Synopsis

Studies on the Effect of Polymers in Concrete for Steel Corrosion

1.0 Introduction:

This thesis primarily addresses the issues on the use of polymers in nurturing and building durable concrete structures. The class of polymers used is generally represented by the nomenclature “Construction polymers.” These polymers have three different roles in the corrosion control measures of steel in concrete structures, (i) As a primary component of surface coating formulations on concrete surface (ii) As an integral part of concrete, known as polymer concrete (iii) as a protective coating to the embedded rod interfacing with pristine concrete. It is the latter category (ie) third one about which this thesis deals with.

The polymer as an integral part of coating again has varied options in relation to effecting a corrosion control in the concrete structures. There are sizable number of polymer coatings complete with each other in offering protection to the steel reinforcement rod, the nature and method of diagnosing their respective protection has not been hither to spelt. While assessing its utility as protective coating, the factors affecting structural engineering design is to be taken into consideration while caring the electrochemistry that operates in the protective measures. This requires to be addressed completely and also in synergistic mode to each other through which qualification and quantification of the protective role of each coating can be done. This is precisely the concern of this thesis for which several diagnostic approaches have been evolved to qualify and also quantify the protection offered to the concrete structure.
2.0 Scope and Objectives:

The objectives are targeted to address key fundamental issues in assessing any protective coating normally prescribed for the protection of steel reinforcement bar. Thus this study intends to stress the importance of meeting the requirement of structural engineering and electrochemical requirements together for achieving better corrosion control measures for steel reinforcement bar.

Thus this investigation aims:

- To examine the bond strength provided to steel – concrete interface by the introduction of corrosion protective layer.
- To correlate the bond strength in terms of its influence of adhesion, friction and bearing components.
- To compare and analyse the effect of each protective coating on the influencing parameters of bond strength.
- To provide correlation of the bond strength to the nature of protective coating.
- To propose a model for the correlation of bond strength with various types of coating.
- To quantify the behaviour of corrosion resistance ability of the candidate coatings under damaged conditions.
- To correlate the performance of corrosion resistance ability under macrocell conditions with the nature of coating.
- To examine the interfacial characteristics of coated steel – concrete interface and ascertain the nature of corrosion resistance property.
- To elucidate the chloride tolerance limit of coated steel reinforcement with respect to the coating system chosen.
- To qualify and quantify the protective property of the coating by AC impedance study and elucidate the mechanism of protection.
To elucidate the potential dynamic polarization behavior of the coating chosen and quantify their role of protection

To classify the protective coatings applied to steel – concrete interface according to its nature and extent of protection offered

3.0 Experimental:

The experimental procedures adopted in this study has followed the prescribed methods in construction engineering and electrochemical science. Using these the following characterization of all the protective coatings chosen in this study have been investigated:

- Bond strength by pullout measurement
- Macrocell corrosion characteristics
- Photo micrograph analysis
- Chloride tolerance by anodic polarization method
- AC impedance and DC polarization characteristics

4.0 Results and discussion

4.1 Bond strength:

Bond between Concrete and coated Steel in reinforced concrete is considered for slipping or sliding in the concrete. There are three factors that contribute to develop bond between steel and concrete: they are (1) adhesion, (2) friction, and (3) mechanical shear similar to that provided by the deformations in reinforcement bars.

The protective coatings chosen for this investigation is primarily derived by the desire of qualifying and quantifying the prescribed protective coatings and accordingly IP Net, ESPEC, Cempol have been identified as candidates in this investigation as the widely practiced in construction industry. The main mechanism of adhesion is due to surface interaction by the cement paste. The
steel in concrete gets readily passivated due to high alkalinity prevailing in the concrete.

The influence of interface between steel and concrete either of the inorganic, organic, composites or metallic type of coating film on the steel surface is studied. Hence the adhesion is mainly resisted by the coating film and surface of the steel. The adhesion efficiency depends upon the reactivity to the steel and the mechanical property of the film. In addition, the interaction between concrete and surface of the film may also contribute certain extend of adhesion resistance. The study proves that all the coating systems have been exhibited higher adhesion than in the uncoated bar. The adhesion resistance alone not a criterion for creating bond strength of the steel rebar in concrete.

