CHAPTER 7

CONCLUSIONS

7.1 GENERAL

Over seven hundred experiments were conducted to evaluate the performance of protective coatings on high yield strength cold twisted deformed (CTD) and Thermomechanically Treated (TMT) bars. Four different coating systems are considered which include inhibited cement slurry coating (passivating), cement polymer composite coating (passivating-cum-barrier), galvanizing (barrier-cum-sacrificial) and cement polymer anticorrosive coating (passivating) developed in the laboratory. The performance of coated rebars with and without coating damage were also studied in control and inhibitor admixed concrete. Sodium nitrite-based anodic mixed inhibitor developed in the laboratory was used as an inhibitor. The tests such as chemical resistance test, applied voltage test, impressed voltage test, open circuit potential test, macrocell corrosion test and atmospheric exposure test were conducted to investigate the corrosion resistance properties of the coating systems. Bond strength to concrete test, impact test and adhesion test were conducted to study the mechanical properties of the coating material.

Based on the various test results, the performance evaluation of the various coating systems were done and the following conclusions were drawn for the individual coating systems.
7.2 INHIBITED AND SEALED CEMENT SLURRY COATING
(Corrosion Inhibitor-containing Cementitious Slurry Coating)

- The coating did not blister or soften or lose bond in all the tested mediums irrespective of type of rebar in the chemical resistance test and also meets the requirements of Indian and ASTM Standards.

- Both coated Cold Twisted Deformed (CTD) and Thermo mechanically Treated (TMT) bars did not fail during the one hour applied voltage test and passes the requirements of Indian Standards.

- Impressed voltage test results exhibited a significant increase in cracking resistance time of the order of 1.8 to 2.0 as compared to uncoated bars in control concrete irrespective of type of rebar, coating damage and inhibitor modification in concrete. This reveals an improved tolerance of coated bars against coating damage and better compatibility for addition of inhibitors in concrete.

- Open circuit potential test results revealed a low corrosion risk for coated bars irrespective of coating damage, type of rebar and inhibitor modification in concrete. Passivity of the rebar was also maintained during the test period.

- Macrocell corrosion test results indicated a significant increase in current development for CTD coated bars and marginal increase in macrocell current for TMT coated bars in control concrete. Damaged coated bars showed an remarkable increase in macrocell current irrespective of the type of rebar in control concrete. Significant reduction in macrocell current was observed for CTD and TMT coated
bars in inhibitor admixed concrete irrespective of coating damage.

- Bode plots showed an increase in impedance values for rebars embedded in inhibitor admixed concrete irrespective of coating damage and exposure conditions. Coating damage did not show any significant variation in impedance values irrespective of the type of rebar in control concrete.

- Atmospheric exposure test results indicated that the coated bars can be stored in the site for a maximum period of two months provided good stocking arrangements are available.

- There is a significant increase in bond strength of the order 17% for coated CTD bars as compared to uncoated bars, whereas for TMT coated bars the increase is only 8%. Inhibited cement slurry coated bars surpasses the codal requirements as per Indian Standards.

- In the impact test, there was no shattering or cracking or bond loss of coating around the impact area and the codal provisions of Indian Standards are satisfied.

- Adhesion test results suggested that irrespective of the type of rebar, these coatings have to be applied over rebars after cutting and bending operation is over.

