Chapter 10

SUMMARY AND CONCLUSIONS

10.1 INTRODUCTION

Annual increase in maintenance expenditures demands the urgent need for building durable and efficient roads. Severe climatic conditions, growing traffic volume and insufficient drainage conditions results in faster deterioration of the pavements in Kerala. Stone matrix Asphalt (SMA) has proved to be the right choice to handle such situations. This research is an attempt to study the influence of additives in improving the characteristics of SMA mixtures and to propose a durable surface course.

This chapter presents summary and conclusion of this study based on the various objectives addressed.

10.2 SUMMARY

Additives are added to improve the characteristics of SMA, which is a gap graded mixture with rich binder content. The influence of additives, both natural fibres and polymers on the characteristics of SMA is studied. The natural fibres like coconut fibre, sisal fibre, banana fibre and a polymer, polypropylene are used as additives. Moreover, the use of waste plastics as an additive to SMA is also explored. The SMA mixture without any additive is taken as the control mixture. The volumetric and stability characteristics are studied by Marshall tests and the strength characteristics by indirect tensile strength tests, compressive strength tests and triaxial strength tests. The drain down sensitivity of the mixture is also studied by a drain down apparatus. Statistical Analysis is conducted to test the significance of various mix types considered in this research. Major conclusions of this research are discussed in the succeeding sections.
10.3 CONCLUSIONS

The major conclusions deduced from this study are presented in five different sections - influence of additives in SMA, comparison of fibre stabilized mixtures, comparison of mixtures with polypropylene and waste plastics, comparison of various stabilized mixtures and statistical analysis of the test results.

10.3.1 Influence of additives in SMA

Additives influences the characteristics of SMA mixtures by showing an enhancement in strength and stability, reduction in water induced damages and drain down, while maintaining the specified volumetric characteristics.

10.3.1.1 Volumetric and stability characteristics

*Marshall Stability test results show that:*

- The air voids of stone matrix asphalt mixtures increase after adding fibres into the mixture due to the net working effect of the fibres within the mix. Owing to the filling property offered by the additives waste plastics and polypropylene resulted in less air voids in the mixture as compared to the control mixture. However, the air voids of all mixtures are located within the required specification range of 3 to 5% (AASHTO T 312) which support the use of these additives.

- Increasing the fibre additive content in the SMA mixture resulted in an increase in the voids in mineral aggregate (VMA) and a reduction in voids filled with bitumen (VFB) values. But the values of VMA decreases and VFB increases by the addition of waste plastics and polypropylene additives to the SMA mixtures. But VMA values are within the required specification range of 17% minimum, which also supports the use of these additives.

- The bulk specific gravity of SMA mixtures slightly decreases with the addition of fibre additives and increases with waste plastics and polypropylene additives. This is due to the variations in air voids in the mixture as compared to the control mixture.
• With the increase in the percentage of additives in the SMA mixture, Marshall stability and Marshall quotient values increase with respect to the control mixture showing its better resistance against permanent deformations. The maximum values for these properties are obtained at 0.3% fibre content irrespective of the type of fibre, 5% polypropylene content and 7% waste plastics content by weight of mix. Beyond this percentage of additives, the results show a decreasing trend.

• Flow value of SMA mixtures decreases due to the addition of fibres. The mixes become less flexible resulting in a low flow value. By adding waste plastics and polypropylene to SMA mixtures, flow value of mixtures decreases initially (up to 7% WP and 5% PP) and after that there is an increase due to the decrease in the stone to stone contact of mixtures. However, flow values are located within the required specification range of 2 to 4mm (AASHTO T 245) supporting the use of additives in SMA mixtures.

10.3.1.2 Strength characteristics

Based on the indirect tensile strength test, compressive strength test and triaxial strength test, the following conclusions can be drawn.

• The mixtures containing additives have higher values of indirect tensile strength at failure under static loading as compared to the control mix, indicating the improved cracking potential of SMA mix.

• The effect of additive in increasing the indirect tensile strength value of SMA mix is more influential in the conditioned state due to the improved adhesion property.

