CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 General

During the last few years several serious damages to concrete structures have been reported due to corrosion of reinforcing steel. Most visible effect of the corrosion of embedded rebar is the cracking and delamination of the concrete cover. Therefore an effective corrosion protection has to be developed to prevent the occurrence of such types of failure. In this thesis attempts have been made to study the effect of various coatings, cover and mineral admixture in resisting corrosion of rebars in reinforced concrete specimens.

7.2 Summary

To begin with, the study of effectiveness of modification in or on steel in the prevention of rebar corrosion for different cover to diameter ratios and different grades of concrete was carried out. The diameter of the rod was kept constant as 25 mm. Ordinary uncoated HYSD rebars, Corrosion Resistant Steel (CRS), rebars coated with Cement Slurry Inhibitor (CSI) and Epoxy Zinc Rich Primer (EZRP) were used. The cylinder specimens of size, 100 mm diameter and 150 mm height, 150 mm diameter and 300 mm height and 200 mm diameter and 350 mm height were cast with different grades of concrete, viz. M 15, M 20 and M 25. Totally thirty six cylinder specimens were subjected to accelerated corrosion process by galvanostatic method. Effect of concrete cover to diameter ratio, type of steel and grade of concrete on corrosion has been studied.
Subsequently beam specimens of cross section 100 mm x 150 mm and length 1000 mm reinforced with two numbers of HYSD bars of 10 mm diameter as main rebars and two numbers of 8 mm diameter as hanger rebars were cast using M 20 grade of concrete. Epoxy Zinc Rich Primer and Cement based coating were used for rebars and their effectiveness for rebar protection from corrosion was studied. Accelerated corrosion process (galvanostatic method) and alternate wetting and drying method have been used for inducing corrosion. Nine specimens were subjected to the galvanostatic method of corrosion process for a period of 60 days, 75 days and 100 days (each three specimens). Under alternate wetting and drying method, nine specimens were subjected to 12 hours wetting with electrolyte solution having 3 % Nacl concentration and thereafter exposed to atmosphere for the next 12 hours in a day and night cycle. The test was continued for a period of one year. Gravimetric method was used to quantify the extent of corrosion.

For the next part of the study, Rice Husk Ash Cement (RHAC) has been used as corrosion inhibitor. It is obtained by blending 30 % of RHA (Hyper 2000) with 70 % of Ordinary Portland Cement (OPC). M 30 and M 35 grades of concrete with OPC and RHAC have been used for the test specimens. IPNet coating and Nito Zinc Primer coating were the two different coatings applied on the surface of the rebars. Twelve numbers of beam specimens were subjected to the accelerated corrosion process under galvanostatic method for a period of 15 days. Weight loss of rebars was taken into consideration for determining the effect of corrosion. XRD analysis and Scanning Electron Micrograph (SEM) study were carried out on the concrete samples of OPC and RHAC to determine the presence of various minerals in the samples and to study the structure respectively. Pull out test was carried out to determine the bond strength of coated rebars. The role of RHAC in preventing / retarding the corrosion and also the effectiveness of various coatings on rebars in resisting corrosion was studied.

In the next part of the research work, the effect of corrosion under simulated sustained loaded condition was studied. Thirty two numbers of beam specimens were cast using M 30 and M 35 grades of concrete. The specimens were clamped
back to back after curing to simulate the loaded condition (Two point loading). Five percent above crack load was applied on sixteen specimens and five percent below crack load was applied on the remaining sixteen specimens. Galvanostatic method was used to accelerate the corrosion process for a period of 15 days. The effect of load intensity, coating and cement type on corrosion was studied and discussed.

For the final part of the study, the service life of beam specimens subjected to corrosion under various environmental conditions provided by surrounding concrete were predicted. Three set of specimens, sixteen each were subjected to accelerated corrosion process for a period of 10, 15 and 20 days respectively. The beam specimens were cast using M 30, M 35 grades of concrete with OPC and RHAC. Four specimens were used as companion specimens. Service life of beam specimens are obtained based on serviceability and ultimate load conditions.

7.3 Conclusions

7.3.1 Influence of Cover Concrete

a. There is increase in crack initiation time for M25 grade of concrete compared to lower grades for coated and uncoated bars for specified cover to diameter ratios.

b. As the cover thickness increases from 37.5 to 62.5 mm (67 %) and 62.5 mm to 87.5 mm (40%), the rebar is more resistant to corrosion. For example, Nito Zinc Primer coated rebars with 62.5 mm cover showed a weight loss of 38 % less than that of the same with 37.5 mm cover for M 25 grade of concrete.

c. The CRS rebar has less loss of weight by 18 % compared to uncoated ordinary steel for cover to depth ratio of 1.5 for M15 grade of concrete.
d. The efficiencies of coating can be approximately rated as 27% for NZP, 26% for CSI and 16% for CRS when compared with uncoated rebars for M25 grade of concrete for cover to diameter ratio of 3.5.

e. CRS is not showing appreciable improvement in corrosion resistance compared to coating; CRS steel is significantly less efficient. Cost of coated rebars may be cheaper than CRS. The rebars coated with Cement Slurry Inhibitor and Nito Zinc Primer are more efficient in resisting corrosion than uncoated rebars and CRS rebars for all cover thickness and concrete grades considered.

f. As the cover/diameter ratio increases, the time taken for cracking also increases.

