Waste plastic as a stabilizing additive in Stone Mastic Asphalt

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Abstract - The present study investigates the benefits of stabilizing the stone mastic asphalt (SMA) mixture in flexible pavement with shredded waste plastic. Conventional (without plastic) and the stabilized SMA mixtures were subjected to performance tests including Marshall Stability, tensile strength and compressive strength tests. Triaxial tests were also conducted with varying percentage bitumen by weight of mineral aggregate (6% to 8%) and by varying percentage plastic by weight of mix (6% to 12% with an increment of 1%). Plastic content of 10% by weight of bitumen is recommended for the improvement of the performance of Stone Mastic Asphalt mixtures. 10% plastic content gives an increase in the stability, split tensile strength and compressive strength of about 64%, 18% and 75% respectively compared to the conventional SMA mix. Triaxial test results show a 44% increase in cohesion and 3% decrease in angle of shearing resistance showing an increase in the shear strength. The drain down value decreases with an increase in plastic content and the value is only 0.09 % at 10% plastic content and proves to be an effective stabilizing additive in SMA mixtures.

Index Terms- Compressive strength Draindown, Marshall Stability, Triaxial shear strength, Stone Mastic Asphalt, Split tensile strength.

I. INTRODUCTION

Scientists and engineers are constantly searching on different methods to improve the performance of asphalt pavements. Considerable research has been carried out to determine the suitability of plastic waste modifier in construction of bituminous mixes [1],[2].Recycled polythene from grocery bags may be useful in bituminous pavements resulting in reduced permanent deformation in the form of rutting and reduced low-temperature cracking of pavement surfacing [3]. Zoorab & Suparma [4] reported the use of recycled plastics composed predominantly of polypropylene and low density polyethylene in plain bituminous concrete mixtures with increased durability and improved fatigue life. Resistance to deformation of asphaltic concrete modified with low density polythene was improved in comparison with unmodified mixes [5]. Dry process involves direct incorporation of waste plastic which is blended with aggregate before adding in bitumen, to prepare a plastic modified bituminous concrete mix. Wet process involves simultaneous blending of bitumen and waste plastic.

Various additives like polymers and fibres have been utilized for the purpose of improving the high and low temperature characteristics of bitumen compositions, as well as to improve their toughness and durability. Additives such as styrene based polymers, polyethylene based polymers, polychloroprene, gilsonite, various oils, and many other modifiers including tall oil have been added to bitumen to enhance various engineering properties of bitumen[6] .

Asphalt concrete which employs polyethylene modified binders is more resistant to rutting during elevated seasonal temperatures [6]. It is reported that modifier improves the properties of asphalt mixtures [7]. Recycled plastics comprising predominantly of polypropylene and low density polyethylene can be incorporated into conventional bituminous road surfacing mixtures. Greater durability and fatigue life have been reported for these modified mixes as compared to conventional mixes [8].

Since 1960s, Stone Mastic Asphalt (SMA) pavement surfaces have been used successfully in Germany on heavily trafficked roads. In recognition of its excellent performance a national standard was set in Germany in 1984. Since then, because of its excellent performance characteristics, the use of SMA increased in popularity amongst the road authorities and asphalt industry [9]. Stone Mastic Asphalt is a gap graded bituminous mixture containing a high proportion of coarse aggregate and filler. It has low air voids with high levels of macro texture when laid, resulting in a waterproof layer with good surface drainage [10]. Stabilizing additives are needed in the mastic which is rich in binder content to prevent the binder from draining down from the mix. Polymers and fibres are the commonly used stabilizing additives in SMA. Based on many research reports and engineering case studies [11] has been shown that the use of stone mastic asphalt (SMA) on road surfaces can achieve better rut-resistance and durability. The SMA mixtures are designed to have high aggregate content, high asphalt content typically 5.5–7% and high filler content. For ordinary SMA, the use of unmodified bitumen together with fibrous material as a drainage inhibitor is sufficient. Under high temperatures and heavy loading, a harder bitumen grade will also suffice. A polymer (such as PP, PE or styrene–butadiene–styrene (SBS)) modified binder may be used to substitute the fibrous material. It is possible to increase the capability of resistance to permanent deformation at the expense of a higher price. The demand for higher pavement quality from users is ever-increasing. The cost of a pavement failure is also mounting higher. Hence; there is a strong desire to have better bitumen mixture from highway agencies. SMA can control or limit the distress failure such as rutting, shoving, stripping, etc. through polymer modification. This study is an attempt to develop a plastic stabilized SMA paving mixture that resist the action of temperature, temperature changes, the action of air and water and the action of traffic.