• Presence of additives strengthen the bonding between the aggregates provided by the binder and thereby enhancing the stone to stone contact which will result in increasing the resistance to crushing. This gives rise to a stiffer and tougher mix with considerable improvement in compressive strength.

• It is also observed that with respect to the control mixture, the compressive strength of stabilized mixtures decreases with increase in temperature. But the
percentage decrease in strength is less with the increase in additive content up to a certain level.

- SMA stabilized mixtures has the highest cohesion and shear strength as compared to the control mixture, proving its rutting resistance against shear. This result is in agreement with the higher peak stress and the extended duration of its occurrence, which can be attributed to the role of additives as an additional reinforcement to the bituminous mixtures in resisting permanent deformation and retarding the occurrence of shear failure.

- The influence of additives on the value of angle of internal friction of SMA mixture is very less.

- Due to the presence of additives in SMA mixture tangent modulus of the mix increases with increasing confinement pressure, indicating their stress dependent behaviour and its improved elastic stiffness.

- For stabilized mixtures, it is also observed that the shape change of the stress-strain curves is more gradual with increase in additive content and brittle type failure does not seem to occur as in the case of control mixture.

### 10.3.1.3 Moisture susceptibility

*The retained stability value, tensile strength ratio and index of retained strength which are the indicators of the ‘extent of moisture induced damage’ shows that all stabilized SMA mixtures exhibits higher values against the lower values of control mixture. This support the influence of additives in significantly reducing the water induced damages of the SMA mixture. In addition, it also indicates that additives do not cause the mixture to weaken when exposed to moisture.*

- The values of retained stability, tensile strength ratio and index of retained strength for the control mixture is less than the required minimum values of 70% (LS 283), 70% (AASHTO T 283) and 75% (ASTM D 1075) respectively. When additives are added, these values are enhanced to above 90%.
10.3.1.4 Drain down sensitivity

The potential effects of the inclusion of additives in SMA mixtures are beneficial in preventing the bleeding phenomenon of the mixtures and the drain down of SMA mix. The role of additive is to stiffen the mastic and thereby reducing the drainage of the mixture at high temperatures during storage, transportation, placement and compaction of SMA mixture.

- All the five additives used in the SMA mixture for the present investigation act as an effective stabilizing agent and provide significant stabilization to the mixture as compared to the control mixture.

- Due to the gap graded gradation and rich binder content in SMA, the control mixture is subjected to heavy drain down of 6.5% which is beyond the specified limits of 0.3% by weight of mix. The presence of additives in the SMA mix bring down the drain down of the mixture to the specified level. This again supports the need of the additive in SMA mixtures.

10.3.2 Fibre stabilized SMA

Optimum fibre content of fibre stabilized mixtures and the best fibre additive is arrived by analysing the volumetric, mechanical, moisture susceptibility and drain down characteristics of the SMA mixture with various fibre additives such as coir, sisal and banana fibre. In this research, fibre length is kept as constant (6 mm) and the content is varied from 0.1% to 0.4% at an increment of 0.1% by weight of mixture.

10.3.2.1 Stability and volumetric characteristics

- Irrespective of the type of fibre, the maximum values of stability, Marshall Quotient and bulk specific gravity of SMA mixtures are obtained at 0.3% fibre content.

- Comparing different types of fibre stabilized SMA mixtures, mixtures with coir fibre have the highest stability (12.58 kN), indicating their higher rutting resistance and better performance than mixtures with other fibres. The percentage increase in stability with respect to the control mixture is about 70% for SMA with coir fibre and about 60% for SMA with other fibres.
Flow value of SMA mixtures decreases after adding fibres. Owing to the stiffness of fibres in the mixture, the mixes become less flexible resulting in a low flow value. However, flow values of all SMA mixtures are located within the required specification range of 2 to 4 mm.

The Marshall quotient of coir fibre stabilized SMA mixture at 0.3 % fibre content is almost doubled with respect to the control mixture, indicating its better resistance against permanent deformations and also indicates that these mixtures can be used in pavements where stiff bituminous mixture is required.

