Chapter - 5

Summary & Conclusions
Chapter 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

For the construction of bituminous roads, good quality aggregates and bitumen or asphalt are required. In many parts of the world like deserts, seashores and along rivers, there is scarcity of good quality aggregates for road construction, but sand in the form of desert sand, beach sand and river sand, is available in large quantities. However a bituminous mix containing only sand as aggregate is not suitable for use as a structural layer in pavements because of its low mechanical stability, high voids and requirement of high asphalt content. But it has been found that when a sand - asphalt mix is further mixed with molten elemental sulphur, the properties of the former are improved considerably. Stability is increased, voids content decreased and the asphalt requirement reduced. The use of sulphur in sand-asphalt mixes resulted in increased stability, though the amount of voids in the mixes is considerably high. It is also proved that the distribution of the voids are such that the permeability of such mixes is less than those of bituminous concrete mixes prepared with coarse and fine aggregates. To improve the properties of sand - asphalt - sulphur mixes sand is replaced by flyash or pondash in various proportions and the studies are carried out by earlier investigators using 80/100 grade asphalt. But it is suggested in MOST specifications that different grades of asphalts are to be used depending on the intensity of traffic, temperature and rainfall in that area.
This investigation is carried out to find out the effect of different grades of asphalt on sand, asphalt, sulphur, flyash or pondash mixes used for pavements. In the mixes 80% of the total mix, beach sand or desert sand is used. However to find out the extent to which beach sand can be replaced with flyash or pondash, the beach sand and flyash or pondash are used in the proportions 100:0, 80:20, 60:40, 50:50, 40:60, 20:80 and 0:100. In the case of desert sand mixes, the desert sand and flyash or pondash are used in the proportions 100:0, 50:50 and 20:80 only. The effect of three grades of asphalt i.e. 80/100, 60/70 and 30/40 is studied in this work. To determine the extent up to which sulphur can replace asphalt, asphalt is used from 5 to 10% and sulphur is used from 15 to 10%. The Marshall procedure was used with 10 blows on each face of Marshall samples. Based on permeability tests the limits of air voids are decided as 7 to 20% and adopted in the mix design. In order to have comparison of the mixes studied in this work with the normally used asphalt concrete mixes, the properties of 20mm asphalt concrete mix also are studied. The design of the mixes is based on chosen A/S ratio or chosen Marshall property. Based on this investigation the following important conclusions are arrived.

5.2 MARSHALL PROPERTIES

5.2.1. Stability

1. In asphalt concrete mixes, the stability increases reaching a maximum and then decreases as asphalt content increases. This is true for all the three grades of asphalt.
2. Highest stability values of 7.70 kN, 8.74 kN and 9.51 kN are obtained for asphalt concrete mixes of 80/100, 60/70 and 30/40 asphalt grade mixes respectively. This shows that the stability values increase as the penetration grade of asphalt decreases.

3. In the BA and DA mixes, with all the three grades of asphalt, the stability decreased as the asphalt content is increased. In BA mixes highest stability values of 0.37 kN, 0.43 kN and 0.55 kN are obtained for 80/100, 60/70 and 30/40 grade mixes respectively. This shows that the stability values of all the three grades of asphalt mixes do not satisfy even light traffic and are lower than those of asphalt concrete mixes.

4. In DA mixes highest stability values of 0.18 kN, 0.25 kN and 0.26 kN are obtained for 80/100, 60/70 and 30/40 grade mixes respectively. This shows that the stability values of all the three grades of asphalt do not satisfy even light traffic. In all the three grades, BA mixes have higher stability values than DA mixes. This is because beach sand is coarser than desert sand.

5. In the case of all the mixes prepared with sulphur only or sulphur with flyash or pondash, the stability values decrease as the A/S ratio increases. This trend is observed in all three grades of asphalt.

6. Maximum stability values of 15.28 kN, 18.86 kN and 24.46 kN are obtained for 80/100, 60/70 and 30/40 BAS mixes respectively. This shows that the stability values increase with reduced penetration value of asphalt in BAS mixes. By adding sulphur, the BA mixes which are not fit for
taking even light traffic, are brought to the level of taking heavy traffic.

