Chapter 7

CONCLUSIONS AND SCOPE FOR FURTHER RESEARCH

7.1 CONCLUSIONS

This experimental study was undertaken to assess the behaviour of high early-strength concrete mixtures for the accelerated rehabilitation of rigid pavements of dual two-lane carriage national highways of India, as their rehabilitation is imminent due to increased axle loads and environmental conditions. Accelerated (fast-track) rehabilitation is the present day need, as conventional rehabilitation causes hardships like traffic interruption due to longer closure, loss in toll collections and so on. In the beginning of the experimental study, the common and few particular causes for the failure of rigid pavements were assessed to understand the suitability of repair based on the failure pattern. It was concluded that most of the deteriorating pavements qualify for full-depth repair if left unattended and in case of full-depth repair, production of concrete mixtures that satisfy both strength and durability requirements assumes greater significance.

Hence high early-strength concrete mixtures were designed with conventional ingredients and a commercial non-chloride hardening accelerator. Three types of cements, namely OPC, PPC and PSC were used for the production of concrete mixtures. Two different curing methods, namely water curing and curing by membrane forming curing compound were adopted for the hydration process of all the 24 mixtures (8 each for OPC, PPC and PSC concrete with varying accelerator dosage). The accelerator dosage was varied from 2 litres to 5 litres, with an increment of 0.5 litres, following the guidelines of the manufacturer and was expressed as percentage of cement mass. The concrete mixtures were assessed based on their compressive and flexural strength properties at early and later age. Durability
attributes of the mixtures were investigated by water permeability and acid resistance tests. Following are the conclusions from the experimental programme.

1. Workability of all the three series of mixtures (OPC, PPC and PSC) was found to be low. Mixtures were insensitive to slump test. Increase in accelerator dosage resulted in further reduction in the workability, as measured by compacting factor and Vee-bee tests. Workability of the PPC mixture for a given dosage of accelerator was lower than that of OPC and PSC mixture. Of all the mixtures, OPC mixtures showed higher workability. Vee-bee test was found to be most suitable for measuring workability of high early-strength pavement mixtures.

2. Accelerator was effective at early age of concrete mixtures. Strength of the mixtures at full maturity was the least affected due to the addition of accelerator. All the water-cured mixtures attained stipulated design strength at 28 days, whereas none of the mixtures cured with curing compound could do so. In general the strength response of the membrane-cured mixtures to the addition of accelerator was lower than that of corresponding water-cured mixtures. There was steady hike in compressive and flexural strengths of the mixtures with increase in the accelerator dosage. At a given dosage of accelerator and at a given curing age, the compressive strength of OPC mixture was higher than that of PPC and PSC mixtures irrespective of curing age. In general OPC mixtures, irrespective of curing method, attained higher flexural strength than PPC and PSC mixtures at early age, whereas PSC mixtures were found to give higher flexural strength at full maturity. The response of accelerator was comparatively better in case of flexural strength requirements.
3. The compressive strength response of the water-cured OPC mixtures to accelerator was moderate with maximum percentage strength hike of 39.84, recorded at 5 days for the mixture with maximum (1.46 per cent) accelerator dosage. Membrane-cured OPC mixtures responded poorly to the addition of accelerator, with 32.59 as maximum percentage hike in compressive strength, observed at 1 day due to the maximum accelerator dosage.

4. There was excellent compressive strength response of water-cured and membrane-cured PPC mixtures to accelerator, with maximum strength hikes of 61.26 and 52.88 per cents respectively at 2 days with penultimate (1.28 per cent) and maximum (1.42 per cent) dosages of accelerator.

5. There was moderate to low compressive strength response of water-cured and membrane cured PSC mixtures to the addition of accelerator. The maximum percentage increase in strength in case of water-cured PSC mixture was 33.41, observed at 1 day due to penultimate (1.28 per cent) and maximum (1.42 per cent) dosages of accelerator, whereas it was 31.34, recorded at 5 days at maximum accelerator dosage.

6. Irrespective of curing method, the maximum percentage increase in flexural strength was observed at 5 days in case of OPC mixtures, with values of 70.27 per cent (at maximum dosage) and 62.33 per cent (at 1.31 per cent) for water and membrane-cured mixtures respectively.

7. In case of PPC mixtures the optimum performance of accelerator for flexural strength requirement was seen at 3 days irrespective of curing method. The maximum percentage increase in strength in case of water-cured PPC mixtures was 84.64, recorded twice at accelerator dosages of 1.14 per cent and maximum per cent. The uppermost increase in flexural strength in case of
membrane-cured PPC mixture was 80.26, recorded at the maximum accelerator dosage.

8. Like in case of OPC mixtures, the optimum performance of accelerator from the flexural strength viewpoint was observed at 5 days in case of PSC mixtures, with 71.66 and 63.24 as the uppermost percentage increases in the strengths of water-cured and membrane-cured mixtures respectively observed at maximum dosages of the accelerator.