Coir fibre stabilized SMA has the highest bulk specific gravity when compared to mixes with other fibres. Since higher specific gravity results in better design mixes, the coir fibre stabilized mixtures perform better than other stabilized mixtures considered.

Considering the volumetric characteristics, at 0.3% fibre content, air void increases by 11.5%, VMA increases by 2.2%, while VFB decreases by 2.4% for coir fibre stabilized mixtures. The percentage changes are respectively 9.25% increase for air void, 5.4% increase for VMA and 1% decrease for VFB in sisal fibre stabilized mixtures. Whereas 8.5% increase in air voids, 5.9% increase in VMA and 1% decrease in VFB are observed in banana fibre stabilized mixtures. But all the volumetric characteristics are within the required specification range which also supports the use of these fibre additives.

### 10.3.2.2 Strength characteristics

- All the fibre stabilized SMA mixtures has the maximum tensile strength at 0.3% fibre content. The coir fibre stabilized SMA exhibits the highest tensile strength showing its higher cracking resistance as compared to the other fibre stabilized mixtures. The percentage increase in strength with respect to the control mixture is 38% for unconditioned and 160% for conditioned samples for the coir fibre stabilized mixture, whereas around 35% and 153% for both sisal and banana fibre stabilized mixtures respectively.
Fibre reinforcing effect increases initially with increasing fibre content in SMA, but at high fibre content (more than 0.3%) induce coagulation and thus reduce its reinforcing effect, resulting in less stiff mixture with lower strength values.

From the compressive strength test results, all fibre stabilized mixtures show the maximum value of compressive strength at 0.3% fibre content. SMA with coir fibre exhibits higher compressive strength as compared to the other fibre stabilized mixtures indicating its higher crushing resistance.

It can be observed that the percentage increase in compressive strength with respect to the control mixture at 0.3% fibre content for coir fibre stabilized mixes at 25°C and 60°C are 17% and 42% respectively. Similarly, the percentage increase in strength is about 14% and 37% at 25°C and 60°C respectively for SMA with sisal fibre and is about 13% and 35% at 25°C and 60°C when banana fibre is added.

All the stabilized mixtures give the highest cohesion at 0.3% fibre content, irrespective of the type of fibre. The cohesion values are found to be decreasing when additive contents increased beyond this percentage.

All fibre-stabilized mixes has the same angle of internal friction. The cohesion value increases approximately from 100 kPa in control mixture to 170 kPa in SMA mixtures with coir fibre, showing a percentage increase of about 53% exhibiting their higher resistance to shearing stresses than the other fibre stabilized mixtures, which shows 38% and 26% respectively for sisal and banana fibre.

Coir stabilized SMA mixture shows the maximum shear strength of about 385kPa at 300 kPa normal stress. The percentage increase in strength of this mixture is about 21% with respect to the control mixture, showing their much greater resistance to shearing stresses. Sisal and banana fibre mixtures seem to deviate less from each other.

The percentage increase in stress at failure is about 67% and strain at failure is 44% at 100kPa confinement pressure for coir fibre stabilized SMA with respect to the control mixture.
The presence of fibre in the mix enhances the elastic stiffness of the SMA mixture, showing a substantial increase in tangent modulus with respect to the control mixture for the coir fibre mix.

The test results converge to the conclusion that the best performance of the Stone Matrix Asphalt mixture is at 0.3% fibre content and with coir fibre.

10.3.2.3 Moisture susceptibility

- The presence of fibres in SMA mixtures gives the higher retained stability, tensile strength ratio and index of retained strength at 0.3 % fibre content by weight of mix and the best performance is exhibited by SMA with coir fibre indicating its higher resistance to moisture induced damages.

10.3.2.4 Drain down sensitivity

Fibres have a much higher stabilizing effect than the other additives, as they firmly bind the aggregate particles inside the matrix and prevent them of movement and make the mix stiffer.

- Due to the absorptive nature of fibres, fibre stabilizers are found to be effective in reducing the drain down of the SMA mixtures. Among the fibre stabilized mixtures, coir fibre reaches the 0% drain down at 0.3% fibre content.