The stability values are more than even those of asphalt concrete mixes.

7. Maximum stability values of 15.28 kN, 17.99 kN and 20.87 kN are obtained for 80/100, 60/70 and 30/40 DAS mixes respectively. This shows that as in BAS mixes, significant improvement has taken place in the stability values of DAS mixes due to the addition of sulphur to DA mixes. By adding sulphur to DA mixes they are brought to the level of taking even heavy traffic.

8. In the 80/100 BFAAS mixes the decreasing order, in which the various proportion of mixes are present from stability point of view is 50:50, 60:40, 80:20, 40:60, 20:80, 0:100 and 100:0 at most of the A/S ratios. The highest stability values of these mixes are 31.19, 27.34, 26.98, 21.48, 16.86, 14.24 and 12.28 kN respectively. Nearly 70 % of mixes have higher stability values than the maximum stability value (7.70 kN) of the mix with 80/100 grade asphalt concrete mix. Further the values show that stability definitely increased in most of mixes the with the addition of flyash to BAS mixes. The best mix is with the proportion 50:50.

9. In the 60/70 BFAAS mixes the decreasing order, in which the various proportion of mixes are present from stability point of view is 60:40, 80:20, 50:50, 40:60, 20:80, 0:100 and 100:0 at most of the A/S ratios. The highest stability values of these mixes are 35.70, 34.48, 27.96, 24.94, 20.76, 17.69 and 11.29 kN respectively. Nearly 80 % of the mixes have higher stability values than the maximum stability value (8.74 kN) of the
mix with 60/70 grade asphalt concrete mix. The best mix is with the proportion 60:40. As in the case of 80/100 grade mixes, in the case of 60/70 grade also, stability values increased in most of the mixes with the addition of flyash to BAS mixes.

10. In the 30/40 BFAAS mixes the decreasing order, in which the various proportion of mixes are present from stability point of view is 50:50, 80:20, 60:40, 40:60, 20:80, 0:100 and 100:0 at most of the A/S ratios. The highest stability values of these mixes are 38.42, 35.33, 33.64, 32.06, 29.53, 23.56 and 17.79 kN respectively. Nearly 80% of mixes have higher stability values than the maximum stability value (9.51 kN) of the mix with 30/40 grade asphalt concrete mix. Further the values show that stability definitely increased in the most the mixes with the addition of flyash to BAS mixes. The best mix is with the proportion 50:50.

11. From the above results it is clear that the proportion 50:50 is the best in the 80/100 and 30/40 asphalt grade mixes, whereas 60:40 proportion is the best in 60/70 asphalt grade mixes.

12. In the three asphalt grades of BFAAS mixes, 30/40 asphalt grade mixes are better followed by 60/70 and 80/100 asphalt grade mixes.

13. The addition of flyash to BAS mixes has improved the stability in 95% of the mixes.

14. In the 80/100 BPAAS mixes the decreasing order, in which the various proportion of mixes are present from stability point of view is 60:40,
50:50, 80:20, 40:60, 20:80, 100:0 and 0:100 respectively. The highest stability values of these mixes are 24.46, 21.32, 18.68, 14.66, 12.46, 9.56 and 5.14 kN respectively. Nearly 64% of mixes have higher stability values than the maximum stability value (7.70 kN) of the mix with 80/100 grade asphalt concrete mix. In these mixes 60:40 proportions is proved to be better. In almost all BPAAS mixes, the stability values are less than the BFAAS mixes at the respective proportions.

15. In the 60/70 BPAAS mixes the decreasing order, in which the various proportion of mixes are present from stability point of view is 50:50, 60:40, 80:20, 100:0, 40:60, 20:80 and 0:100 respectively. The highest stability values of these mixes are 25.09, 21.81, 18.87, 17.69, 11.98, 10.48 and 9.06 kN respectively. In these mixes 50:50 proportion is proved to be better.

