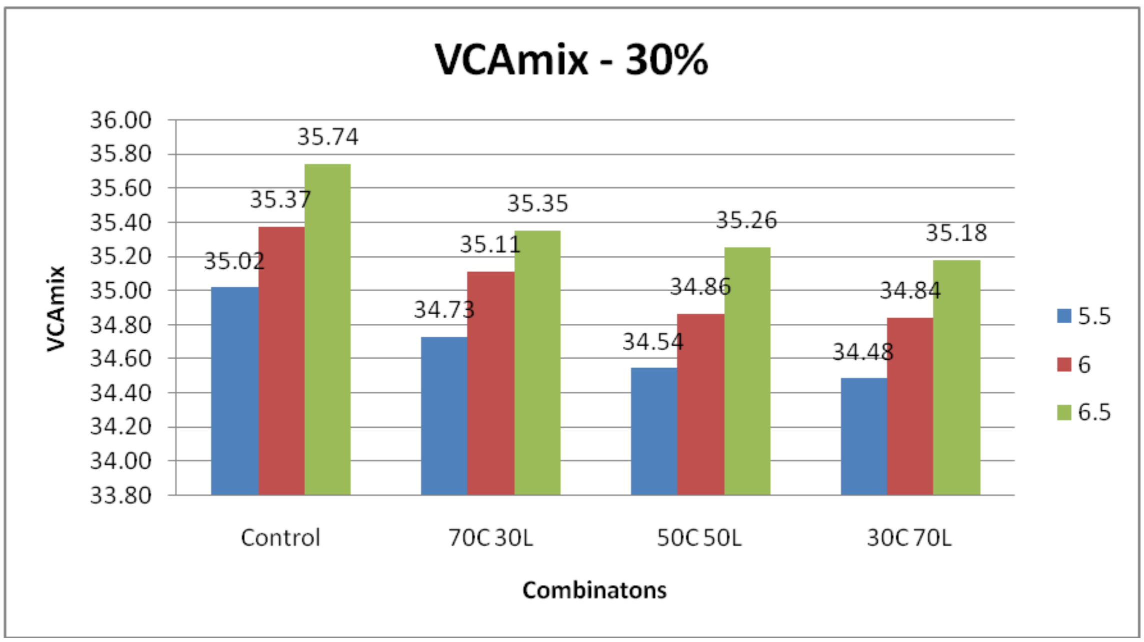

Fig 5(b): Relationship between VCA_{MIX} and Binder Content for SMA with 30% Additive

3.5 Tensile Strength Ratio

The variation of Indirect Tensile Strength Ratio for Mix with different dosgae of the Crumb Rubber and LDPE as additive in the SMA mixes were shown in the Table 9, Fig.6(a) and 6(b). The TSR vary from 85% to 94% for the various dosages of the Crumb Rubber and LDPE. As per specification requirement, Indirect Tensile Ratio for the Mix should be more than 85% as the Design parameters. This shows the presence of the resistance to cracking and moisture damage.

Table 9 Tensile Strength Ratio (%)

Additive	15%			30%		
Bitumen Content, %	5.5	6	6.5	5.5	6	6.5
Control	85	85	86	85	85	86
70C+ 30L	89	87	90	87	86	90
50C+ 50L	89	90	84	85	92	90
30C+ 70L	89	86	91	88	87	94