II. MATERIALS AND METHODS

A. Aggregates

Aggregate was obtained from a local Quarry at Kochi in Kerala and the physical properties of aggregates are given in Table I. Table II shows the recommended gradation limits by the NAPA for SMA mixtures.

B. Bitumen

The bitumen was 60/70 penetration grade obtained from Kochi Refineries Ltd. Physical properties of this bitumen were presented in Table III.

C. Plastic

The plastic used was the waste plastic bottles, bags, wrappers, etc collected from the nearby houses and apartments and from the Cochin University campus, Kerala. It was segregated and cleaned and was shredded using the shredding machine (particle size 2-3 mm).

D. Filler

Ordinary Portland cement was used as the filler material

TABLE I
Physical properties of aggregates

Test Description	Specification	Results
Combined Flakiness and Elongation index (%)	IS 2386 (Pt I – 1963)	18
Water absorption (%)	IS 2386 (Pt III – 1963)	0.5
Specific Gravity	IS 2386 (Pt IV – 1963)	2.65
Impact Value (%)	IS 2386 (Pt IV – 1963)	16

TABLE II
Gradations of Aggregates for SMA

Sieve Size (mm)	Cumulative % by weight of aggregate passing	Permissible Limits
19	100	100
12.5	90	85-95
9.5	47	75 MAX
4.75	24	20-28
2.36	20	16-24
0.600	14	12-16
0.300	13	12-15
0.075	9	8-10

E. Optimization of the mixtures

Marshall mix design (ASTM D-1559) procedure is normally used to optimize the SMA mixtures. In SMA mix design; usually the Marshall method of mix design is used to verify satisfactory voids in SMA mixtures . Laboratory specimens were prepared using fifty blows of the Marshall hammer per side. Seventy-five compaction blows were not used since they would not result in a significant increase in density over that provided by 50 blows. SMA mixtures have been more easily compacted on the roadway to the desired density than the effort required for conventional HMA mixtures.

The optimum asphalt content for SMA mixtures is usually selected to produce 3–5% air voids and a drain down of less than 0.3%. In this research, compaction of all the SMA samples were performed using fifty blows of the Marshall hammer per side. The optimum asphalt content for the control SMA mixture was found to be 6.63 % at 4 % air voids.

TABLE III
Physical properties of Bitumen

Test Description	Results
Penetration (100 gm, 5 sec, 25˚c,0.01 mm)	64
Ductility at 27˚c (cm)	72
Specific Gravity	1.00
Softening Point (˚c)	50
Flash Point (˚c)	240
Fire Point (˚c)	270
Viscosity at 60 ˚c (Poise)	1200

F. Preparation of specimens of stabilized SMA mixtures

An optimum asphalt content of 6.63 % as found from Marshall control mix design (by wt. of total mix) was used in preparing all other plastic modified mixes to maintain consistency through out the study.

The following steps were performed for the formulation of compacted specimens:

1. Graded aggregates were heated at 150-160 ^{0}C in an oven and waste plastic in shredded form varying from 5% - 12% at an increment of 1% was added into hot aggregates before mixing at optimum binder content in dry process.
2. The bitumen was heated up to 160^0 C in an oven.
3. The combination of plastic coated aggregate, filler and modified binder was mixed uniformly at a temperature of 150 ± 5^{0}C.
4. The specimens formulated were then compacted at 135 ^{0}C using Marshall apparatus specified by ASTM D1559.

