CHAPTER 11

CONCLUSION AND FUTURE SCOPE OF WORK

11.1 Conclusion

Use of fly ash, industrial waste in blended cement or in concrete yields the higher value addition to such industrial wastes compared to their other applications, such as, in land fills. By its sheer size, the construction industry provides the ideal home for safe and economical disposal of fly ash. It also leads to reduction in the destructive effect on such concretes by the aggressive environment and ecology. Fly ash is a useful ingredient of modern concretes. Due to its pozzolanic nature fly ash act as useful ingredient of cement also. It cement concrete can not be justified in view of overwhelming test results and also the successful practical cases of utility of fly ashes in concrete. An emphasis on design of concrete mixtures to achieve desired properties of concrete in fresh and hardened stages and implementing proper quality control system including efficient curing during construction will ensure the realization of enormous technical and economical advantages of using fly ash in structural concrete in normal as well as in aggressive condition also.

The study showed that the strength increases with increasing amount of fly ash up to an optimum value, beyond which strength starts to decrease with further addition of fly ash. The optimum value of fly ash for the four test groups is about 20 % in various loading positions of elements in aggressive condition. Fly ash cement ratio is an important factor determining the efficiency of fly ash. As the cement content in the concrete mixture increases hydration product Ca(OH)\(_2\) will also increase and hence the amount of Ca(OH)\(_2\) with which the fly ash will enter into reaction will increase, then an increased amount of C-S-H will result. Consequently, in this way, fly ash will be used more efficiently.

The result obtained from the experimental investigation of effect of fly ash on characteristics compressive strength of concrete confirmed that the

- With addition of fly ash, concrete becomes more homogeneous and has lesser tendency of segregation and bleeding as compare to control concrete and the workability of concrete increases with increase in percentage of fly ash.
At the early age the strength of fly ash concrete is less, but with the age of concrete increases the strength of fly ash concrete also increases. Compressive strength of concrete having 20% of fly ash, 28 days strength decrease by 13% but at 112 days it increase by 10% compare to control concrete in normal condition.

The characteristic compressive strength of concrete in normal condition is less as compare to in aggressive condition, this significant difference in results at the early age of concrete, of same days is due to accelerating effect of higher content of calcium chloride in aggressive condition.

The characteristic compressive strength of control concrete specimens in aggressive environment shows about 18% lower strength and deteriorating cracks also found as compare to concrete specimens having 40% fly ash.

The deteriorating cracks are also found more on concrete cube without fly ash cured in aggressive condition, as compare to cube contains fly ash. The cubes made with fly ash retained their excellent shape and with stand perfect soundness over cubes made without fly ash in aggressive condition.

The percentage increase in strength of concrete in aggressive condition as compare to normal condition at 28 days age for control concrete 10.05%, specimens with 10% fly ash increase in strength is 12.6%, 20% fly ash specimen increase in strength 23.79%, for 30% fly ash increase in strength is 25.98% and for 40% of fly ash increase in strength is 28.06%. The high strength developed in concrete with fly ash due to less crystalline hydrated compound and enhance ettringite formation in the aggressive environment.

If 20% of cement is replaced by fly ash strength at later meets the specified strength of normal concrete, which is economical by 12% and in aggressive condition the strength also at 112 days age is 2% more than control concrete and 5% more at the age of 365 days as compare to control concrete.

The following conclusions are drawn from the study of flexural behavior of beams on conventionally reinforced concrete using fly ash concrete beams over the control concrete beams.

At the age of 112 days, the concrete having 10 percent and 20 percent fly ash have 3% and 9% more strength respectively in normal condition and near to same value in aggressive condition.
At the age of 365 days, the concrete having 10 percent and 20 percent fly ash have 6% and 9% more strength respectively in normal condition and near to same value in aggressive condition.

The beams with the reinforcement less than the minimum specified in the code, the cracking strength was 62% to 67% of ultimate strength for control concrete, while it is 42% to 54% for concrete having fly ash 10% to 40% in normal condition. For aggressive condition the cracking strength was 52% to 62% for control concrete while it is near to 50% for concrete having fly ash.