16. In the 30/40 BPAAS mixes the decreasing order, in which the various proportion of mixes are present from stability point of view is 80:20, 50:50, 60:40, 100:0, 40:60, 20:80 and 0:100 respectively. The highest stability values of these mixes are 27.34, 24.03, 20.21, 17.79, 12.03, 9.38 and 7.30 kN respectively. In these mixes 80:20 proportion is proved to be better.

17. In the three asphalt grades of BPAAS mixes, 30/40 mixes are better followed by 60/70 and 80/100 grade asphalt mixes. With the addition of pondash, the stability has increased only 45% mixes, where as this value
is 95% in BFAAS mixes. This shows that adding flyash is more advantageous than pondash in improving the stability.

18. When compared to BPAAS mixes BFAAS mixes have higher stability values at all A/S ratios. This is true for all the three grades of asphalt.

19. In the case of DFAAS mixes the highest Stability values of 18.58, 19.80 and 22.50 kN are obtained for 80/100, 60/70 and 30/40 grades. These are much higher than those of asphalt concrete mixes. In the case of DPAAS mixes the highest stability values of 7.48, 8.30 and 8.65 kN are obtained for 80/100, 60/70 and 30/40 grades, which are more or less equal to stability values of asphalt concrete mixes.

20. In all the proportions of DFAAS and DPAAS mixes it is observed that stability values of DFAAS and DPAAS mixes are less than BFAAS and BPAAS mixes respectively at the same A/S ratio in the corresponding grades of asphalt mixes.

21. Addition of flyash to desert sand at 50:50 and 20:80 has improved the stability with all the grades of asphalt. On the other hand the addition of pond ash to desert sand at 50:50 or 20:80 has decreased the stability with all the grades of asphalt. Hence adding fly ash to desert sand is an advantage but not pondash.

22. In almost all the mixes, the stability values increased with decrease in penetration value of asphalt at the same A/S ratio.
23. For the same type of mixes, beach sand mixes have higher stability values compared to desert sand mixes. This is because the beach sand is coarser than the desert sand.

24. When the light and medium traffics are considered from the point of the number of mixes satisfying the criteria, the grade of asphalt may not be significant except in the case of BAS and DPAAS mixes. But when heavy traffic is considered 30/40 grade is preferred to 80/100 or 60/70 grades. For heavy traffic, the percentage of mixes satisfying the design criteria range from 33 to 83% in the case of BAS mixes, 69 to 100% in the case BPAAS mixes, 67 to 100% in the case of DPAAS mixes when the grade of asphalt is changed from 80/100 to 30/40.

25. When the percentage increase of maximum stability of BFAAS and BPAAS mixes with 60/70 and 30/40 are compared with 80/100 asphalt it is observed that in some proportions, there is reduction of maximum stability. This shows that with reduction in the penetration grade of asphalt, there is no guaranty of increase of stability.

5.2.2. Unit Weight (Density)

1. In most of the mixes studied with different grades of asphalt the density of the mixes increase reaching a peak and then decrease as the asphalt percent or A/S ratio increases. However in few mixes such regularity is not observed. This is due to the adjustment and position of the ingredients in the mixes. The rate of increase or decrease of density depends upon the
type of mix. In almost all the mixes peak density occurs at A/S ratio of 0.6 to 0.8.

2. Maximum density values of 18.51, 18.94 and 19.00 kN/m$^3$ for BA mixes, 18.30, 18.48 and 18.24 kN/m$^3$ for DA mixes and 23.34, 23.40 and 23.46 kN/m$^3$ for asphaltic concrete are obtained for the 80/100, 60/70 and 30/40 grades asphalt. Thus the maximum density values of BA and DA mixes are less than those of asphaltic concrete mixes. In the BA and DA mixes, the density values of BA mixes are higher than those of DA mixes at many asphalt contents.

3. When compared to BA and DA mixes, the density values of BAS and DAS mixes in all the three grades of asphalt are higher. This is due to addition of sulphur to BA and DA mixes.