7.3 CEMENT POLYMER COMPOSITE COATING
(Polymer-modified Cementitious Slurry Coating)

- The coating did not blister or soften or lose bond in all the tested mediums irrespective of type of rebar in the chemical resistance test and also meets the requirements of Indian and ASTM Standards.
- Both coated CTD and TMT bars did not fail during the one hour applied voltage test and passes the requirements of Indian Standards.
- Impressed voltage test results showed a remarkable increase in cracking resistance time of the order of 6 times as compared to uncoated bars in control concrete irrespective of the coating damage and the type of rebar. There is a drastic reduction in cracking resistance time of the order of 5 times for coated CTD and TMT bars with and without coating damage in inhibitor admixed concrete as compared to control concrete.
- Open circuit potential test results revealed a low corrosion risk for coated bars irrespective of coating damage, type of rebar and inhibitor modification in concrete. Passivity of the rebar was also maintained during the test period.
- Macrocell corrosion test results revealed a significant reduction in macrocell current indicating higher corrosion resistance for coated CTD and TMT bars with and without coating damage in control and inhibitor admixed concrete.
- Bode plots showed an remarkable increase in impedance values for coated bars in control concrete which indicate higher corrosion resistance even after exposure to accelerated corrosion conditions. Although inhibitor modification in concrete did not show any improvement in impedance values initially, it enhances in maintaining the impedance values for coated bars with and without coating damage in the long run.
- Atmospheric exposure test results indicated that the coated bars can be stored in the site for a maximum period of four months beyond which the coating may show distress.
There is an appreciable reduction in bond strength of the order 13 and 9% for coated CTD and TMT bars respectively but meets the codal requirements of Indian Standards.

In the impact test, there is no shattering or cracking or bond loss of coating around the impact area irrespective of the type of rebar and satisfies the codal provisions of Indian and ASTM Standards.

In the adhesion test there is no cracking on the coating surface visible to the unaided eye on the outside radius of the bar and passes the codal requirements of Indian and ASTM Standards.

7.4 CEMENT POLYMER ANTICORROSIVE COATING
(Corrosion Inhibitor-containing Polymer-modified Cementitious Slurry Coating)

The coating did not blister or soften or lose bond in all the tested mediums irrespective of type of bar in the chemical resistance test and also meets the requirements of Indian and ASTM Standards.

The coated CTD and TMT bars did not fail during the one hour applied voltage test and passes the requirements of Indian Standards.

Impressed voltage test results showed an increase in cracking resistance time for coated bars of the order of 2.3 times as compared to uncoated bars in control concrete irrespective of the type of rebar. Inhibitor modification in concrete increases the cracking resistance time of the order of 3.3 and 2.6 times for CTD and TMT bars respectively irrespective of the coating damage. The coating damage did not contribute any
appreciable influence on the cracking resistance behaviour for both control and inhibitor admixed concrete.

- Open circuit potential test results revealed a low corrosion risk for coated bars irrespective of coating damage, type of rebar and inhibitor modification in concrete. Passivity of the rebar was also maintained during the test period.

- Macrocell corrosion test results indicated appreciable macrocell current development for CTD coated bars with and without coating damage in control concrete. Appreciable reduction in macrocell current for CTD coated bars were observed for inhibitor admixed concrete irrespective of coating damage. There is a remarkable reduction in macrocell current for TMT coated bars during the test period irrespective of coating damage and inhibitor modification.

- The coated bars exhibited similar impedance behaviour as seen from Bode plots irrespective of the coating damage, type of rebar, inhibitor modification and exposure conditions. This reveals better tolerance towards coating damage in accelerated corrosion conditions.

- Atmospheric exposure test results indicated that the coated bars can be stored in the site for a maximum period of six months provided good stocking arrangements are available.

- The bond strength behaviour was similar for coated CTD bars as compared to uncoated bars. Marginal reduction in bond strength values were obtained for TMT coated bars of the order of 5% as compared to uncoated bars and meets the codal requirements as per Indian Standards.

- In the impact test, there was no shattering or cracking or bond
loss of coating around the impact area and the codal provisions of Indian Standards are satisfied.

- Adhesion test results suggested that irrespective of type of rebar, these coatings have to be applied over rebars after cutting and bending operation is over.

7.5 GALVANIZATION

- Chemical resistance test results revealed an excellent sacrificial protection to steel rebars in the tested mediums except in 3M NaOH and fails to meet the codal requirements of Indian and ASTM Standards.

- Applied voltage test results suggested that the corrosion control efficacy of these rebars under accelerated corrosion condition is for a limited duration.

