CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The utilisation of PFA for concrete making is a well-established practice over the past many years. However, information in terms of specific methodologies for achieving optimum utilisation of PFA in concrete was very limited. This clearly suggests that the need for the present research effort which was primarily concentrated to obtain a method for an 'effective utilisation' (maximum possible level of PFA), without compromising on the quality and performance of concrete.

6.2 SUMMARY

After reviewing the available literature, it was realised that the design of PFA concrete mixes has not yet been thoroughly explored. Basically, when there is a change introduced in the constituent materials of concrete, its properties at three stages (fresh, hardened and service) have to be assessed, checked and evaluated against the properties of the parent (reference) concrete. This has not been properly studied in any systematic approach. A PFA concrete mix with entirely different workability and water-cementitious ratio can not be compared with reference concrete and deriving the efficiency of PFA from such studies can not lead to any reliable mix proportioning scheme.

Efficiency factor of PFA is an important feature in the design of concrete mixes. This needs an extensive data on the strength of PFA concrete with identical properties of reference concrete at fresh state. Performance of concrete, particularly, against rebar corrosion protection is yet another area to be investigated. Rebar corrosion has also been studied using M15 grade concrete which is used as structural concrete for all general purpose constructions in India. Life span prediction of materials and structures is very vast area of research. It needs refined methods and techniques of life span prediction based on accelerated tests. Based on these themes the present investigation programme was carried out. The salient conclusions of this study can be given as below:

1. Partial replacement of OPC with PFA on equivalent weight basis is found to result in OPC-PFA concrete system with improved workability under constant water/cementitious ratio. Upon adding more quantity of PFA to the extent of twice the weight of cement removed, it is found to result in almost same workability with constant water/cementitious ratio.

2. PFA concrete mixes proportioned with same workability and water/cementitious ratio as those of the respective reference mixes are generally found to be beneficial to obtain comparable strengths. In lean concretes, 15 percent replacement of cement with 30 percent addition of PFA helps to develop comparable strengths right from 7 days onwards. In rich mixes, the proposed method of mix proportioning help to develop comparable 7 days strength of reference concrete at about 28 days; and comparable 28 days strength at about 60 days.

3. In low strength concretes, the efficiency factor of PFA is found to be 0.50 at the age of 7 days and it increases marginally with age as the strength is in the increasing order. In medium strength concretes the efficiency factor is found to be 0.50 at the age of 28 days and it also marginally increases with age.

4. The mix proportioning technique essentially controls the efficiency factor of PFA and all other factors take only secondary importance. Further, while evaluating efficiency factor of PFA, apart from strength criterion the workability criterion should also be taken into consideration.

5. Apart from the impact due to water/cementitious ratio, the physical and chemical characteristics of PFA also contribute significantly to the strength. From the variation of strength with age it is clear that in lean mixes both physical and chemical aspects of PFA contribute to the strength characteristics more or less in

equal participation. In rich mixes, strength contribution is primarily due to chemical action (pozzolanic) of PFA.

6. The restriction imposed on loss on ignition (LOI) by various international standards is in the range of 5 to 12 percent. From the present studies it is clear that LOI up to 10 percent does not affect the water demand adversely and hence the strength. Therefore, restriction on LOI to low percentage levels is found to be redundant. Moreover, such restrictions may even be a hurdle in promoting PFA utilisation.

7. The PFA used in this investigation is coarse one as the residue on 44μm sieve is about 47 percent (Table 3.2). However, using this coarse type PFA more benefits can be derived (both economical and technological) in lean concrete mixes and a slightly reduced benefits (a delay in the strength attainment) could be achieved in rich concrete mixes.

Therefore, the codal provisions can put restrictions on fineness based on at least two or three strength level requirements rather than suggesting a single value for fineness.

8. From the interaction diagrams presented (Fig.4.9) in this work one can obtain more than one option of cement removal for a desired strength and the optimum percentage of cement removal can be decided based on cost estimation.

9. The standard deviations and coefficients of variation of all the PFA concrete mixes are always found to be lower than that of the respective reference concrete mixes (Table 4.1 to 4.4). This indicates that addition of PFA promotes cohesion and above all homogeneity of the mixes.

Various international standards recommend standard deviations for the design of concrete mixes for different quality control to be exercised at the site. After starting of the project and after accumulation of sufficient field test data, the initially assumed standard deviation can be suitably modified for achieving economy and reliability of strength. As the PFA concrete mixes consistently show lower standard deviations, more economy and reliability can be achieved right from the beginning of a project.

