Application of corrosion protection techniques for durability of concrete structures - A consultants perspective

Sudhir Chaturvedi[1] and Anurag Sinha[2]

[1]General Manager (Engineering Division), Engineers India Ltd., New Delhi 110066, India

[2]Assistant General Manager (Structural Department), Engineers India Ltd., New Delhi 110066, India, Member - Indian Concrete Institute (ICI), Member - India Chapter - American Concrete Institute (IC-ACI), Member - Institution of Engineers (India),

Abstract

This paper attempts to evaluate the merits and demerits of various techniques available for protection of reinforcement bars in reinforced concrete structures against corrosion, based on the available data & feedback received from different users across the globe considering technical & commercial aspects, particularly for used in hydrocarbon (oil & gas) industry.

Keywords

Corrosion, reinforcement, durability, concrete

Introduction

Durability of reinforced concrete gets affected drastically due to corrosion of reinforcing bars, especially in corrosive (industrial/ coastal) environments. Corrosion of reinforcement bars especially in coastal areas is a serious problem and is responsible for premature failure of many RCC structures. Techniques like dense concrete around reinforcement, provision of thick covers, addition of corrosion inhibitors, usage of corrosion resistant alloys, coating of re-bars, etc. have been developed and deployed to control the problem of corrosion in reinforcement bars but fool-proof solution is still awaited.

Apart from TMT reinforcing bars along with prevailing corrosion inhibitors, it has been learnt from different sources that use of Fusion Bonded Epoxy Coated (FBEC) re-bars or Corrosion Resistant Steel (CRS) re-bars or Zinc coated re-bars may help in big way to get rid of the corrosion problem forever. Before forming any opinion to use these available alternatives, it is needed to study their quality & performance based on available data.

Corrosion

Corrosion of steel in concrete is a complex phenomenon. There are different factors affecting the process of corrosion in concrete. The increase in volume of reinforcement after corrosion is one of the adverse effects on the structure apart from reduction in cross section area of reinforcement. Corrosion has been found one of the important reason causing weakness to concrete

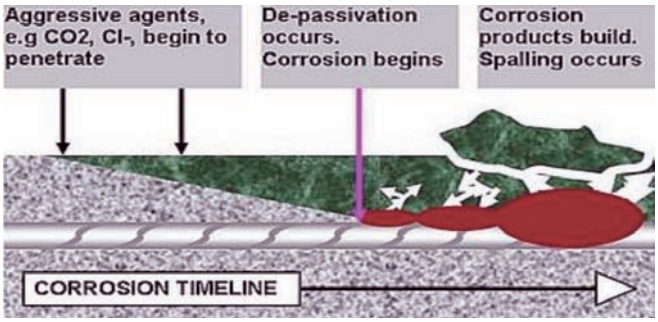

Fig. 1: Corrosion Timeline

structures. Lot of research has been done on this subject in India and abroad to prevent the process of corrosion in concrete structures.

Before discussing the methods to avoid or reduce corrosion, it will be more appropriate to understand some of the fundamentals of process of corrosion of reinforcement in concrete.

The ingress of water and oxygen is must to start the process of corrosion. Following are few commonly known processes causing deterioration to concrete:

Carbonation

New concrete has a high alkalinity or pH, this allows a protective oxide layer to form on embedded metal reinforcement that helps to prevent corrosion. Over time, carbon dioxide in the air diffuses into concrete in moist condition which reacts with hydroxides (hydrated cement) in the concrete, such as calcium hydroxide, to form calcium carbonates. This process significantly lowers the alkalinity or pH, leading to the loss of the protective oxide layer on the steel which poses a potential threat for start of corrosion of reinforcement.

High Chloride Levels

Chlorides from the aggregates or water used in the making of concrete (fixed chlorides) or from chemicals used in concrete curing compounds (free chlorides) in presence of oxygen cause corrosion of the reinforcing steel. As corrosion progresses, oxides build-up and cause expansion resulting in disbondment from the concrete.