7.3.2 Corrosion of Rebars in the Beam Specimens Under Unstressed Condition

a. The weight loss of epoxy coated rebars was 39% and 26% less than that of uncoated rebars and rebars coated with cement based coating under galvanostatic method for a period of 100 days. For the period of 75 days, the loss of weight of epoxy coated rebars was 27% and 10% less than that of uncoated rebars and rebars with cement based coating. Epoxy coated rebars showed weight loss of 27% and 22% less than that of uncoated rebars and rebars with cement based coating for a period of 60 days.

b. Corrosion affects the failure mode. When corrosion is induced for 100 days, the specimens designed to fail by flexural yielding, when loaded, either had a bond failure or had a shear failure. This was witnessed during the test. This may be considered as an important conclusion. The failure mode becomes brittle after corrosion eventhough, the specimens is designed to have a favorable ductile flexural failure.
This behavior was seen especially for beams tested after galvanostatic corrosion. The preferential corrosion of stirrups over main steel is the reason for this unfavourable behaviour.

c. In case of alternate wetting and drying process, epoxy coated rebars showed a weight loss of 35 % and 14 % less than that of uncoated rebars and rebars with cement based coating respectively.

d. The performance of epoxy coating is better than cement slurry coating under both accelerated corrosion process and alternate wetting and drying process.

e. Deterioration due to corrosion is less for specimens with higher grades of concrete.

7.3.3 Influence of Rice Husk Ash Cement

a. For the specimens with uncoated rebar, cast using M 30 grade of concrete with Rice Husk Ash Cement, the loss of weight is 50 % less than that of specimens cast using OPC.

b. The chloride content of beam specimens containing RHAC showed lesser value by 29.09 % than that of the beam specimens with OPC for M30 grade.

c. For the specimens with uncoated rebars cast using M 35 grade of concrete with Rice Husk Ash Cement the loss of weight is 41 % less than that of specimens cast using OPC.

d. By comparing Scanning Electron Micrographs of both OPC and RHAC concrete samples, it is seen that fibre like cellular structure is present in RHAC, which is absent in OPC (Figs.4.5 and 4.6). It is also observed
that the cells are not interconnected and hence it gives an excellent barrier to the movement of chloride ions. This can be attributed as the reason for 29% reduction in chloride content of RHAC concrete of M 30 grade. At the same time it is observed that the cells of OPC are interconnected.

e. The X Ray Diffraction (XRD) analysis of RHAC shows the mineralogical composition (Fig. 4.8). The high percentage of amorphous silica present in RHAC is discernable in the XRD analysis. The presence of amorphous silica was also confirmed by the test on chemical composition of RHAC (Appendix A). These studies confirm the better performance of RHAC against corrosive environment.

7.3.4 Coating Efficiency

a. Specimens of M30 grade concrete with OPC under Type A Loading and rebars coated with Nito Zinc Primer and IPNet showed a weight loss of 75% and 54% less than that of uncoated rebars respectively.

b. For Type B Loading, the specimens of M30 grade concrete with OPC, rebars coated with Nito Zinc Primer and IPNet showed a weight loss of 74% and 46% less than that of uncoated rebars respectively.

7.3.5 Corrosion of Rebars in the Beam Specimens Under Stressed Condition

a. As the intensity of load increased, the amount of corrosion also increased. The loss of weight of rebars in the case of Type A loading was more than that of Type B loading. For the beam specimens cast using M30 grade of concrete with OPC, the loss of weight of rebars is 37% more in the case of Type A loading than Type B loading. For the
specimens using RHAC with M 30 grade of concrete, the weight loss of rebars is 7% more in the case of Type A loading than Type B loading.

b. For the specimens cast with IPNet coated rebars and OPC, loss of weight was 16% more in the case of Type A loading than Type B loading. For the specimens cast with RHAC and IPNet coated rebars, the weight loss for Type A loading was 25% more than that of Type B loading.

c. In the case of specimens with Nito Zinc Primer coated rebars and M30 concrete with OPC under Type A Loading, the weight loss of rebars was 33% more than that of the corresponding specimens under Type B Loading. In the case of M30 grade with RHAC concrete specimens the weight loss is 33% more in Type A Loading than Type B Loading.

7.3.6 Life prediction

The prediction of service life of beam specimens was carried out based on serviceability and ultimate load considerations. The life span derived based on serviceability condition was lower than that of the specimens derived based on ultimate load considerations. The life based on serviceability condition for various specimens lies between 14 and 20 years, whereas in ultimate load condition the range is between 27 to 42 years (Tables 6.8, 6.9, 6.10 and 6.11). Therefore, the life prediction based on serviceability condition was considered as more reliable and safe. The general equations in the chapter 6 give the life of beam specimens under various conditions.

7.4 Suggestions for Future Research

a. Extensive field studies are required with more number of specimens exposed to different environments in the field, to validate the laboratory study.
b. Life prediction study may be carried out for the structures in the field exposed to different environmental conditions. The results of the same may be compared with relevant laboratory findings.

c. The parameters like various cover thicknesses, bar diameter and crack width should be taken into consideration for finding their effect on reinforcement corrosion.

d. In this work, 30 % of OPC was replaced by RHAC. The percentage of RHAC may be varied and tests may be carried out on structural members.

e. Instead of RHAC, the effect of various mineral admixtures like silica fume, fly ash for controlling / retarding corrosion process may be studied.