4. The addition of flyash to BAS mixes has decreased the densities in all the three grades of asphalt. The decrease being more as the flyash content increased.

5. In the case of pondash mixes also, the density values decreased with the addition of pondash to BAS mixes, the decrease being more as the pondash content increased.

6. When compared to BFAAS mixes, the density values of BPAAS are less at most of the proportions at respective A/S ratios. This is true in all the three grades of asphalt.
7. When the maximum density values of the selected DFAAS and DPAAS mixes are compared with BFAAS and BPAAS mixes, the maximum values of the former are less than the latter in the respective mixes.

8. In the three grades of DFAAS mixes 60/70 grade has got highest density value followed by 30/40 and 80/100 grades. In the three grades of DPAAS mixes 60/70 grade has got highest density value followed by 30/40 and 80/100 grades.

9. The density of bituminous concrete mixes is about 23 kN/m³. But in other mixes the values range from 10 to 21 kN/cm³. These lower values raise doubt about the validity of the sulphur mixes in the road construction. Hammond et al. studied the roads laid with sand, asphalt, sulphur mixes and found that immediately after few minutes of laying the mixes became hard and were able to take the loads of heavy construction equipment, even though such roads were constructed on weak subgrades. The unit weight of the Marshall samples of these SAS mixes ranged from 17.99 to 19.62 kN/m³. Hence before rejecting the mixes studied in this investigation based on unit weights, they are to be tested in the field and their suitability found out.

10. In all the mixes the reduction in the penetration grade of asphalt has not significantly increased the unit weights. Hence from the consideration of unit weights, the change in the grade of asphalt is not warranted.
5.2.3 Percent air voids

1. In all the mixes without sulphur (BA or DA mixes) and with sulphur the increase of asphalt or A/S ratio the percent air voids decrease, the rate of decrease depends upon the type of mix. The same trend is observed in all the three grades of asphalt.

2. The air voids of BA and DA mixes are higher than those of asphalt concrete mixes. This is true for all the three grades of asphalt. In the BA and DA mixes, the air voids are less in the latter mixes. Unlike in asphalt concrete mixes, in these mixes the air voids are considerably high. The percent air voids range from 18.57 to 29.75 % for BA mixes and from 20.37 to 27.04 % for DA mixes.

3. Addition of sulphur to BA and DA mixes decreased the air voids in all the three grades of asphalt. The ranges of air voids of BAS mixes in the above three asphalt grades are 11.63 to 15.99 %, 9.72 to 17.44 % and 10.1 to 16.24 % respectively. The ranges of air voids of DAS mixes in the above asphalt grades are 9.01 to 16.67 %, 8.26 to 13.31 % and 7.41 to 15.55 % respectively.

4. Addition of flyash to BAS mixes have reduced the air voids up to 40:60 proportion and then increased the air voids beyond this limit. This is true for all the three grades of asphalt.

5. Addition of pondash replacing beach sand has no benefit at all in reducing air voids. The same trend is obtained in all the three grades of asphalt.
the three asphalt grades of BPAAS mixes at given A/S ratio many 30/40 asphalt grade mixes have less air voids than those by 60/70 and 80/100 asphalt grade mixes. In the latter two there is a mixed trend.

6. In all the three grades of asphalt addition of flyash to DAS mixes, the air voids are reduced up to the proportion 20:80 where as the addition of pond ash has increased or decreased the air voids depending upon the amount of pondash in the mixes.

7. When the air voids of selected DFAAS and DPAAS mixes are compared with those of BFAAS and BPAAS mixes, the air voids are more in the former mixes.

8. When the mixes are considered from the point of view of satisfying the design criteria all the BAS and DAS mixes have satisfied the criteria with all the three grades of asphalt. In the other mixes BFAAS have satisfied from 70 to 83 %, BPAAS have satisfied from 11 to 31 % only, DFAAS have satisfied from 25 to 100 % and DPAAS have satisfied from 75 to 84 %.

This shows that adding pondash to BAS mixes is not as advantageous as flyash. But same is not the case with DAS mixes.