Table 1
Analysis of available techniques

Technique vs Parameters	**FBEC Re-bars**	**CRS Re-bars**	**Zinc Coated Re-bars**	**TMT Re-bars + Corrosion Inhibiting Admixture**
Product/ Technology	Fusion Bonded Epoxy Coating forms an insulation layer to corrosion or a barrier coating that prevents corrosion to take place. It has a history of past 60 years of use worldwide. Dedicated plant can also be set up at the construction site.	Corrosion resistant elements such as Cu, Cr & P are added singly or in combination. Cu-Cr TMT re-bars are 1.5 to 1.9 times more corrosion resistant than PC-TMT re-bars. Corrosion risk for TMT Cu-Cr re-bars is much lower than CTD re-bars in aggressive environments like admixed chloride and marine. Available in all regular diameters.	Pure electrolyte zinc dust in suspension with synthetic resin and automatic solvents. Dry film contains 96% metallic zinc which provides efficient & effective cathodic protection. Surface is rough enough to provide an adhesion to the concrete and passes the pull out test according to standard RILEM/CEB/FIP Rec. RC6-1978. Coating is flexible and will does not gets damaged when the re-bars are bent or handled roughly.	TMT Re-bars are readily available with all prime manufacturers in India. Bipolar Concrete Penetrating Corrosion Inhibiting Admixture are also available with several Indian manufacturers
Application	Surface preparation is done by shot blasting using steel shots and steel grits with complete recovery and recycled abrasives through a bucket elevator system and the dust and the corrosion protects through a cyclone recovery system. Thickness of FBEC is 100 to 300 µm	No coating is required over normal reinforcement. Cu plugs pores in rust. Phosphorus acts as an inhibitor. Chromium content has improved resistance against pitting	Abrasive blast cleaning thickness 30 (±10) µm DFT and after proper surface preparation, application by brush, spray gun or roller. Degreasing by steam cleaning then grit blasting or slurry blasting and de-dusting with non-contaminated compressed air	Dosage of corrosion inhibiting admixture is generally 2 to 3 kg per cubic meter of concrete (as per manufacturer's specifications)
Codal Support & Approval	More than 35 countries have adapted codes for Fusion Bonded Epoxy Coating. Bureau of Indian Standards has IS:13620.	CRS re-bars are supported by Bureau of Indian Standards vide IS:1786.	Zinc coated/ Galvanised re-bars are supported by ASTM A767M	TMT Re-bars are supported by IS:1786.
Performance standards/ Test reports	Standards as per IS:13620 are available for coating thickness, continuity of coating, adhesion, bond strength & abrasive resistance.	Corrosion resistance Index (CRI) of CRS Re-bars is significantly superior to ordinary re-bars. CRI during alternate immersion test is 1.5 times higher. CRI during salt spray test is 1.3 times higher. CRI during field exposure test is 1.3 times higher.	Test reports from National Test House, SAIL, MHADA, National Metallurgical Laboratory & Andhra University are available.	TMT re-bars are complying all listed tests in BIS. For corrosion inhibiting admixture, short and long term test results are available.
Constraints	Handling, transportation, bending & binding may be a problem. Double transportation may have cost & time implications.	No negative feedback so far. CRS re-bars are gradually picking up in the industrial market.	No feedback (positive or negative). Double transportation may have cost & time implications.	Workmanship at site. Life span yet to be established.
Manufacturers (commonly available) in India	M/s PSL Ltd.	M/s RINL (TempCore) M/s SAIL (HCR) M/s TATA steel (TISCON-CRS)	M/s SRMB Srijan Ltd. (SRMB AZAR)	M/s Sunanda Speciality Coatings (Polyalk CP-293) M/s Krishna Conchem (EPCO-KP-200) M/s Clean Coats (ConProof-IA)

Table 2
Recommendations for usage

Sl.	Structure Description	Environmental Conditions	Recommended Technique	Areas of usage
1	**Sub-structure**	Normal soil conditions	TMT + Corrosion inhibitor	Industrial areas & Buildings
			CRS re-bars	
			FBEC re-bars	
		Soils having excess chlorides and sulphates (as per soil report, in severe corrosive conditions)	FBEC re-bars	Coastal & marine environments
			CRS re-bars + Corrosion inhibitor	
2	**Super-structure**	Mild and Moderate environment exposure conditions (as per Table-3, IS:456)	TMT + Corrosion inhibitor	All areas
			CRS re-bars	All areas
			FBEC re-bars	Buildings and & Utilities
		Severe, Very Severe and Extreme exposure conditions (as per Table-3, IS:456)	CRS re-bars	All areas
			FBEC re-bars	Buildings and & Utilities
3	**Liquid retaining structures**	All exposure conditions	Zinc coated re-bars	All areas

Eventually, the concrete cracks leading to failure of the structure.