Two hundred samples for all percentages of shredded plastic were fabricated. For each percentage of plastic, five specimens were used for Marshall Stability at 60 ^{0} C for 35 min water immersion. 40 specimens were prepared to determine the tensile strength values. These 40 specimens were divided into two groups (20 specimens each). The first group was tested at 25 ^{0}C for 2 h and the second set was tested after immersion at 60 ^{0}C for 24 h followed by 2 h immersion at 25 ^{0}C with 51 mm/ min deformation rates then the percentage loss in tensile strength and the tensile strength were determined.
Another set of 40 specimens were prepared to determine compressive strength values and divided into two groups similar to those for indirect tensile strength test but tested with a deformation rate of 3.2 mm/min for Marshall specimen. Then the compressive strength and index in retained strength were calculated.

60 Triaxial samples were prepared with and without plastic contents at varying confining pressures of 0.25 kg/cm^2, 0.5kg/cm^2, 0.75 kg/ cm ^{2} and 1kg/ cm ^{2}. Each test was repeated thrice and average values were taken to represent Mohr- Coulomb envelop. The strength parameters 'c' and 'φ' corresponding to with and without plastic content are obtained from the Mohr's Coulomb envelope.

III. LABORATORY TESTING

A. Tests on plastic coated aggregates

A series of tests were carried out on plastic coated aggregates. The tests results are shown in Table IV.

TABLE IV
Comparison of Physical properties of aggregates with plastic coated aggregates

Property	Ordinary Aggregate				Plastic Coated Aggregate			
Impact value (%)	16				14			
Abrasion value (%)	20				16			
	After(hrs)				After(hrs)			
Stripping value (%)	2	24	72	96	2	24	72	96
	0	0	2	5	0	0	0	0
Water Absorption Value (%)	0.4%				Nil			
Soundness value (%)	5%				Nil			

B. Drain down

Drain down test using wire basket method as proposed in the NCHRP Report No. 425 was run on the mixes evaluated. In this test, the laboratory-prepared loose mix was placed in a forced draft oven for 1 h at a pre-selected temperature. At the end of 1 h, the basket containing the sample is removed from the oven along with the plate and the mass of the plate was determined. The amount of increased weight of the plate is the amount of drain down of the mix. The oven temperature for performing the drain down test should be at the mixing temperature or the mixing temperature plus 15^0 C. Thus, an oven temperature of 175^0 C was used for the test. The results of the drain down test were summarized in Table V.

C. Marshall test

The variation of Marshall properties with % plastic are given in Table V and the variation of Marshall properties with % bitumen are shown in Fig: I(a) to Fig: I(e).

D. Moisture sensitivity test

The test was carried out to find the water susceptibility of SMA mixtures. The difference in the stability loss of SMA mixtures with and without plastic is determined by immersing the six Marshall samples for each plastic content in the water bath at 60˚C. The Stability values for three samples from each mixture were obtained after 35 minutes of water immersion and the remaining samples were tested after 24 hours of water immersion. The results are shown in Table V.

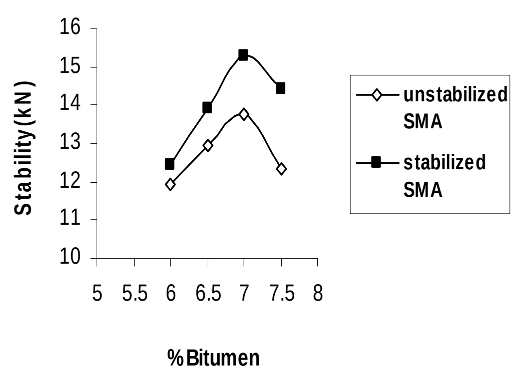


Fig: 1(a)

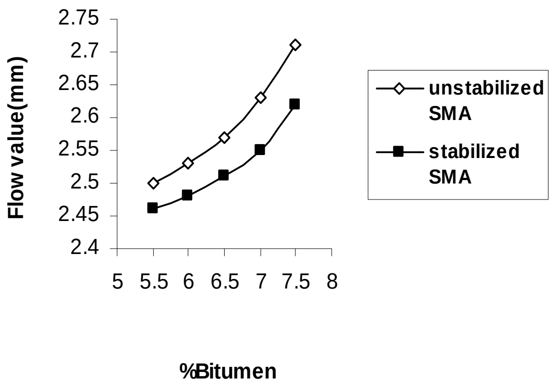


Fig: I (b)

