

Overview of Corrosion and Advanced Corrosion Prevention Techniques

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Abstract— Corrosion of reinforcement in concrete is one of the main causes of structural deterioration, the aim of our work is to develop corrosion preventions systems for reinforced concrete structures by using advanced techniques and metal such as stainless steel, copper, nickel etc. Corrosion of steel in concrete is a slow process due to the protective nature of concrete. It takes a reasonably long time for this process of rebar corrosion in a limited duration available for performing tests studies. In this paper, described about an overview of corrosion & its types and advanced methods of advanced prevention techniques. The major application of advanced methods of corrosion prevention techniques, in nano-composite materials and coatings for reinforcement.

Key words: Corrosion, Rebar, Electrochemical, Linear Polarization Resistivity (LPR)

I. INTRODUCTION

Corrosion is a general term used to describe various interactions between a material and its environment leading to degradation in the material properties. Interaction with ambient oxygen can cause the formation of oxide layers via diffusion controlled growth. These may passivate the material against further oxidation. In a wet environment, aqueous corrosion can occur due to electrochemical processes which depend upon metal ion transport and reaction. Gradients of metallic and electrolytic ion concentrations, temperature, ambient pressure, and the presence of other metals, bacteria, or active cells, all influence the corrosion rate. Electric fields applied to corroding systems can accelerate or inhibit the rate of corrosion or material deposition. Galvanic corrosion between different metals in an aqueous environment is due to the electric field arising from the different electrode potential of the two materials. External fields may enhance or suppress this corrosion. In all of these reactions, electron and ionic transport occurs. The following sections will be concerned with these processes and the effect of conditions on the corrosion rates. Suitably monitoring the structures for corrosion problem and taking appropriate measurements at right time could affect huge savings. With the help of corrosion monitoring we can get wide-ranging info about fluctuating conditions of structure in time. The methods used for the assessment of corrosion are Open Circuit Potential (OCP) method, Surface Potential method, Linear Polarization Resistivity (LPR) measurement and many more but didn't give current corrosion stage in RC structures. Present study include the review of some modern methods like Acoustic Emission, Galvanic Monitoring Probe, Potentio-Dynamic, High Frequency UV and Fibre Optics method summarising their merits, demerits and suitability in field use. This will be helpful for other researchers gaining fundamentals of corrosion monitoring, different methods and equipment. Also will be use full to continue further research and development of commercial instruments for precise determination of corrosion status in existing structures (1). Extensive research

work has been devoted to develop models that predicts the time for corrosion initiation. The study reveals that though Calcium palmitate and its combination with calcium nitrite reduces the concrete strength but inhibition to the corrosion of the rebar increases the service life of the Reinforced concrete by 8 to ten times. (2). The mechanism of corrosion attack and consequent deterioration of reinforced concrete structures is well understood and documented. New structures can be designed and built to withstand corrosion. However, due to short-term economic restraints, many new reinforced concrete structures continue to suffer as a result of corrosion damage, which results from the corrosion of the steel reinforcing. This paper explores the economic and practical benefits offered by the application of hot dip galvanizing as a viable means of protecting reinforcing steel concrete structures. The paper also discusses technical misconceptions that exist about application and performance provided by the use of hot dip galvanized reinforcing steel (3). A survey and review of recent patents on electrochemical methods for corrosion monitoring from 1999 to 2009 are presented in this paper. The patents were classified into 4 groups according to different electrochemical theories, which are potential, polarization, electrochemical impedance and electrochemical noise. A future outlook of the development on new research aspects particularly on methods based on electrochemistry is prospected (4). One solution to this problem, developed by Fiber Optic Systems Technology Inc. (FOX-TEK), combines very sensitive nonintrusive FT fiber-optic wall thickness sensors with networked monitoring instrumentation and a satellite- or cell-based modem. This system allows accurate remote tracking of pipeline corrosion from virtually anywhere (5). Tests with a wet and a concrete electrochemical corrosion cells show that the developed sensor has a performance comparable to costly and bulkier bench top potentiostats. An accelerated corrosion test was conducted by embedding the electrodes in concrete for 24 days. Linear polarization resistance measurements obtained from the developed sensor show the initiation and progression of corrosion. An uncertainty evaluation is carried out showing that the developed RFID sensor has an accuracy compatible with precision bench top instruments (6). Corrosion is a natural process, which converts a refined metal to a more chemically-stable form, such as its oxide, hydroxide, or sulphide. It is the gradual destruction of materials (usually metals) by chemical and/or electrochemical reaction with their environment. Corrosion engineering is the field dedicated to controlling and stopping corrosion. In the most common use of the word, this means electrochemical oxidation of metal in reaction with an oxidant such as oxygen or sulphur. Rusting, the formation of iron oxides, is a well-known example of electrochemical corrosion. This type of damage typically produces oxide(s) or salt(s) of the original metal, and results in a distinctive orange colouration. Corrosion can also occur in materials other than