- Impressed voltage test results indicated an appreciable increase in cracking resistance time for CTD and TMT bars of the order of 1.8 to 2.0 times as compared to uncoated bars in control concrete irrespective of the coating damage. There is a drastic reduction in cracking resistance time for galvanized CTD and TMT bars with and without coating damage in inhibitor admixed concrete.

- Open circuit potential test results revealed a low corrosion risk for galvanized rebars irrespective of coating damage, type of rebar and inhibitor modification in concrete. The final potential observation revealed that zinc offered excellent sacrificial protection to steel rebar during the exposure period.

- There is an increased macrocell current development for galvanized CTD and TMT bars in control concrete irrespective of coating damage which exhibits an improved
sacrificial protection offered by zinc in the initial stages. Appreciable reduction in macrocell current was observed for galvanized CTD and TMT bars in inhibitor admixed concrete irrespective of the coating damage as compared to control concrete.

- Impedance test results indicated that galvanized bars in control concrete provide sacrificial protection to rebars irrespective of coating damage. Galvanized rebars in inhibitor admixed concrete improves the impedance values irrespective of coating damage indicating high corrosion resistance. No appreciable variation in impedance values were observed because of coating damage or inhibitor modification in concrete.

- Atmospheric exposure test results revealed that galvanized CTD and TMT bars performed well during the one year exposure period and showed an excellent sacrificial protection offered by zinc to steel rebars.

- There is marginal reduction in the bond strength values for both galvanized CTD and TMT bars as compared to uncoated bars but meets the codal requirements of Indian Standards.

- In the impact test, there was no shattering or cracking or bond loss of coating around the impact area irrespective of the type of rebar and satisfied the codal provisions of Indian and ASTM Standards.

- In the adhesion test there is no cracking on the coating surface visible to the unaided eye on the outside radius of the bent galvanized CTD and TMT bars and passes the codal requirements of Indian and ASTM Standards.
7.6 CONTRIBUTIONS

- A cost effective simple sodium nitrite and styrene-butadiene based anticorrosive polymer cementious coating was developed. This coating system offers necessary corrosion resistance and mechanical properties as required by Indian and ASTM Standards.

- A cost effective sodium nitrite-based anodic mixed inhibitor was developed which imparts significant corrosion resistance properties to reinforced cement concrete even under highly accelerated corrosion conditions.

7.7 IMPORTANT RESEARCH FINDINGS

- The usage of corrosion inhibitor along with protective coating needs thorough investigation for their compatibility in the concrete environment.

- Addition of corrosion inhibitor in concrete improves the performance of cement based passivating type coating systems such as inhibited cement slurry coating and cement polymer anticorrosive coating.

- Addition of inhibitor in concrete significantly affects the performance of galvanized rebars and cement polymer composite coated rebars in the highly accelerated corrosion conditions.

- Failure mechanism of galvanized rebar in the inhibitor admixed concrete under accelerated electrochemical corrosion conditions were established.
Coating damage of 1% did not significantly reduce the corrosion resistance properties of coated rebars except for cement polymer composite coated bars.

In all the corrosion related tests, Thermomechanically Treated (TMT) coated bars showed better performance as compared to Cold Twisted Deformed (CTD) coated bars which may be due to improved chemical composition and homogeneity.

To maximize the influence of inhibitor on the corrosion resistance efficacy of reinforced cement concrete, it has to be used alone rather than using it along with coated bars.

7.6 SCOPE FOR FURTHER RESEARCH

Similar studies can be conducted using different types of cement and by varying the grade of concrete.

In macrocell corrosion test and open circuit potential test, the exposure period can be extended to study the long term behaviour of coated bars.

Percentage coating damage can be varied and similar studies can be conducted.

Bond strength test can be conducted on higher ages with inhibitor modification to study the long term performance.

Test for abrasion resistance and salt spray test can be conducted for coated specimens.

In impressed voltage test, acceleration factor can be reduced and the behaviour can be studied.