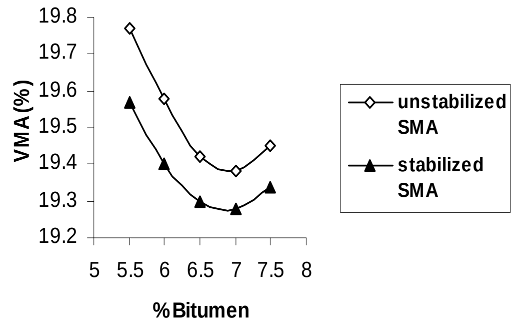
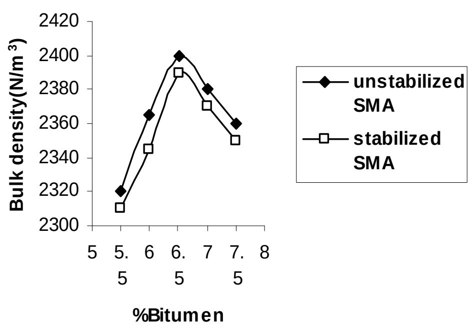


Fig: I(c)



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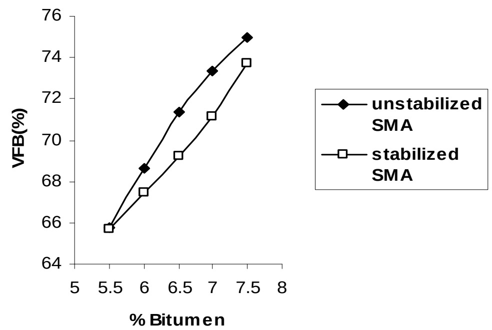

Fig: I (e)

Fig: I (a) – I (e) Variation of Marshall properties with % Bitumen

TABLE V
Design Parameters at OBC for Various Plastic Contents

%Plastic	Stability (kN)	Retained stability	Flow (mm)	Bulk density(kg/m^3)	Air void (%)	VMA (%)	VFB (%)	Draindown (%)
0	10.25	79.4	4.19	2447	4.2	19.26	81.23	0.303
6	13.92	84.14	4.05	2457	4.18	19.23	80.52	0.287
7	14.12	86.18	4.15	2463	4.08	19.17	79.94	0.222
8	14.84	89.90	3.97	2476	3.92	19.09	78.28	0.186
9	15.64	91.55	3.8	2492	3.78	18.92	77.05	0.12
10	16.82	94.56	3.56	2505	3.29	18.28	74.25	0.09
11	15.98	91.48	3.4	2548	3.12	18.12	72.95	0.05
12	14.96	89.45	3.2	2572	2.94	17.77	70.26	0.01

E. Triaxial Test

This test measures the shear strength of the test mix and its results give better information for the prediction of field performance. The tests were carried out on cylindrical specimens 100 mm in diameter and 150 mm in height. 60 Triaxial samples were prepared with and without plastic contents at varying confining pressures of 0.25 kg/cm^2, 0.5kg/cm^2, 0.75 kg/ cm ^{2} and 1kg/ cm ^{2}. Each test was repeated thrice and average values were taken to represent Mohr- Coulomb envelop. The strength parameters 'c' and 'φ' corresponding to various plastic contents are obtained from the Mohr's Coulomb envelope. Stress Versus Strain curves corresponding to confining pressures of 0.25kg/cm^2 and 0.50kg/ cm ^{2} are shown in Figures: II (a) and II(b). The similar trend is shown in the other confining pressures also. The variations of shear parameters with and without plastic content are shown in Table VI.

TABLE VI
Shear parameters for conventional and stabilized SMA.