The concrete contain fly ash cured in aggressive condition shows same or slightly less ultimate strength than the companion control beams at early age, while it is more in normal condition.

The theoretical strength prediction of beam in flexure as per IS 456-2000 shows the average value of 28 days, 56 days, 112 days and 365 days of $M_{u, \text{exp}} / M_{u, \text{theory}}$ was 1.31 for control concrete and 1.32 for 10 percent fly ash, 1.35 for 20 percent fly ash, 1.22 for 30 percent fly ash and 1.17 for 40 percent fly ash concrete in normal condition.

The theoretical strength prediction of beam in flexure as per IS 456-2000 shows the average value of 28 days, 56 days, 112 days and 365 days of $M_{u, \text{exp}} / M_{u, \text{theory}}$ was 1.34 for control concrete and 1.38 for 10 percent fly ash, 1.44 for 20 percent fly ash, 1.26 for 30 percent fly ash and 1.22 for 40 percent fly ash concrete in aggressive condition.

The ratio of $M_{u, \text{exp}}$ in aggressive condition and in normal condition of the companion beams are near to 1.01 to 1.05 at the age of 28 days.

The ratio of $M_{u, \text{exp}}$ in aggressive condition and in normal condition of the companion beams are near to 0.98 to 1.08 at the age of 56 days.

The ratio of $M_{u, \text{exp}}$ in aggressive condition and in normal condition of the companion beams are near to 1.01 to 1.16 at the age of 112 days.

The ratio of $M_{u, \text{exp}}$ in aggressive condition and in normal condition of the companion beams are near to 1.04 to 1.12 at the age of 365 days.

Generally, the fly ash concrete beams with 10% and 20% fly ash recorded slightly higher transverse deflections at service load as compare to control concrete. But the beam having 30% and 40% fly ash have more deflection.

At service load the crack width varying from 0.082 to 1.25 mm for all the beams. The control shows equal or 4 to 5% more crack width than the companion fly ash
concrete beams. The crack width in aggressive condition, at service load as well as at ultimate load was higher than the normal condition for all the companion beams.

- The experimental investigation clearly demonstrated that there was no difference in strength, deformations and structural performance between the control and the having 10 percent fly ash and 20 percent fly ash.

- As for design, the theory applied for strength prediction of control beams is equally valid for that of fly ash concrete beams.

- Design flexural micro-cracking has very little influence on service life of RC members with respect to rebar corrosion.

- RC members cast with concrete incorporating fly ash, has much longer service life against rebar corrosion, even for flexural members with micro cracks in the tension zone, vis-à-vis control concrete members.

- 20 percent fly ash concrete beam shows higher strength, permissible deformations and superior structural performance as compare to control concrete after 56 days age of concrete. control concrete one cubic meter needs 383 Kg cement and 20 percent replaced cement by fly ash needs 306 Kg cement which is clear saving of cement of 77 Kg per cubic meter of concrete.

The following conclusions are drawn from the study of flexural behavior of plates in normal condition and aggressive condition on conventionally reinforced concrete incorporating different % of fly ash in concrete reinforced plates over the control concrete plates.

- At the early age the characteristic compressive strength of concrete with fly ash is less than control concrete, but at the age of 56 days, the concrete having 10 percent and 20 percent fly ash have same and 3 % more strength respectively in normal condition and in aggressive condition.

- At the age of 112 days, the concrete having 10 percent and 20 percent fly ash have 3 % and 9 % more strength respectively in normal condition and near to same value in aggressive condition.

- At the age of 365 days, the concrete having 10 percent and 20 percent fly ash have 6 % and 9 % more strength respectively in normal condition and near to same value in aggressive condition.