9. The optimum performance of accelerator was high and was consistent in case of flexural strength requirements irrespective of curing method and cementitious material.

10. Early opening compressive strength requirement of 20.7 MPa was attained in 1 day in case OPC mixtures and water-cured PPC mixtures, in 2 days in case of membrane-cured PPC mixtures and water-cured PSC mixtures and 5 in days in case of membrane-cured PSC mixtures. The flexural strength requirement of 2.6 MPa was achieved in 1 day by OPC mixtures and water-cured PPC mixtures, in 2 days by membrane-cured PPC mixtures and water-cured PSC mixtures and in 3 days by membrane-cured PSC mixtures. Except compressive strength requirement of water-cured OPC mixtures (achieved without accelerator), all other strength requirements were due to administration of moderate accelerator dosages.

11. Average flexural strength, expressed as percentage of average compressive strength at early age (up to 7 days) was found to be lower than that at maturity in case of all the three series of mixtures. Average flexural strength was higher in case of PSC mixtures. The correlation equations given by Indian standards were found to underestimate the 28-day flexural strengths of the tested
mixtures. The correlations depended on type of cement, method of curing and accelerator dosage.

12. The compressive strength average efficiency of the curing compound was optimum (92.16 per cent) at 2 days for OPC mixtures, whereas it was at 3 days in case of for PPC and PSC mixtures with values of 90.61 76.42 per cents respectively. The flexural strength average efficiency of the curing compound was maximum at 1 day in case of OPC and PSC mixtures with values of 89.91 and 85.69 per cents respectively and was at 2 days with a value of 89.84 per cent for PPC mixtures. In general the average efficiency was found to be higher at early age; this underlined the waning effect of curing compound with progressive age of curing.

13. Water permeability and acid resistance tests revealed the positive and negative role of accelerator, which was not revealed by the strength results. Except in case of membrane-cured OPC mixtures, the impermeability and acidic resistance of the mixtures increased with increase in the dosage of accelerator up to a certain limit and reduced for the further dosages. For a given accelerator dosage, impermeability and acidic resistance of membrane-cured concrete were found to be much lower than those of water-cured concrete, irrespective of cementitious material used.

14. From the permeability view point, an accelerator dosage of 0.87 per cent was found to be optimum in case of water-cured OPC mixtures, whereas a dosage of 1.14 per cent was ideal in case of water-cured PPC and PSC mixtures. The least coefficient of permeability among all the mixtures was recorded by water-cured PPC mixture which was 1.679 x 10^{-12} m/sec at 1.14 per cent accelerator dosage. The lowest values of coefficients of permeability in case of
water-cured OPC and PSC mixtures were almost similar. The permeability of membrane-cured PPC and PSC mixtures followed the trends of their water-cured counterparts, whereas the permeability of membrane-cured OPC mixtures was found to increase with accelerator dosage. In case of membrane-cured mixtures, the lowest coefficient of permeability ($2.864 \times 10^{-12}$ m/sec) and hence the optimum performance of accelerator was observed in case of both PPC and PSC mixtures but at dosages of 0.72 and 0.85 per cents respectively.

15. Acidic resistance of PSC mixtures was found to be higher followed by that of PPC and OPC mixtures, irrespective of the curing method.

16. Maximum resistance to acidic attack was observed at 0.87 (3 litres per cubic metre) per cent accelerator dosage in case of water-cured OPC mixtures and at 0.85 (3 litres per cubic metre) per cent accelerator dosage in case of PPC and PSC mixtures, irrespective of curing method. Like in case of permeability results, the accelerator had no positive role in membrane-cured OPC mixtures.

17. Acidic resistance tests confirmed the behaviour of non-chloride hardening accelerator in fast-track pavement concrete mixtures, which was revealed by permeability tests. It is advisable to limit the dosage of non-chloride hardening accelerator in the fast-track concrete mixtures from the durability view point.

18. Non-chloride hardening accelerator can be used in moderate proportion together with blended cements to produce reasonably good fast-track pavement concrete mixtures, especially for dual two-lane carriageway national highways of India, which can satisfy the requirements of strength, durability and economy. The findings of this study will help in the value addition to the literature on the fast-track pavement concrete, as its need is being realized for
the accelerated rehabilitation of the rigid pavements of India, particularly with
the revised guidelines of concrete mix proportioning as given by Indian
Standards Institution.

7.2 SCOPE FOR FURTHER RESEARCH

Following studies are suggested for further research.

1. Effect of accelerator on the strength properties of PQC in the colder regions.
2. Effect of freeze-thaw resistance on the fast-track concrete, aided with non-
   chloride hardening accelerator.
3. Effect of replacement of natural sand by crushed stone, quarry dust on the
   properties of PQC aided with non-chloride hardening accelerator.
4. Comparative study of skid resistance of PQC with different cementitious
   materials and accelerator.
5. Study of microstructure and fracture mechanics of fast-track pavement
   concrete.