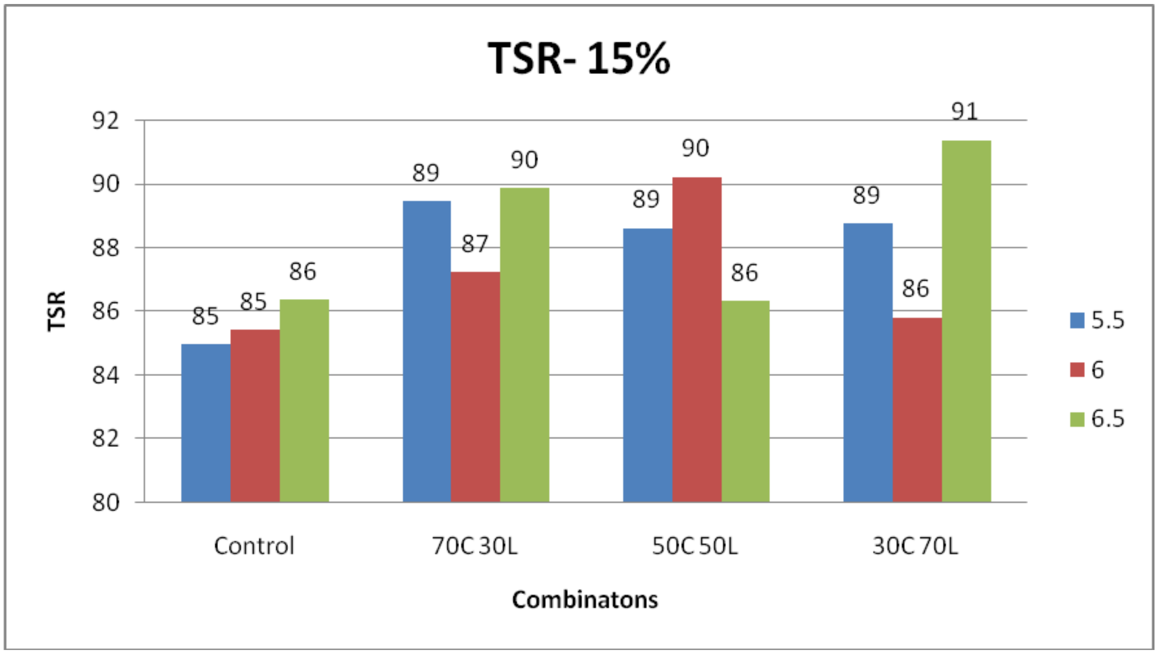

Fig. 6(a): TSR for SMA Mixes with 15% Additive

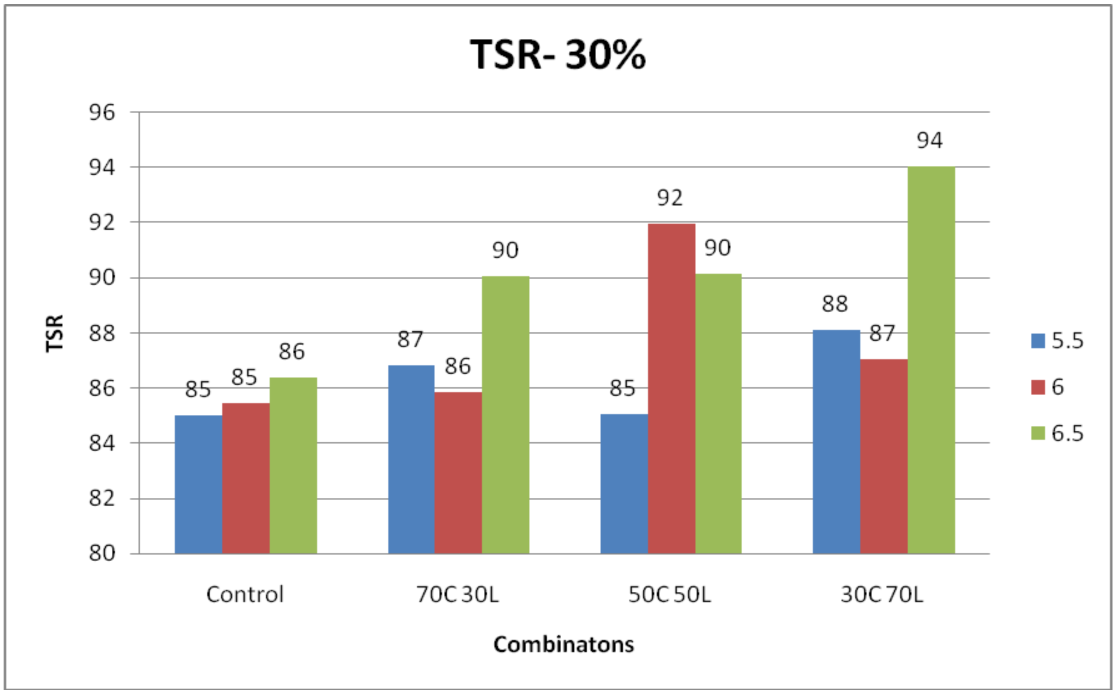

Fig.6(b): TSR for SMA Mixes with 30% Additive

3.6 Drain Down Sensitivity

The variation of Drain down Sensitivity for the sample under uncontrolled condition is given in the Table 10, Fig. 7(a) and 7(b). The Drain down values was in the range of 0.04% to 0.17% by weight of the mix. As per specification requirement, drain down can be Maximum of 0.3% as the Mix Design parameters. This shows that the Crumb Rubber and LDPE as additive (Combined) sustains the drain down and stabilizes the SMA Mix.

Table 10 Drain Down Sensitivity

Additive	**15%**			**30%**		
Binder Content, %	5.5	6	6.5	5.5	6	6.5
Control	0.13	0.16	0.17	0.13	0.16	0.17
70C+ 30L	0.09	0.10	0.07	0.07	0.09	0.09
50C+ 50L	0.11	0.07	0.06	0.09	0.06	0.04
30C +70L	0.07	0.05	0.07	0.09	0.07	0.05