Properties	Conventional SMA	Stabilized SMA
Cohesion (kg/cm^2)	0.9	1.3
Angle of shearing resistance (^{0}C)	35	34

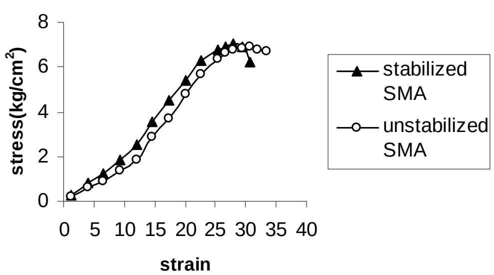

Fig: II (a) Variation of stress with strain at a Confining pressure of 0.25 kg/cm^2

F. Split tensile test

Although SMA is not nearly as strong in tension as it is in compression, SMA tensile strength is important in pavement applications. Tensile strength is typically used

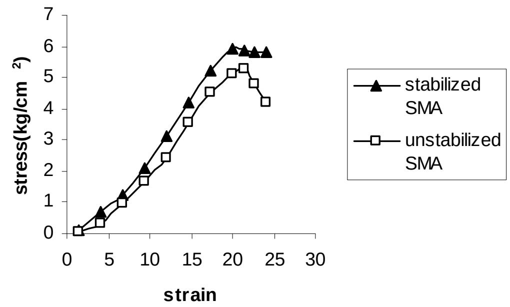

Fig: II (b) Variation of stress with strain at a Confining pressure of 0.5 kg/cm^2

as SMA performance measure for pavements because it best simulates tensile stresses at the bottom of the SMA surface course as it is subjected to loading. These stresses are typically the controlling structural design stresses. It is difficult to directly measure the tensile strength because of secondary stresses induced by gripping a specimen so that it may be pulled apart.

Therefore, tensile stresses are typically measured indirectly by a splitting tensile test.

The samples were prepared in the same manner as that of Marshall Method. Three specimens were placed in soaked (24 hour water immersion) and un-soaked condition (after 35 minutes of specimen making) and the test was conducted at 25˚C, 30˚C, 40˚C and 60˚C. Apply the load continuously at a constant rate until failure occurs. Record the maximum load at failure. Calculate the split tensile strength *f*st using the formula $f\text{st} = \frac{2P}{\pi l d}$, Where P is the maximum load at failure and '*l*' and 'd' are the length and diameter of the cylindrical specimen, respectively. The test was conducted at an optimum plastic content of 10 % at four different temperatures 25˚C, 30˚C, and 40˚C, 60˚C both in soaked and un-soaked condition**.** The variation of split tensile strength with temperature is shown in Figure. III and TableVII.

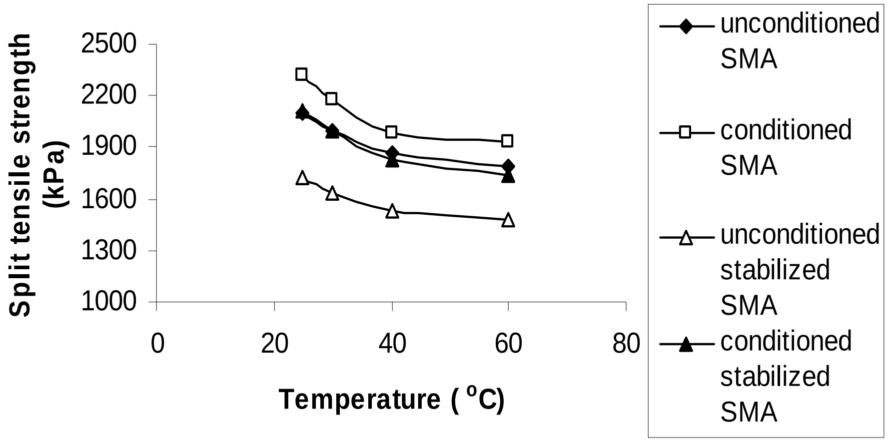

Fig: III Variation of split tensile strength with temperature

TABLE VII

Split Tensile Strength of SMA mixtures at different temperatures

Type of mix	Split tensile strength (k Pa)							
	Temperature 25^0 C		Temperature 30^0 C		Temperature 40^0 C		Temperature 60^0 C	
	Uncond -itioned	Condition -ed	Unconditi -oned	Condition ed	Unconditi oned	Condition ed	Uncond itioned	Conditi oned
Conventional SMA	2100	1722	1995	1636	1862	1526	1795	1472
Plastic stabilized SMA	2314.5	2110.05	2175	1995.06	1989	1829.88	1925	1730.8

TABLE VIII
Compressive Strength of SMA mixtures at different temperatures

	Compressive strength (k Pa)				Retained strength (%)	
	Conventional SMA		Stabilized SMA			
Temp. (^{0} C)	Unconditioned	Conditioned	Unconditioned	Conditioned	Conventional SMA	Stabilized SMA
25^0 C	5066.2	4298.4	6128	5924.2	84.84	96.67
60^0 C	4082	3292.7	6090.2	5778.4	80.66	94.88

G. Compressive strength test

The values of the compressive strength and the % retained strength at different temperatures are given in Table VIII.