10. The compressive strength of PFA concrete can be assessed with confidence from the expressions developed based on the results of this investigation.

11. Adjustment (reduction) of coarse aggregate along with the fine aggregate to correct the yield of concrete (Scheme II mixes) results in lower strength at early ages but, it picks up strength at later ages. This kind of mix proportioning technique can be adopted for mass concreting jobs which will lead to higher economy.

12. The relationships between compressive strength of PFA concrete mixes and pulse velocity evaluated in this work show the trend as that of normal concrete mixes.

13. PFA concretes (proportioned by the method proposed in this investigation) are also found to have comparable flexural and split tensile strengths. Flexural tensile strength is found to be in the range of 13 to 30 percent of compressive strength, and split-tensile strength is in the range of 9 to 16 percent of compressive strength of PFA concretes. Split tensile strength is in the range of 57 to 75 percent of flexural tensile strength.

The early research reports on tensile strength of PFA concretes generally stated that PFA concrete mixes with comparable compressive strength failed to show comparable tensile strength. But, from the results of the present study it could be emphasised again that with suitable mix proportioning technique one could certainly bring the tensile strength of PFA concrete mixes to comparable levels. This further strengthens the validity and applicability of the efficiency factor of PFA mentioned before.

14. Steel rods embedded in PFA concretes (up to 20 percent replacement of cement and 40 percent addition of PFA with water/cementitious ratio of 0.55) are found to be well protected from corrosion activities. Rods embedded in PFA concretes

crossed the threshold potential after about 2 to 8 months than that had crossed by the reference rods.

15. Though the potential measurements reflect qualitative status of rebar corrosion, while comparing the rate of corrosion, it is found that at the age of reaching threshold potential the corrosion rate lies in the range of about 6 to 10 percent of maximum corrosion rate (found after 2 years of exposure). Therefore, potential levels are found to be a promising measure of identifying the onset period of active corrosion leading to a state of general corrosion.

16. Alkalinity (pH) of PFA concrete is found to be lower than the reference concrete, and it is decreasing with the increase of PFA content. This may be due to consumption of calcium hydroxide by pozzolanic reactions. However, pH level of PFA concretes has not gone below the level of 12 (over the period of exposure) which is found to be sufficient enough to maintain the passive state of rebars.

17. In general, electrical resistivity of concrete is found to be increasing with age. Addition of PFA improves this property of concrete further thereby the corrosion activities in PFA concrete are restricted more than that of OPC concrete.

18. Loss on ignition up to 10 percent of PFA is not found to reduce the resistance of concrete, which is confirmed by the electrical resistivity values.

19. Rate of corrosion of rebars in PFA concrete is found to be lesser than that of rebars embedded in OPC concrete. Initially the difference was about 12 percent, which has gradually increased to about 20 percent after 2 years of exposure.

20. Tafel extrapolation method of corrosion rate assessment yields lower values than that obtained by gravimetric method. However, as the corrosion activities extend to more or less a state of general corrosion, this electrochemical method yields nearly true values.

21. The PFA concrete admixed with 20 percent replacement of cement by 40 percent PFA, attained comparable 28-day strength at about 60 days. However, this has offered equally good protection against rebar corrosion as those of mixes with lower level cement replacements. This may be due to the fact that the rate of strength gain should have been more than the rate of ingression of corrosion causing agents.

22. The conclusions arrived on the performance of PFA concrete against rebar corrosion are applicable to all the three PFA samples (of in-source). However, while carefully going through the performance characteristics (pH, resistivity, open circuit potential and rate of corrosion) of concretes made out of three PFA samples (P, Q, R) it can be observed that the sample (Q) with more fineness and less carbon content is found to protect the rebar against corrosion with a little more efficiency than the remaining two samples.

23. The study on life span prediction of concrete shows that PFA concrete is found to possess 65 percent more life span than the conventional concrete, which may be considered yet another important advantage that could be derived from PFA utilisation.

6.4 SCOPE FOR FURTHER STUDY

Based on the experience gained from the present investigation the following studies are suggested to enrich the knowledge on PFA utilisation.

1. The possibilities of incorporating PFA to the maximum extent using PFA obtained from bituminous coals with more fineness in particular may be explored.

2. A study of other structural properties of PFA concretes proportioned by the proposed approach.

3. Other durability behaviour of PFA concretes proportioned by the proposed approach may be studied.

4. Studies of rebar corrosion in PFA concretes exposed to actual marine conditions and to monitor the behaviour over a still extended period of time.