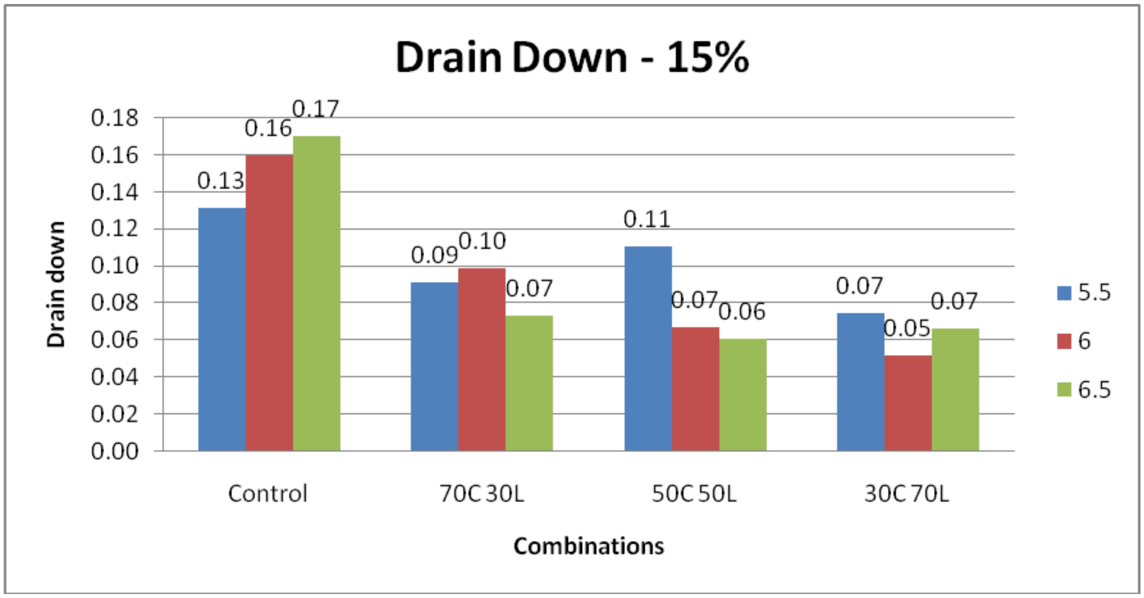

Fig. 7(a):Drain Down for SMA Mixes with 15% Additive

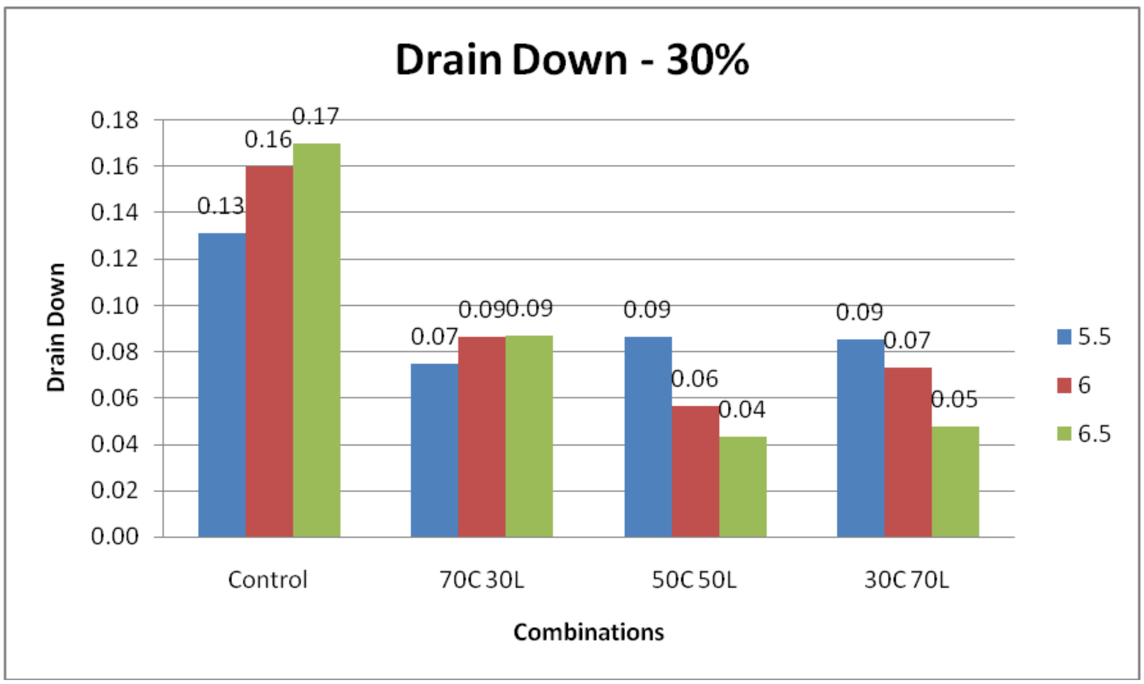

Fig.7(b) :Drain down for SMA Mixes with 30% Additive3.7 Compressive Strength

The variation of Compressive Strength for Mix with different dosgae of the Crumb Rubber and LDPE as additive in the SMA mixes were shown in the Table 11, Fig. 8(a) and 8(b). The Compressive Strength for Mix varies from 410 Kg/cm^2 to 860 Kg/cm^2 for the various combinations.

Table 11 Unconfined Compressive Strength (kg/cm^2)

Additive	**15%**			**30%**		
Binder Content, %	**5.5**	**6**	**6.5**	**5.5**	**6**	**6.5**
Control	1680	1952	2080	1680	1952	2080
70C+ 30L	2160	2800	2240	2080	2800	2720
50C+ 50L	2000	3040	2880	2720	3040	3520
30C+ 70L	3200	2640	2800	2160	2640	4000