The frictional resistance mainly governs by the surface friction and also by the chemical reaction of the coated bars. This is best seen in the case of an organic coating system, like ESPEC in which the coating provides a smooth surface, thus reducing the bond strength due to friction. This is attributed to the absence of compatibility factor with concrete environment as realized by the property made. The Cempol coating system has a primer and a sealing coat. The primer enhances adhesion property by virtue of its functional property and the sealing coat of the same polymer providing monolithic interactions between the inter coats. Finally, the surface of the sealing coat has the reactive components of the cement aiding chemical reaction with the surrounding concrete making the coated rods perform higher bond strength.

Through this experiment, it is evidenced that the slope of the friction zone is critical. In this slope the bond stress is proportional to bond strain which can termed as bond modulus \( E_B \). Based on this information the bond capacity of any surface modification can be compared with uncoated steel reinforcing bar.
A model is proposed which is to be utilized for the selection of coating system or any other surface modification / alteration to the reinforcing steel in concrete. The stiffness factors derived from the frictional resistance can be useful for designing concrete element based on bond capacity.

Thus this model establishes guidelines to assess the bonding property of any coating system. If any bond improvement is to be established in the coating system, the deficiency in the bond capacity can be easily identified and proper reactive components can be incorporated accordingly. For good compatibility the bond strength shall be equal or slightly higher than the uncoated bar. However, the bond strength can alone not been considered for the suitability of the coating system for steel in concrete in corrosive environments. Corrosion resistance is also to be considered while assessing the protective coating system.

4.2 Macrocell corrosion

The commonality of all the diagnostic approaches lie at examining the steel – concrete interface provided with a protective coating as a sandwich between these two parts of reinforced concrete are normally prescribed for the protection of steel reinforcement bar, which has to address for its targeted objectives of corrosion resistance. The mechanism of macro cell corrosion in concrete is of great importance as the local imperfection of concrete cover may result in galvanic cells with high ratios of cathode to anode area.

During construction operation the wet concrete is normally pumped and poured with certain amount of pressure and at certain height. The impact due to pouring of wet concrete creates damage to the coated reinforcement bars. Vibrators are in use for compacting the concrete will also damage the coated steel. These damages are irreparable and creating pinholes on the coated bar, leading to galvanic coupling between damaged area of the coated steel and with adjacent coated surface. Flow of macro cell current attributed from the exposed
steel to the near by unaffected portions. Prior damages may create pitting corrosion, under cutting and delaminating the coated steel reinforcement.

The coated rods were subjected for wet concrete impact by pouring from two meters and three meters height. These damaged coated bars were introduced in the macro cell test specimen. Macrocell studies were carried out to examine the damages in the Cempol, ESPEC and Inhibited cement slurry coated rebars.

The inhibited cement based inorganic system inhibits the corrosion of steel in concrete by the mechanism that involves forming a passive film on the steel surface and reducing the chloride ion penetration. Cempol coated specimen in the macro cell study exhibited negligible current flow at the initial stage and after the behaviour was as like in the case of cement slurry system. Cempol system has the property of passivating cum barrier effect. The coated specimen initially acted as barrier type and when it is contacted with water it acted as passivating type. Also during service the cement particles available in the sealing coat get hydrated and enhance the passivating effect. Therefore the behaviour of Cempol coated specimen initially shown negligible increase of current flow at the initial stage and maintained decreased current flow as like in cement slurry system.

In marine condition the concrete structures are mostly contaminated with chlorides. These types of contamination reflected in the macro cell set up. For chloride contaminating concrete the selection of coating to steel reinforcement shall be protective to macro cell corrosion. It is evidenced that the cement-based systems are suitable for chloride contaminating concrete. Highly barrier type of system may be useful if the coated steel reinforcement does not subject to the damage during handling and transportation.
4.3 Microstructure analysis:

The surface characterization employed through the photomicrograph visualized through Scanning Electron Microscope and Metallurgical Microscope reveal the important facts of steel-concrete interface after a pullout action. It has been found that the abrasive blasting on the metal surface makes steel surface rough by way of forming peaks and valleys at micro level. The damages to the barrier coating are clearly realized at the tip of the peak under pullout performance. The passive film formation on the exposed steel surfaces is clearly realized when cement based coating such as Cempol is imported to the steel. Also the formation of passive film has been found to be facilitated on the pinhole developed during the painting operation. Also the rust formation has been found to be seen on the peeled off portion due to pullout force thus indicating the importance of protective coating. The most important findings in this analysis is that cement hydration enhances the coating integrity with concrete in the case of Cempol system. Additionally higher flexibility if introduced to the coating can lead to craze formation as evidenced by this study. This is due to unequal shear stress in the interface layer.