- The coir fibre had the highest stabilizing capacity of 16% followed by sisal and banana fibre.

Based on the volumetric, mechanical and drain down characteristics of the various fibre stabilized mixtures it can be concluded that the optimum fibre content of the fibre stabilized Stone Matrix Asphalt mixture is 0.3% by weight of mixture and the coir fibre additive is the best among the fibres investigated.

10.3.3 Polypropylene and waste plastics stabilized SMA

A polymer, polypropylene and a waste material, waste plastics are also tried as additives in SMA mixture. The additive content is varied from 1% to 9% at an increment of 2% by weight of mixture. Optimum additive content of the stabilized mixtures and the best additive among this is arrived from the volumetric, mechanical,
moisture susceptibility and drain down characteristics of the SMA mixture with these additives at different proportions.

10.3.3.1 Volumetric and stability characteristics

- Owing to the filling property offered by the waste plastics and polypropylene additives, the stabilized mixtures resulted in a less air void as compared to the control mixture and other fibre stabilized mixtures. But the results are within the specified limit of 3 -5%. But VMA values of these mixtures shows a decreasing trend but VFB values, an increasing trend, which is opposite to the trend shown by fibre stabilized mixtures. But all the results are within the specification range.

- The addition of 5% polypropylene raises the Marshall stability of control mix by 73% and that of 7% waste plastics by 82% and at these additive contents, a reduction in flow value (within the specified limit of 2 to 4 mm) is observed due to the enhanced interlocking of aggregates in the mixture. Beyond this percentage of additive content, the stability value decreases. The mixtures with waste plastics have higher stability (13.7 kN) than mixtures with polypropylene and fibres, indicating their higher rutting resistance. The reduction in flow value increases its resistance to plastic flow.

- The Marshall quotient of SMA mixture is almost doubled with respect to the control mixture at 5% PP content and 7% WP content and slightly higher with the additive, waste plastics, showing its better resistance against permanent deformations.

- Bulk specific gravity increases with an increase in waste plastics and polypropylene content in SMA. Both additive contents show almost the same trend and the values are greater than the fibre stabilized mixtures.

10.3.3.2 Strength characteristics

- The maximum values of indirect tensile strength, compressive strength and shear strength are obtained for the SMA mixtures with 5% PP content and 7% WP content and the strength decreases beyond this additive content.
SMA mixture stabilized with waste plastics exhibit higher indirect tensile strength than polypropylene stabilized mixtures showing its capability to withstand slightly larger tensile strains prior to cracking.

Waste plastics stabilized SMA mixtures show the highest compressive strength than the polypropylene stabilized mixtures indicating its higher resistance to crushing.

Waste plastics stabilized SMA mixtures show slightly higher cohesion value than the polypropylene stabilized mixtures, showing its greater resistance to shearing stresses. The values of the angle of internal friction of both mixtures are the same.

Strain and stress at failure for waste plastics stabilized SMA is slightly higher than that of polypropylene stabilized mixtures. The values of tangent modulus for both mixtures are almost the same indicating the same elastic stiffness.

10.3.3.3 Moisture susceptibility

The retained stability of the mixture increases with increasing additive content up to 7% for waste plastics and 5% for polypropylene and after that it is found to be decreasing.

Waste plastics stabilized SMA mixture exhibits the maximum retained stability and index of retained strength of about 98% and a tensile strength ratio of about 99% showing its higher protection against water damage.

10.3.3.4 Drain down sensitivity

At 5% PP and 7% WP content, the drain down of the mixes is within the required specified limits, indicating the effects of these additives in SMA mixtures to prevent the bleeding and the drain down of mixtures.

The waste plastics and polypropylene have almost similar stabilizing capacities, but less than that of fibre stabilized mixtures.

Based on the volumetric, mechanical and drain down characteristics of these mixtures it can be concluded that, the optimum additive content for SMA mix with waste plastics is 7% and for polypropylene, it is 5%. Waste Plastics, which is the best
additive among this, showing better resistance to rutting, cracking, crushing, shearing and stripping off and also the superior water resistance property, can replace the expensive polymers in SMA mixtures.