- The plates with the reinforcement less than the minimum specified in the code, the cracking strength was 42 % to 44 % of ultimate strength for control concrete, continuously increasing with age of concrete, while it is 35 % to 45 % for concrete
having fly ash 10 %, 34 % to 43 % for concrete having fly ash 20 %, 33 % to 39 % for concrete having fly ash 30 %, and 31 % to 36 % for concrete having fly ash 40 % continuously increasing with age of concrete, in normal condition.

- For aggressive condition the plates with the reinforcement less than the minimum specified in the code, the cracking strength was 45 % to 51 % of ultimate strength for control concrete, continuously increasing with age of concrete up to 112 days age, while it is decrease at 365 days age of concrete, 35 % to 38 % for concrete having fly ash 10 %, 33 % to 36 % for concrete having fly ash 20 %, 33 % to 42 % for concrete having fly ash 30 %, and 30 % to 40 % for concrete having fly ash 40 % continuously increasing with age of concrete up to 56 days age and decreasing at 112 days and later.

- The control concrete in aggressive condition at early age shows higher ultimate strength than in normal condition, while at 56 days and later the ultimate strength in normal condition is higher than aggressive condition.

- The concrete contain fly ash cured in aggressive condition shows same or slightly higher ultimate strength than the certain case of 30 percent fly ash concrete, in normal condition. But less in case of 40 percent fly ash concrete.

- The theoretical strength prediction of plate in flexure as per IS 456-2000 shows the average values of 28 days, 56 days, 112 days and 365 days age are \( \frac{M_{u \text{ expt}}}{M_{u \text{ theory}}} \) was 1.14 for control concrete and 1.22 for 10 percent fly ash, 1.27 for 20 percent fly ash, 1.17 for 30 percent fly ash and 1.14 for 40 percent fly ash concrete in normal condition.

- The theoretical strength prediction of plate in flexure as per IS 456-2000 shows the average values of 28 days, 56 days, 112 days and 365 days age are \( \frac{M_{u \text{ expt}}}{M_{u \text{ theory}}} \) was 1.03 for control concrete and 1.21 for 10 percent fly ash, 1.27 for 20 percent fly ash, 1.14 for 30 percent fly ash and 1.08 for 40 percent fly ash concrete in aggressive condition.

- The ratio of \( M_{u \text{ expt}} \) in aggressive condition and in normal condition of the companion plates are near to 1.01 to 1.06 at the age of 28 days.

- The ratio of \( M_{u \text{ expt}} \) in aggressive condition and in normal condition of the companion plates are near to 0.92 to 0.98 at the age of 56 days.

- The ratio of \( M_{u \text{ expt}} \) in aggressive condition and in normal condition of the companion plates are near to 0.98 to 1.03 at the age of 112 days.
The ratio of \( M_u \) in aggressive condition and in normal condition of the companion plates are near to 0.98 to 1.02 at the age of 365 days.

Generally, the fly ash concrete plate with 10 % and 20 % fly ash recorded slightly higher central deflections at service load as compare to control concrete. But the plate having 30 % and 40 % fly ash have more deflection.

The crack width varying from 0.080 to 2.25 mm for all the plates. The control concrete shows equal or slight more crack width than the companion fly ash concrete plates. The crack width in aggressive condition, starts later than normal condition but the widths are more.

The development of crack patterns and width of crack shows that the control concrete in normal condition and also concrete with fly ash in aggressive condition shows regular as per yield line theory, while the control concrete in aggressive condition shows irregular crack patterns.

The experimental investigation shows that, there was no difference in ultimate strength, central deflection and structural performance between the control and the having 10 percent fly ash and 20 percent fly ash. At early age the strength for control concrete is slight less but later it is higher.

As for design, the theory applied for strength prediction of control plates is equally valid for that of fly ash concrete plates.

20 percent fly ash concrete beam shows higher ultimate strength, permissible deformations and superior structural performance as compare to control concrete after 56 days age of concrete. Hence the use of fly ash shows clear saving of cement, which lead to economical concrete.