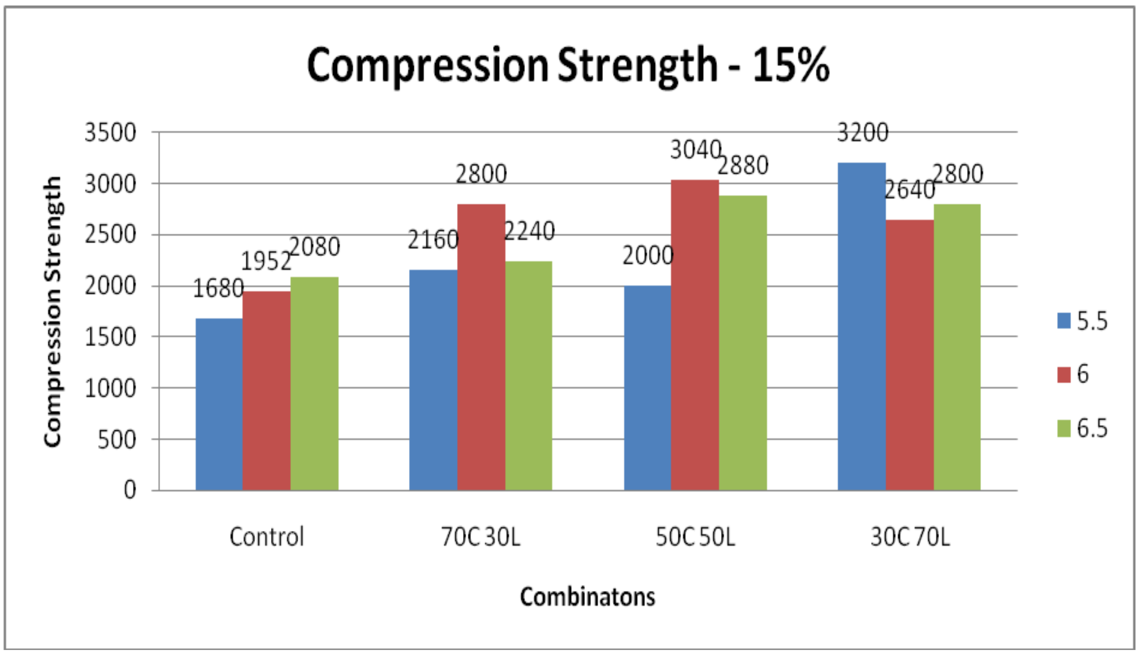

Fig.8(a) Relationship between Compressive Strength Vs Binder content for SMA with 15% Additive

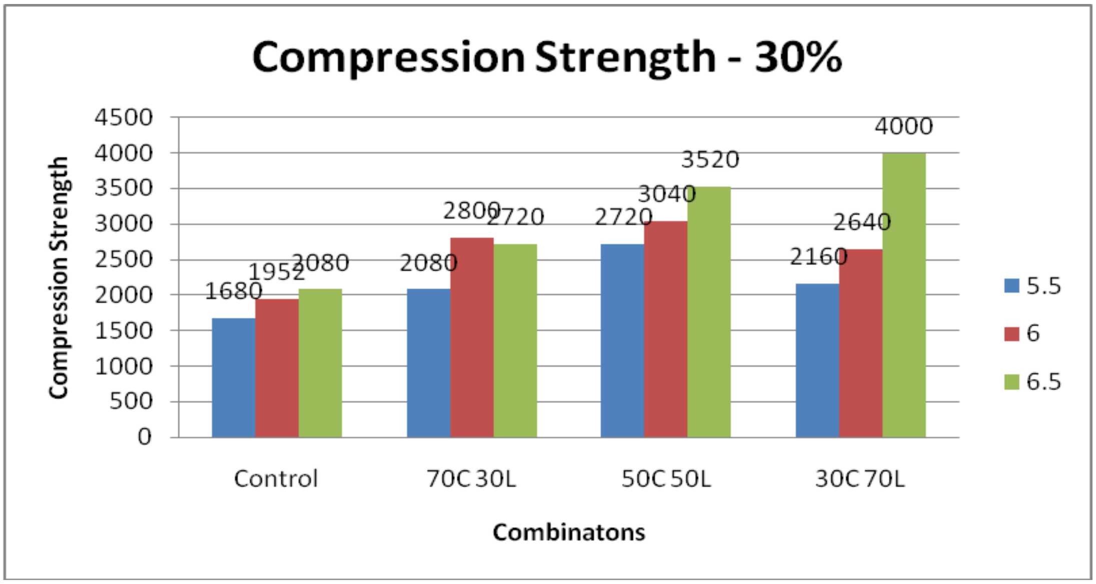

Fig. 8(b) :Relationship between Compressive Strength Vs Bindedr Content for SMA with 30% Additive