10.3.4 Comparison of various stabilized mixtures

- Test results have illustrated that, the type of additive and its content play significant roles in the volumetric and mechanical properties of bituminous mixtures. Results show that different additives have different reinforcing effects.

- Regarding the volumetric characteristics, fibre stabilized mixtures show higher air voids and voids in mineral aggregates than the other mixtures, but the voids filled with bitumen is more in waste plastics stabilized mixtures. But in all stabilized mixtures, the results are within the specification range.

- It is observed that SMA mixes with 7% waste plastics has the highest Marshall stability, Marshall quotient, bulk specific gravity, indirect tensile strength and compressive strength showing its better resistance against permanent deformations, cracking and crushing as compared to other stabilized mixtures.

- The flow values of fibre stabilized mixtures are slightly more than that of waste plastics stabilized mixture.

- All the stabilized SMA mixtures show higher retained stability, tensile strength ratio and index of retained strength. The addition of 7% waste plastics in the SMA mixture gives the best result and exhibit superior water resistance property.

- When compared with the control mixtures, coir fibre stabilized mixtures has 1.5 times higher cohesion and waste plastics stabilized mixtures has 1.3 times higher value. Coir stabilized mixtures has the maximum shear strength when compared to other mixtures.

- In all stabilized SMA mixtures, due to the absorptive nature of fibres, fibre stabilizers are found to be more effective in reducing the drain down than the waste plastics and polypropylene additives. But all SMA mixes with additives at optimum bitumen content satisfy the specified drain down values.
The effective utilization of the waste plastics for SMA mixtures will result in substantial increase in the scrap value for this otherwise undesirable waste material, which are getting littered all over the area. This will also lead to an ecofriendly sustainable construction method.

10.3.5 Statistical Analysis of the test results

Statistical Analysis using SPSS package Ver.16 verified the precision of the results of various experimental programmes.

- ANOVA analysis shows that there is significant difference between different percentages of additives in SMA at 1% level of significance indicating the influence of additives on the strength, stability and drain down characteristics of SMA mixtures.

- From the Tukey’s multiple comparison tests, homogeneous groups are identified and arrived at the optimum additive content for SMA mixtures as 0.3%, 5% and 7% by weight of mix with fibres, polypropylene and waste plastics respectively.

- A comparison of different fibre stabilized mixtures at optimum contents are carried out by ANOVA and arrived at the best fibre additive as coir fibre.

- The t-test show that waste plastics stabilized SMA is having significantly higher values than polypropylene stabilized SMA for all properties except in bulk specific gravity.

- The t-test reveals that the mean values of stability, bulk specific gravity, compressive strength and tensile strength for waste plastics stabilized SMA is significantly higher than that of coir fibre stabilized SMA at 1% level of significance (p-value < 0.01). But the values of cohesion and shear strength are significantly higher for coir fibre stabilized SMA as compared to waste plastics stabilized SMA.

- A pair wise comparison between the best among these stabilized mixtures (coir fibre stabilized and waste plastics stabilized) by t-test for independent samples shows that waste plastics stabilized SMA mixture is the best.
The results of this research clearly establish the influence of additives in the performance of SMA. Among the additives investigated, waste plastics have great promise as an environmental friendly sustainable material. The comprehensive evaluation of this waste plastics stabilized Stone Matrix Asphalt mixture strengthens the confidence level in the field application of this material as an ideal surface course.

10.4 SCOPE FOR FURTHER RESEARCH

Further research is recommended on the following aspects:-

*Long term Performance Evaluation* - This research was mainly concentrating on the laboratory investigations. Hence the results of this research are to be ascertained in the field by constructing experimental test tracks, monitoring and conducting long term performance evaluation under varying traffic and environmental conditions.

*Fatigue failure resistance & Rutting Characteristics* - Repeated load testing can give us an idea about the fatigue failure resistance of the bituminous mixtures. This can be recommended for further research to assess the effect of additives on fatigue behavior. Hamburg wheel tracking Test can be recommended for the further study of rutting characteristics, which are already arrived in this research by Marshal stability test and Triaxial test.

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