5.2.4 Flow values

1. In the case of 20mm bituminous concrete mixes flow values increase with increase of asphalt or A/S ratio for all types of mixes. This is true for all the grades of asphalt.
2. In the case of asphalt concrete mixes the flow values range from 24 to 38%, the values being more in the 30/40 grade asphalt mixes. More number of mixes with 80/100 and 60/70 grades do not satisfy the criteria.

3. The flow values of BA mixes range from 10 to 25. Only 30 % mixes satisfy the criteria. In the DA mixes, none of them satisfy the criteria.

4. The flow values of 50 % BA mixes are higher than DA mixes. At given asphalt content flow values of 30/40 grade BA mixes are higher, compared to 80/100 and 60/70 asphalt grades; in the case of DA mixes flow values of 30/40 and 60/70 grade mixes are more or less the same but in 80/100 grade asphalt flow values are lower than 30/40 and 60/70 asphalt grade.

5. The addition of sulphur has increased the flow values of BA and DA mixes in all the three grades of asphalt. Most of the flow values of BAS and DAS mixes are within the specification limits.

6. Increase of flyash and pondash has decreased the flow values in most of the mixes in all the three grades of asphalt.

7. BFAAS mixes have higher flow values than BPAAS mixes in general for all the three grades of asphalt. Where as DPAAS mixes have higher flow values than DFAAS mixes.

8. Grade of asphalt has little effect on flow values of many BFAAS and BPAAS mixes.
9. The addition of flyash or pondash have increased or decreased the flow values in some mixes in such a way that the BAS or DAS mixes are brought to an advantageous position in the limits of flow values specified.

10. When the flow values are considered from the point of view of satisfying the criteria nearly more than 60% of the mixes satisfy the criteria for light and medium and heavy traffic in all the three grades of asphalt mixes. However the difference is maximum with DPAAS mixes, in which with 80/100 grade asphalt 83% mixes satisfy the heavy traffic and only 42% satisfy with 30/40 grade asphalt. Also only 17% of asphalt concrete mixes satisfy the criteria with all the three categories of traffic with 80/100 and 60/70 grade asphalts.

5.2.5. Percent voids in mineral aggregate (%VMA)

1. The percent V.M.A. values decrease and again increase as the asphalt content or A/S ratio increases in most of the mixes. In the case of few mixes there is an irregular trend.

2. The V.M.A. values range from 20 to 55% and have satisfied the mix criteria in all the three grades of asphalt.

3. The addition of flyash or pondash have increased or decreased the percent V.M.A. values depending upon the proportions.
5.2.6. Percent Retained Stability

The retained stability of the selected mixes is more than 80%, which is more than the prescribed value of minimum 75 % of MOST specifications. Hence it is felt that durability of the mixes prepared with sulphur, flyash and pondash is satisfactory.

5.3 EFFECT OF ADDING SULPHUR, FLYASH OR PONDASH TO BEACH SAND OR DESERT SAND AND ASPHALT MIXES.

Based on the investigation carried out, the effect of adding sulphur, flyash or pondash to beach sand or desert sand, asphalt mixes are discussed below.

5.3.1 Effect of Adding Sulphur

1. In the mixes where sulphur is used, the stability values decrease as the A/S ratio increases. This indicates that at higher sulphur content, the stability values are higher. This is true in all the three grades of asphalt.

2. By adding sulphur to BA mixes of 80/100, 60/70 and 30/40 asphalt grade mixes the maximum stability values increase from 0.37 kN to 15.28 kN, 0.43 kN to 18.86 kN and 0.55 kN to 24.46 kN respectively for the above mixes. This clearly indicates that the maximum stability values of BA mixes increase by 4030 % in 80/100 grade, 4286 % in 60/70 grade and 4347 % in 30/40 grade by adding sulphur.