3.8 Properties of SMA Mixture at Optimum Binder Content

OBC for SMA Mix has been estimated considering the Air Voids (V_a), Minimum Voids in Mineral Aggregates (VMA) and Tensile Strength Ratio (TSR) respectively. Volumetric analyses of SMA mixtures at various binder contents are presented in the Table 12.

Table 12 Volumetric Properties of SMA Mixtures at OBC

Properties	Value Obtained
CR+LDPE Additive by Weight of bitumen, %	30% (30C+ 70L) Combination
Optimum Binder Content by Weight of Aggregate, %	6.50
Optimum Binder Content by Weight of Mix, %	6.10
Bulk Specific Gravity of Compacted Mixture, G_{mb}	2.34
Air Voids, %	3.90
VMA, %	18.82
VCA_{DRC}, %	48
VCA_{MIX}, %	35.18
TSR, %	94
Drain Down, %	0.05
Compressive Strength, kg/cm^2	860

IV. ANOVA Analysis

A NOVA analysis was conducted to determine the effect of CR+LDPE on properties of SMA. In the Single- factor tests of ANOVA, rubber content was chosen as factor and compressive strength were response respectively. The results of ANOVA analysis are summarized in Table 13. It can be seen from Table 13, the case of variance analysis of 15% additive of UCS, value of F(1.171950) is less than $F_{critical}$ (4.256), it can be concluded that rubber content has no significant effect on the UCS. In case of variance analysis of 30% additive of UCS, value of F(8.99116) is bigger than $F_{critical}$ (4.256), it can be concluded that rubber content has significant effect on the UCS. Therefore, the SMA mixture containing 30% additive has the best performance.

Table 13
Results of ANOVA analysis of Unconfined compressive strength test (α=0.05)

	SS	d_f	MS	F	$F_{critical}$	p-value
Source of variance (15% additive)						
Between	253824	2	126912	1.17194	4.256	0.8824
Within	974624	9	108292			
Total	1228448	11				
Source of Variance (30% additive)						
Between	1693184	2	846592	8.99116	4.256	0.8856
Within	847424	9	94158			
Total	2540608	11				

V. Conclusion and Recommendations

From the experimental investigations the following conclusions are drawn.

- The Tensile strength Ratio values are found to be in the range 85 - 94 % which is more than 85 % as specified for a SMA mixture.
- The Compressive strength values are found to be in the range 1600 kg/cm^2 - 4000 kg/cm^2. The Compressive strength of SMA Mix with Crumb Rubber and LDPE blend as additive improved the longevity from the Compressive strength value.
- The SMA mixes designed with available aggregates showed good stone on stone contact ($VCA_{DRC} < VCA_{MIX}$).
- The 17% Voids in Mineral aggregate and 3 - 5% air voids in the mix were fulfilled as SMA Mix design criteria.
- The Drain down values was in the range of 0.04% to 0.17% by weight of the mix.
- Based on the above performance, Combined Combination of Crumb Rubber and LDPE could be used as stabilizing additive in the form of dry processing showed without affecting the design criteria of SMA mixture.
- The optimum dosage of the Additive was found to be 30 % (Combined Combination with 30% Crumb Rubber and 70 % LDPE) by weight of the bitumen.
- From the results of ANOVA analysis of UCS, 30% rubber content by weight of bitumen has significant effect on best performance.
- The long-term performance of recycled CR+LDPE blend on SMA mixture using dry process will need to be further studied.