IV. Results and discussion

A. Physical Properties

The Physical Properties of waste plastic coated aggregates were evaluated and the results are presented in Table V. The results indicate that waste plastic coating is effective in improving the physical properties of aggregate. Examining Table IV, it can be seen that the water absorption for aggregate without waste plastic (0.4%) reduces to nil for aggregate coated with plastic. Similarly, soundness of aggregate was 5%, whereas nil for plastic coated aggregates. The impact and abrasion values shows increased toughness and hardness for the plastic coated aggregates

B. Marshall Properties

Table: V indicates that as plastic content increases, the stability increases up to 10 % plastic content and the flow value decreases. The Marshall Stability value of SMA with 10 % waste plastic is 16.82kN and the percentage increase in stability value has been found to be 64 % as compared to the mix without plastic.

This was attributed due to the enhanced interlock of aggregates. Beyond 10% Plastic contents the stability decreases and the flow increases. This is related to the decrease in interlocking offered by binder and plastic coated aggregate particles. Density is increasing with plastic content. VMA and VFB show a decreasing trend. The air voids decreased for all plastic content due to the filling property attributed by plastic coating. Examining Table V indicates that 10% Plastic content satisfies the specified limits of 3–5% air voids and a drain down less than the minimum allowable of 0.3% mentioned by SCDOT specification for SMA

Figure: II indicate that with an increase in bitumen content, the Marshall Stability value of SMA increases first and then decreases. This is because, bitumen holds the aggregates in position, and the load is taken by the aggregate mass through the contact points. If all the voids are filled by bitumen, then the load is rather transmitted by hydrostatic pressure through bitumen, and strength of the mix reduces. That is why stability of the mix starts reducing when bitumen content is increased further beyond a certain value. This is true when a reinforced SMA is used.

C. Moisture Damage

From Table.V, it is found that the retained stability increases with the increase in plastic content upto 10 %. On further addition of plastic, it is found to be decreasing. The retained stability in fibre reinforced SMA is about 95 %whereas in conventional mix, it is found to be 79 %. This shows that the mix with 10 % plastic content is least affected by water, when compared to conventional SMA.

D. Draindown sensitivity

From Table V, it can be observed that the values of drain down for conventional and with 10% plastic-modified SMA samples are 0.303 and 0.09 respectively. The potential effects of the inclusion of waste plastic in the mix are therefore beneficial in preventing the bleeding phenomenon of the SMA mixtures. No fiber was needed to prevent drain down when this waste plastic was used.

E Triaxial test

Table: VI shows that SMA with 10 % plastic has 44 % higher cohesion than SMA without fibre. The larger the cohesion value, the larger the mix resistance to shearing stresses. But there is a 29 % decrease in angle of shearing resistance value. The results of the shear parameter showed that the stabilized SMA has much greater resistance to shearing stresses than conventional SMA. Analyzing the stress - strain behaviour of SMA, it is found that in plastic stabilized SMA, the failure is of ductile nature while in conventional SMA, it is of brittle nature.

F. Split tensile strength test

These results greatly exceeded the minimum requirement of 448 k Pa set by the SC DOT. This indicates that these waste plastic do not cause a decrease in the strength of the SMA due to the intrusion of water into the mix.

The results indicate that tensile strength is increased, while the percentage loss in tensile strength is decreased for both testing temperatures (i.e. increase the adhesion between aggregate and asphalt, which leads to a decrease in the stripping of SMA). Tensile strength for stabilized mixtures is slightly higher than for conventional mixtures.