The following conclusions are drawn from the study of flexural behavior of plates in normal condition and aggressive condition on conventional ferrocement plate incorporating fly ash in mortar ferrocement plates over the control mortar ferrocement plates.

Deboning between the steel- mortar interfaces makes the actual moment capacity of a cracked section higher than the calculated value based on plane deformation assumption.

The plates with the reinforcement less than the minimum specified in the code, the cracking strength was 49 % to 61 % of ultimate strength for control mortar. while it is 48 % to 63 % for mortar having fly ash 10 %, 41 % to 54 % for mortar having fly
ash 20 % and 34 % to 48 % for mortar having fly ash 30 %. And strength is continuously increasing with age of mortar in normal condition.

- For aggressive condition the plates with the reinforcement less than the minimum specified in the code, the cracking strength was 42 % to 70 % of ultimate strength for control mortar, strength is increasing with age of mortar up to 56 days age, while it is decrease at 365 days age of mortar, 40 % to 60 % for mortar having fly ash 10 %, 39 % to 67 % for mortar having fly ash 20 % and 35 % to 57 % for mortar having fly ash 30 %. Strength is continuously increasing with age of mortar up to 365 days age for 10 percent and 20 percent fly ash mortar, while for 30 percent fly ash mortar at 365 days age the strength is reduced.

- The control mortar in aggressive condition at early age shows higher ultimate strength than in normal condition, while at 365 days and later the ultimate strength in normal condition is higher than aggressive condition.

- The mortar contain fly ash 10 percent and 20 percent cured in aggressive condition shows same or slightly higher ultimate strength than in normal condition. But less in case of 30 percent fly ash mortar.

- The ratio experimental flexure strength of plate calculated as per IS 456-2000 and the theoretical flexure strength plate predicted are average values of 28 days, 56 days, and 365 days age are \( \frac{Mu_{expt}}{Mu_{theory}} \) was 1.25 for control mortar and 1.24 for 10 percent fly ash, 1.27 for 20 percent fly ash and 1.16 for 30 percent fly ash mortar in normal condition.

- The ratio experimental flexure strength of plate calculated as per IS 456-2000 and the theoretical flexure strength plate predicted are average values of 28 days, 56 days, and 365 days age are \( \frac{Mu_{expt}}{Mu_{theory}} \) was 1.29 for control mortar and 1.33 for 10 percent fly ash, 1.34 for 20 percent fly ash and 1.13 for 30 percent fly ash mortar in aggressive condition.

- The ratio of \( Mu_{expt} \) in aggressive condition and in normal condition of the companion plates are 1.03 for control mortar, 1.09 for the mortar containing 10 percent fly ash, 1.16 for the mortar containing 20 percent fly ash and 0.95 for the mortar containing 30 percent fly ash at the age of 28 days.

- The ratio of \( Mu_{expt} \) in aggressive condition and in normal condition of the companion plates are 1.08 for control mortar, 1.15 for the mortar containing 10 percent fly ash, 1.14 for the mortar containing 20 percent fly ash and 0.95 for the mortar containing 30 percent fly ash at the age of 56 days.
Generally, the fly ash mortar ferrocement plate with 10% and 20% fly ash recorded slightly higher central deflections at service load as compared to control mortar ferrocement plate. But the plate having 30% fly ash have more deflection.

The crack width calculated, varying from 0.0405 to 0.0412 mm for all the plates. The control mortar shows equal or slight more crack width than the companion fly ash mortar ferrocement plate. The crack width in aggressive condition starts later than normal condition but the widths are more.

The development of crack patterns and width of crack shows that the control mortar in normal condition and also mortar with fly ash in aggressive condition shows regular as per yield line theory, while the control mortar in aggressive condition shows irregular crack patterns.

The experimental investigation shows that, there was no difference in ultimate strength, central deflection and structural performance between the control and the having 10 percent fly ash and 20 percent fly ash. At early age the strength for control mortar is slight less but later it is higher.

As for design, the theory applied for strength prediction of control mortar ferrocement plate is equally valid for that of fly ash mortar ferrocement plates.