References

[1] Chui-Te Chiu , Li-Cheng Lu (2006), "A laboratory study on stone matrix asphalt using ground tire rubber " Chung Hua University, Taiwan.

[2] Punith V.S et.al (2004) "Comparative studies on the behaviour of SMA and AC utilizing reclaimed polyethylene" HRB, Pg No 61-76 Volume No 71 Dec 2004

[3] Brown E R, Haddock JE, Mallick RB, Lynn AT,(1977) "Development of a mixture design procedure for stone matrix asphalt (SMA)" , NCAT Report No. 97-3.

[4] Yongjie Xue et al.,(2007) "Utilization of municipal solid waste incineration ash in stone mastic asphalt Mixture" Wuhan University of Technology, China.

[5] Brown ER, Haddock JE, Mallick RB, Bukowski J.(1997) " Performance of stone matrix asphalt (sma) in the US", AAPT vol. 66, 1997.

[6] Brown, E.R., Mallick, R.B., Haddock, J.E., and Bukowski, J. 1997. Performance of stone matrix asphalt (SMA) mixtures in the United States. National Center for Asphalt Technology, Auburn University, Auburn, Ala. Report no. 97–1.

[7] Kandhal, P.S., Roberts, F.L., Brown, E.R., Lee, D.-Y., and Kennedy, T.W. 1996. Hot mix asphalt materials mixture design and construction. NAPA Education Foundation, Lanham, Md.

[8] C.Kamaraj, G.Kumar, G.Sharma, P.K.Jain And K.V.Babu "Laboratory Studies On The Behaviour Of Stone Matrix Asphalt Vis-À-Vis Dense Graded Bituminous Mixes Using Natural Rubber Powder (Wet Process)', Highway Research Bulletin, No 71, December 2004.

[9] C.Kamaraj, P.K.Jain, V.K.Sood And P.K.Sikdar " Design Of Stone Matrix Asphalt Using Different Stabilizing Additives" Journal of Indian Roads Congress, April 2006, Vol-67(1).

[10] B.M.Sharma and C.Kamaraj, "Construction And Performance Evaluation Of Experimental Sections Laid On Urban Roads Using Stone Matrix Asphalt Mixtures", 23rd ARRB Conference – Research Partnering with Practitioners, Adelaide Australia, 2008.

[11] Brown ER, Haddock JE et al., J.(1997) " Performance of stone matrix asphalt (SMA) in the US", AAPT vol. 66, 1997.

[12] Zhu Horan, Yang Jun, Cong Ling, Cui Juan and Wan Jun (2007) of Southeast University, China " The influence of polyester fibre on the performance of asphalt mixes", 26th Southern African Transport Conference (SATC 2007)

[13] Simantini Behera and Narayan Panda, (2010), " Laboratory investigations on stone matrix asphalt using sisal fibre for Indian roads", National Institute of Technology Rourkela.

[14] Bukowski J.R (1992)," The Future SMA in America", The Asphalt Institute, Volume 6, #3, FHWA.

Authors

First Author – Dr. Ganapathi Malarvizhi, M.E,Ph.D Assistant Professor, Division of Transportation Engineering, Civil Department, College of Engineering, Anna University, Chennai – 600 025, India., Email: malarnaveen1@gmail.com

Second Author – N.Senthil , Post Graduate Student in M.E Transportation Engineering, Civil Engineering Department, College Of Engineering, Guindy, Anna University, Chennai-25, India.

Third Author – C.Kamaraj, M.E (Civil Engg), Transportation Planning and Environment Division, CSIR-Central Road Research Institute, New Delhi, India.

Correspondence Author – Dr.Ganapathi Malarvizhi, M.E,Ph.D ,Assistant Professor, Division of Transportation Engineering, Civil Department, College of Engineering, Anna University, Chennai – 600 025,India. Email: malarnaveen1@gmail.com. Contact no: +91-9840726596, 044-22357516