Available techniques

Several methods have been developed for protection of reinforcing steel from corrosion in concrete. The most commonly known systems of protection of reinforcing steel from corrosion which are in popular use and deployed in substantial volumes of reinforced concrete in the hydrocarbon (oil & gas industry) are:

1. Fusion Bonded Epoxy Coated (FBEC) Re-bars

The Fusion Bonded Epoxy Coating is a process where epoxy powder is applied by electrostatic spray on hot steel at pre-set temperature level. The powder, when in contact with the hot bar, melts, flows, gels, cures cools and produces a well-adhered continuous corrosion resistant protective coating. This thermosetting is an irreversible process and provides the protection to rebar against corrosion. It prevents attack of chloride ion on the metallic surface and occurrence of electro-chemical reaction initiating corrosion of steel.

2. Corrosion-resistant Steel (CRS) Re-bars

Corrosion-resistant Steel rebars have dual micro structures i.e. the surface layer is tempered martensite while the inner shell is ductile ferrite-pearlite. To increase corrosion resistance of these bars certain elements like nickel, chromium, copper and phosphorus are also added. These bars form a protective layers on the surface when they come in contact with atmospheric oxygen and moisture.

3. Zinc Coated/ Hot-dip Galvanised Re-bars

Galvanizing is the process of deposition of zinc over the surface of rebars. One of the methods to prevent the steel from undergoing corrosion is to galvanized rebars. Zinc coating offers protection in more than one way. Firstly, inter-metallic and metallic layers of zinc act as a physical barrier between the steel material and corrosion environment. In this case, corrosion resistance of the steel owes to the corrosion resistance of zinc. Further, wherever steel is exposed to the corrosive environment due to the breakdown of the protective coating, steel is still protected by the selective dissolution of zinc.

4. **TMT Re-bars with added corrosion inhibiting admixture in concrete**

   Regular TMT rebars can be used in concrete mixed with bipolar concrete penetrating corrosion inhibiting admixture which upon addition into the concrete matrix inhibits the corrosion process. It need not be in direct contact with the steel. Its vapours penetrate through fissures, honeycomb structure of concrete, pure water solution added in concrete and seals steel reinforcement at both anodic & cathodic sites, for inhibition. This is due to the bipolar mechanism property of the system. Non-concrete penetrating, nitrite & nitrate corrosion inhibitors are excluded here.

Analysis

The available techniques have been analysed against various parameters as mentioned in Table 1.

Conclusion

Based on the properties and details available, the recommendation for usage of above techniques may be concluded as mentioned in Table 2:

However, as mentioned in the introduction, a fool-proof solution to this problem is yet to be evolved and it is expected from the industry to develop such technology which may be deployed to prevent the corrosion of reinforcement bars resulting in increase if service life of reinforced concrete structures and reduction in their life cycle cost.

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M/s Krishna Conchem Products Pvt. Ltd.

M/s Clean Coats Pvt. Ltd.

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3. ASTM A767M : Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement, American Society for Testing & Materials.

Mr. Anurag Sinha

BE (Civil)

Current position: Deputy General Manager, Engineers India Ltd., New Delhi, India

Professional Experience : Over 25 years of professional experience on various project phases ranging from FEED, EPCM, EPC/ LSTK, OBE and PMC. Specialized in engineering design and review of Reinforced Concrete and Structural Steel Industrial Structures. Experience in repair, rehabilitation and retrofitting of Concrete & Steel Structures. Conversant with National and International design practices.

Experience : Petroleum Refinery and Petrochemical process and non-plant structures, Aluminum Refinery process structures, Cement Plant structures, Heavy RCC structures for Satellite Launch Vehicle Integration facilities, Structures in South Polar region, Structures associated with Nuclear Power Plants and related facilities, review of Cryogenic Containment Tanks.