3. By adding sulphur to DA mixes of 80/100, 60/70 and 30/40 asphalt grade mixes maximum stability values increase from 0.18 kN to 15.28 kN, 0.25
kN to 17.99 kN and 0.26 to 30.87 kN respectively for the above mixes. This clearly indicates that the maximum stability values of DA mixes increases by 8389 % in 80/100 grade, 7096 % in 60/70 grade and 7927 % in 30/40 grade by adding sulphur.

4. By adding sulphur to BA and DA mixes the density is increased by about 12 %.

5. When sulphur is added to BA mixes the air voids decreased in all the three grades of asphalt. The amount of decrease varied from 37 % to 50 % depending upon the type of mix.

6. When sulphur is added to DA mixes the air voids decreased in all the three grades of asphalt mixes. The decrease ranged from 38 % to 67 %.

7. The flow values have increased in BA and DA mixes with the addition of sulphur. The flow values which were not satisfactory in BA and DA mixes are raised to a more satisfactory range in most mixes.

8. The change is not great in the V.M.A. values, when sulphur is added.

5.3.2 Effect of Adding Flyash

1. By adding flyash to BAS mixes the maximum stability values increased by 104% in 80/100 asphalt grade, 89% in 60/70 grade and 57% in 30/40 asphalt grade. This indicates that adding of flyash to BAS mixes is more advantageous in 80/100 asphalt grade followed by 60/70 and 30/40 asphalt grade.
2. By adding flyash to DAS mixes the maximum stability values increased by 22% in 80/100 asphalt grade, 10% in 60/70 asphalt grade and 8% in 30/40 asphalt grade. This indicates that adding of flyash to DAS mixes is more advantageous in 80/100 asphalt grade followed by 60/70 and 30/40 asphalt grade.

3. Addition of flyash improves stability values better than pondash in all the grades of asphalt.

4. Addition of flyash decreases density in most of the mixes, the decrease being more with the increase of flyash content.

5. Addition of flyash to BAS mixes have reduced the air voids upto 40:60 proportions and then increased the air voids beyond this limit. This is true for all the three grades of asphalt.

6. At the same air voids level the mixes with flyash show less permeability compared to conventional asphalt concrete mixes (Table: 4.3).

7. The addition of flyash has decreased the flow values in most of the mixes in all the grades of asphalt.

8. The addition of flyash has increased or decreased the flow values in some mixes in such a way that they are brought to a better position in the specification limits.
5.3.3. Effect of Adding Pondash

1. By adding pondash to BAS mixes the maximum stability values increased by 60 % in 80/100 asphalt grade, 33 % in 60/70 asphalt grade and 12 % in 30/40 asphalt grade. This indicates adding pondash to 80/100 asphalt grade is more advantageous followed by 60/70 and 30/40 asphalt grade.

2. By adding pondash to DAS mixes the stability values increased by 2 % in 80/100 asphalt grade, decreased by 9 % in 60/70 and 18 % in 30/40 asphalt grade. This indicates that adding pondash to DAS mixes is not useful in increasing the density.

3. Addition of pondash improves stability values in BAS mixes and not in DAS mixes in all three grades of asphalt.

4. Addition of pondash decreases density in most of the mixes, the decrease being more with the increase of pondash.

5. Addition of pondash replacing beach sand has no benefit at all in reducing air voids. The same trend is observed with all the three grades of asphalt. Addition of pondash to DAS mixes has increased air voids.

6. With the addition of pondash in a good number of mixes, which had lower or higher flow values, the flow values have increased or deceased and come to better position of specification limits of 20 to 50 units. This is one of the great advantages of using pondash.

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5.4. Suitability of the Mixes

1. Of all the 252 mixes of beach sand tested (84 of 80/100, 84 of 60/70 and 84 of 30/40) 31 of 80/100, 27 of 60/70 and 32 of 30/40 satisfied Marshall criteria. This means 37% of 80/100, 32% of 60/70 and 38% of 30/40 grade asphalt mixes have satisfied Marshall criteria. The maximum difference is only 6% and hence not significant.