It can be seen that the plastic-modified SMA mix improves the resistance to moisture susceptibility of the bituminous mixtures. It can be observed from Figure: III that the tensile strength of the plastic stabilized bituminous mixes was found to be higher when compared to conventional mixes. Table. VII shows that the split tensile value increases at all temperatures in stabilized SMA and at a temperature of 60˚C the % increase in split tensile value due to the addition of plastic is about 18% in conditioned sample . This shows that stabilized SMA mix has good strength under soaking.

G. Compressive strength test

Table.VII shows that the ranges of compressive strength for conventional and stabilized SMA mixes are 4928.4 –5924.2 kPa and 3292.7– 6090.2 kPa at 25^0C and 60^0C, respectively. The percentage increase in the averaged compressive strength is found to be comparatively significant. The study showed that the percentage increase in compressive strength value in the stabilized SMA mix was found to be 75% at 60^0C in conditioned sample. It was found that the index of retained compressive strength of the control SMA mixture was increased by 14 % at 10 % Plastic content.

V. CONCLUSIONS

Based on this study of the utilization of shredded plastic in SMA mixtures, the following findings were made:

- The Marshall Stability value of stabilized SMA was found to be 17kN, which is higher than the prescribed value of 6.2 kN and the percentage increase in stability value has been found to be 64% as compared to the conventional mix.
- The flow value of SMA with 0.3% fibre was found to be 3.56 mm which is in the range of the prescribed value (2 - 4mm) whereas the flow value for conventional mix is 4.19 mm.
- Retained Stability of SMA increases with increase in plastic content upto 10 % and the percentage increase in retained stability as compared to conventional mix was found to be 16%.
- The shredded plastic was effective in preventing excessive drain down of the SMA mixtures (i.e. bleeding phenomenon) and at 10% plastic content the drindown reduces to 0.09%.
- Triaxial test results show that stabilized SMA has 44% higher cohesion and 29% decrease in angle of shearing resistance than the conventional mixes.
- The mixtures containing the plastic greatly exceeded the indirect tensile strength requirements set by the SC DOT and the % increase is about 18 % at 60˚C. This shows that stabilized SMA mix has good strength under soaking.
- 14% increase in the index of retained compressive strength of stabilized mix than the conventional mix. This indicates that the stabilized SMA mix has good strength under soaking.

Results indicated that flexible pavement with high performance and durability can be obtained with 10% shredded plastic.

REFERENCES

[1] L.R Schroceder, "The Use of Recycled Materials in Highway construction', *Public Roads, Vol 58(*Issue 2), 1994.

[2] Sunil Bose, Sridhar Raju , "Utilization of waste plastic in Bituminous Concrete mixes", *Roads and Pavements*, (2004),

[3] L.Flynn, "Recycled Plastic finds it home in Asphalt Binder", *Roads and Bridges* , (1993)

[4] S.E Zorrob, and L. B Suparama " Laboratory Design and Investigation of Proportion of bituminous Composite Containing Waste Recycled Plastics aggregate Replacement (Plastiphalt)", *CIB Symposium on construction and Environment Theory into Practice*

[5] D N Little, "Enhancement of asphalt concrete mixtures to meet structural requirements through the addition of recycled polythene, use of waste materials in hot mix asphalt", *ASTM Special Tech Publication,1193*(1993)

[6] J.H Denning, & J Carswell, "Assessment of Novophalt as a Binder for Rolled Asphalt Wearing Course", TRRL Report 1101, *Transport and Road research Laboratory, Crowthrome (England)*, 1983.

[7] J.L Goodrich, "Asphalt and Polymer Modified Asphalt related to the performance of Asphalt Concrete Mixes", *Association of the Asphalt Paving Technology*, 1998.

[8] S.E Zorrob, "Laboratory Design and Performance improved Bituminous Composite Utilizing Plastics Packaging waste", *Conference on Technology watch and Innovation in Construction Industry, Belgium, Building Research Institute, Brussels, Belgium*, 2000

[9] 10. AAPA Asphalt Guide, "Stone Mastic Asphalt Surfacing, *Austroads and Pavement Design", volume 5*,(Issue. 2), 239 – 249.

[10] 11. BCA Specification for Stone Mastic Asphalt, BCA 9808, *New Zealand Pavement & Bitumen Contractors' Association, August, 1-10*, (1999).