The moment capacity of elements depends on arrangement of reinforcement, cover of reinforcements, but it decrease by nominal values in corrosive environment, because the greater change in compressive strength leads only to a small change in the lever arm at the cracked section. The cracks of the elements have an insignificant influence on corrosion of steel.

20 percent fly ash mortar ferrocement plate shows higher ultimate strength, permissible deformations and superior structural performance as compared to control mortar ferrocement after 56 days age of concrete. Hence the use of fly ash shows clear saving of cement, which lead to economical concrete.

From experimental investigation of effect of fly ash on water absorption, permeability and bond strength of concrete following conclusions are drawn,

The effective water absorption for the mix without fly ash is 8.10% while controlled concrete this value is 8.30%. There was slight reduced water absorption as percentage of fly ash was increases.

The sorptivity for the control concrete mix was 9.04 x 10^-6 m^2/√s, where as for the concrete mixes containing fly ash 10% to 40% are less than that of control concrete, range of 6.48 x 10^-6 m^2/√s to 9.04 x 10^-6 m^2/√s. Thus the mix having fly ash shows
more durability and would improve further in view of the continuation of pozzolanic activity of fly ash. Also chloride diffusion coefficient and chloride permeability are less in cases of mixes containing fly ash as compare to control concrete.

➢ The pull out force at early age of control concrete is more than the concrete mixes containing fly ash, but for long term the force the mixes with fly ash are more than the control concrete. The specimens shows the higher bond strength for early age of concrete in aggressive condition as compare to normal condition for companion mixes.

➢ It is noted that the concrete mix with 20% fly ash content had the lowest value of saturated water absorption, sorptivity and chloride diffusion when compare with that of the control concrete mixes. Therefore, it can be concluded that replacement of cement with fly ash up to 20% would render the concrete more durable and corrosion resistant, besides meeting the strength requirements.

It is beyond doubt that a distinct shift is evident in the Indian scenario of fly ash utilization from pessimism to optimism if the increased production of PPC is any indication. The fly ash based bricks and cement are far superior in engineering properties over their conventional competitors in aggressive condition. The opportunity to abate CO₂ is 35 million tonnes in cement and 45 million tonnes in bricks by using fly ash in both the segments in India. When Kyoto Protocol comes into effect, fly ash utilization proves as the money-spinner in “green trading” point of view, for achieving CO₂ abatement.

Use of fly ash is one of the efficient measures for sustainable development of country like India. It is efficient method to produce high performance concrete economically, eco-friendly way for disposal of this industrial waste and effective approach for preservation of resources like lime stone and coal. Fly ash should be considered as resource material considering its beneficial effects of using it in the material concrete for construction industries.

“Not all the armies in the world put together are as powerful as an idea whose time has come”

-- Victor Hugo

The time has come for appreciating the concept that fly ash can be gainfully used in making concrete strong, durable, eco-friendly and economical, without any reservations.
11.2 Future Scope of Work

The slight reduction in the workability of the fly ash based mixes shows that fly ash collection and processing technology in India need to be improved in order to produce good and acceptable quality of fly ash. Maximum sources of Indian fly ash are some of the best lots in the world, but there is wide variability in the quality of fly ashes because no processing facilities available to ensure uniformity in quality, as in countries abroad. The Indian fly ashes, in certain cases, may not meet the stringent requirements of international codes, such as BS: 3892. This may be due to quality of coal, lower firing temperature and collection procedures. At present, not much have been done towards processing of fly ash using techniques, such as, cyclone separators, so that good quality fly ashes are made available to make either blended cements or to use the fly ash as admixture/additives at the stage of mixing concrete.

Extensive experimental work is required to established how the properties of concrete like tensile strength, modulus of elasticity, strength gain, shrinkage, heat of hydration etc. are affected in aggressive condition with properties of fly ash and the deleterious effects on long-term durability of concrete, particularly corrosion of reinforcement.