2. Of all the 108 mixes of desert sand tested (36 of 80/100, 36 of 60/70 and 36 of 30/40) 20 of 80/100, 16 of 60/70 and 22 of 30/40 satisfied Marshall criteria. This means 55% of 80/100, 44% of 60/70 and 61% of 30/40 grades mixes have satisfied the Marshall criteria. The maximum difference is 11% between 80/100 and 60/70, 17% between 60/70 and 30/40 and 6% between 80/100 and 30/40 grade mixes. Hence using 80/100 or 30/40 grade asphalts are advantageous.

3. When all mixes are considered 42% of 80/100, 35% of 60/70 and 46% of 30/40 grade mixes have satisfied Marshall criteria. The maximum difference is only 11% and hence the effect of grade of asphalt is not much significant.

4. As shown in Table 4.49b, when the traffic intensity is considered, 80/100 and 30/40 grade mixes are better than 60/70 grade mixes in satisfying the criteria.

5. In the mixes which do not satisfy the Marshall criteria (total 222 mixes do not satisfy the Marshall criteria) 45 (12%) mixes do not satisfy stability criteria, 163 (44%) mixes do not satisfy percent air voids criteria, 96 (26%) mixes do
not satisfy flow criteria. So, more mixes fail based on air voids criteria. This deficiency is more in BPAAS mixes than in BFAAS mixes.

5.5 Replacement of Asphalt by Sulphur

Depending upon the type of sand normally 6 to 14 % asphalt is required for sand - asphalt mixes used in the base course or surface finish. In the present study 10 % asphalt was used to get the lowest air voids of 20 % in BA mixes. For this mix a stability of 0.10kN only is obtained. By using BAS mix of 80-5-15, BFAAS mix of 16-64-5-15, BPAAS mix of 40-40-5-15, DAS mix of 80-5-15 etc. it was possible to prepare mixes even to take heavy traffic loads. In these mixes only 5 % asphalt is used, though sulphur was used up to 15 %. This means what is not possible with 10% asphalt in BA mixes is made possible by using 5 % asphalt and 15 % sulphur in other mixes. This means there is 50 % saving in asphalt requirement. Further the mixes are brought to the level of even taking heavy loads.

Where coarse aggregates are not available, especially in desert areas, mixes like BAS, BFAAS, DAS, DFAAS etc. can be used replacing the asphalt partly by sulphur.

The work of Fromm and Kehnepohl show that even in the case of asphalt concrete mixes 50 % of asphalt can be replaced by sulphur and better results can be obtained.

The above works show that nearly 50 % of asphalt can be replaced by sulphur and better results can be obtained than those of conventional sand-asphalt or
asphalt concrete mixes. The same saving can be achieved with semi-gap grading mixes used in United Kingdom and South Africa.

5.6 Replacement of Sand by Flyash and Pondash

a. As the beach sand and desert sand mixes with the proportion of sand: flyash of 0:100 and 20:80 have satisfied the Marshal criteria, it can be inferred that flyash can replace beach sand up to 100 % and desert sand up to 80 % by properly proportioning the mix ingredients.

b. As the beach sand and pondash and desert sand and pondash mixes satisfied the criteria up to the proportions of 50:50 and 20:80 respectively. It can be concluded that the pondash can replace beach sand up to 50 % and desert sand up to 80 %.

Even though the above mentioned mixes satisfy the Marshall design criteria, the unit weight of some of these mixes is as low as 11kN/m³. Hence field investigations have to confirm the adoption of such mixes from the considerations of unit weight.

5.7 Effect of Grade of Asphalt

Three grades of asphalts i.e. 80/100, 60/70 and 30/40 are used in this study to find out the significance of using lower penetration grade asphalts in preference to higher penetration grade asphalts. In the case of asphalt concrete mixes, sand - asphalt mixes, lower penetration grades are used to increase stability, durability, and to withstand higher temperatures.
By properly proportioning the mixes, and using 80/100 grade asphalt, mixes can be prepared to obtain a stability value up to 30 kN which is nearly 4.5 times higher than the maximum stability i.e. 6.672 kN adopted for heavy traffic.