4.4 Chloride tolerance:

It is obvious that chloride is a main phenomenon for corroding steel in concrete. The amount of chloride required for initiating corrosion is thus, in part, dependent upon the pH of the liquid in the cement paste. The quantum of corrosion in reinforcement bar is due to its chloride concentration near the steel surface. To avoid the chloride-induced corrosion for steel in concrete protective coatings are prescribed for the purpose. In such cases the efficacy of the coating system is dependent on its resistance against the chloride penetration. Most of the coating systems may have pinholes, which are formed during the application of the coating system. These pinholes are vulnerable for corrosion to initiate. Chloride has the tendency to absorb on the metallic surface, which are normally migrating through the concrete to the steel surface causing corrosion.
The chloride tolerance for any protective coating is crucial in its applicability to the steel reinforcement bar and hence widely practiced industrial diagnostic mode namely anodic polarization has been used to qualify the coating system examined. In this study different coating systems such as Cement Slurry, ESPEC, IP Net, Cempol coatings and AEPP red oxide coated systems were selected to find out its maximum tolerable limit for chloride.

The anodic polarization studies by applying 290 μA/cm² through a counter electrode will act as a clear tool for assessing tolerable limit of chloride for any coating system applied on the steel reinforcing bar. The tolerable limit mainly based on the passivation property of the steel surface and the barrier effect of the coating surface. Concrete possesses a higher pH value at the order of 12.5 and above. Normally the steel reinforcement bar is readily passivated in highly alkaline medium. This is contributed by the cement hydration in the concrete during curing period. The inorganic cement based systems are applied on the reinforcing steel may act as fully passivated type of system.

Cempol has shown highest tolerance level for the chloride ion than any other system. Other system such as ESPEC has shown a considerable tolerance due to by virtue of its thicker coating leading to barrier action. The study reveals that the chloride tolerable limit is based on the film integrity and its property.

4.5 AC impedance and potentiodynamic polarization:

AC impedance measurements of the protective coating system chosen in concrete embedded conditions have clearly demonstrated the protective role of all the coating chosen in this investigation. However, the data generated under exposure conditions to the simulated concrete pore solution and corrosive environment comprising saturated Ca(OH)₂ a well known pore solution and 3% NaCl (sea water condition) has enabled to ascertain the nature of protection as well as extent of protection. Cempol coating has unambiguously proved to have
barrier cum passivating action, while cement slurry has a passive only action. On the other hand, ESPEC has been found to have only barrier action. The level of protection has been found to be higher for Cempol coating in both the corrosive environment followed by cement slurry and ESPEC. The nature of corrosion protection has been subjected to fitting of equivalent circuit model, which has corroborated the above findings.

Polarization measurements of the coated steel reinforcement in concrete mortar have also been analyzed which has clearly demonstrated the passivating action of slurry and Cempol systems in both the environment namely saturated Ca(OH)₂, and 3% NaCl. The determination of corrosion rate has indicated that Cempol coating has been proved to offer protection than ESPEC in saturated Ca(OH)₂ environment. On the other hand, cement slurry has provided lesser protection in 3% NaCl environment. This compliments the finding realized in elucidation of chloride tolerance limit through anodic polarization method.

5.0 Conclusions:

Thus, the above diagnostic approaches have been found to elucidate the different type of protective coatings in terms of nature and level of protection they offer to the steel reinforcement bar especially in concrete embedded conditions. Among the protective coatings examined in this investigation, Cempol coating has been found to fulfill the requirements of the structural engineering (bond strength, macro cell corrosion) and electrochemistry requirements (chloride tolerance, impedance analysis, polarization) better than the other systems considered. Thus, this investigation has provided diagnostic protocol to be followed in the assessment of the protective coatings. The thesis is supported by relevant references at the end.