When the effect of grade of asphalt on unit weight is observed in majority of the mixes, almost the same unit weight is observed for the same proportion of mixes even when the grade of asphalt is changed.

When the mixes with the same proportions are considered maximum variation in percent air voids is about 15% only when the grade of asphalt is changed. In number of mixes the percent air voids are less with 80/100 grade asphalt. As the permeability of the mixes studied is less than $10^{-7}$ cm/sec, the mixes with 80/100 grade asphalt can be considered as very less permeable. Hence such mixes will do well even in high rainfall areas.

When the same proportion of the mixes are considered, the flow values of majority mixes do not significantly change with change or grade of asphalt.

41.6% of 80/100 grade mixes, 35.2% of 60/70 grade mixes, and 45.6% of 30/40 grade mixes satisfy the design criteria. The variation between 80/100 and 30/40 grade mixes is only about 10%, which is not significant.

From the above discussion it becomes clear that by properly proportioning the mixes, good quality mixes can be prepared with 80/100 grade asphalt itself. Unless otherwise proved or required there is no necessity of using lower penetration grade asphalts like 60/70 or 30/40 grade asphalts in the sand, asphalt, sulphur, flyash or pondash mixes.
Hammond et al. comments on SAS mixes as follows, 'Relative to asphaltic concrete mixes, the role of the asphaltic binder is minimized in the thermopave mix and preliminary indications are that there is a potential for using inferior asphaltic binders'.

5.8 Economics aspects of mixes

At present it is difficult to make comparison in the cost of construction of conventional asphalt concrete pavements and pavements constructed with sand, asphalt, sulphur, flyash or pondash mixes. The comments made by Hammond et al., mentioned below, are worth noting.

a. The cost of sulphur and mixing of sulphur with asphalt are required and are not fully known.

b. The cost of transportation of sand (also flyash and pondash used in this study) is to be ascertained and depends upon the places of availability.

c. Separate mixing plants are required and the cost involved is to be known.

d. The procedure of compaction of the BAS etc. mixes is simple and hence this factor also is to be taken into consideration.

Field studies are to be carried out to make a cost analysis of construction of the pavements with these mixes.

5.9 Conclusions

The present investigation has revealed that
1. Poor quality aggregate like beach sand or desert sand can be used in the construction of high strength roads near seashores and deserts where good quality coarse aggregate is not available.

2. Sulphur can replace asphalt to the extent of 50% in all the three grades of asphalt.

3. Flyash can replace beach sand up to 100%, desert sand to the extent of 80%. Pondash can replace beach sand up to 50% and desert sand up to 80%. However, as the unit weight of these mixes are low, use of such mixes is to be confirmed with field studies.

4. In most of the mixes, the stability values increased as the penetration value of the asphalt decreased. But an opposite trend is observed in few mixes. This shows that with the decrease of penetration value of asphalt there is no guaranty of increase of stability.

5. Because of high stability and low permeability of mixes prepared with 80/100 grade asphalt with sulphur, there is no necessity of preferring still lower penetration grade asphalts unless otherwise proved or required necessary.

When Marshall criterion is satisfied it is normally considered that the pavements constructed with such mixes give satisfactory performance in the field. As good number of mixes prepared with beach sand or desert sand, asphalt of different grades, sulphur, flyash or pondash have satisfied Marshall criteria, it is hoped that the pavements construed with the mixes.
tested in this investigation will give satisfactory performance. With the present investigation the basic laboratory research work utilizing weak aggregates like beach sand, desert sand etc. abundantly available sulphur, waste and problematic materials like flyash and pondash and preparing asphalt mixes for good quality pavements is completed. Based on these investigations research laboratories like Central Road Research Institute (CRRI) Delhi, Highway Research Station Chennai etc. have to construct pavements with the mixes studied in this investigation and specifications are to be prepared for such mixes and pavements.

As the availability of asphalt is fast depleting and may become scarce in near future, and many countries are thinking of the use of flyash in large quantities in the construction of pavements, it is hoped that the results of this investigation are going to be put to practical use in the near future.