metals, such as ceramics or polymers, although in this context, the term "degradation" is more common. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases. Many structural alloys corrode merely from exposure to moisture in air, but the process can be strongly affected by exposure to certain substances. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area more or less uniformly corroding the surface. Because corrosion is a diffusion-controlled process, it occurs on exposed surfaces. As a result, methods to reduce the activity of the exposed surface, such as passivation and chromate conversion, can increase a material's corrosion resistance. However, some corrosion mechanisms are less visible and less predictable.

A. Types of Corrosion

- 1) Uniform corrosion
- 2) Galvanic correction
- 3) Pitting corrosion
- 4) Crevice correction
- 5) Filiform correction
- 6) Microbiologically Influenced Corrosion
- 7) Inter granular corrosion
- 8) Fretting corrosion
- 9) 9. High-Temperature Corrosion
- 10) 10. Environmental Cracking corrosion
- 11) 11. Flow assisted correction

1) Uniform Corrosion or General Corrosion

Uniform corrosion is defined as a type of corrosion attack (deterioration) that is more or less uniformly distributed over the entire exposed surface of a metal (see illustration below). Uniform corrosion also refers to the corrosion that proceeds at approximately the same rate over the entire surface. Cast irons and steels corrode uniformly when exposed to open atmospheres, soils and natural waters, leading to the rusty appearance shown in Figure.1



Fig. 1: Uniform corrosion

a) Prevention Uniform Corrosion

- Use thicker materials for corrosion allowance
- Use paints or metallic coatings such as plating, galvanizing or anodizing
- Use Corrosion inhibitors or modifying the environment
- Cathodic protection (Sacrificial Anode or Impressed Current -ICCP) and Anodic Protection

2) Galvanic Corrosion or Bimetallic Corrosion or Dissimilar Metal Corrosion

Galvanic corrosion is defined as the accelerated corrosion of a metal because of an electrical contact (including physical contact) with a more noble metal or non-metallic conductor

(the cathode) in a corrosive electrolyte. The less corrosion resistant or the "active" member of the couple experiences accelerated corrosion while the more corrosion resistant or the "noble" member of the couple experiences reduced corrosion due to the "cathodic protection" effect. The most severe attack occurs at the joint between the two dissimilar metals. Further away from the bi-metallic joint, the degree of accelerated attack is reduced shown in Figure.2

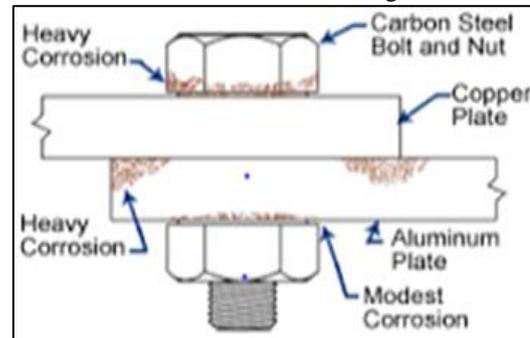


Fig. 2: Galvanic corrosion

a) Prevention Galvanic Corrosion

- Select metals/alloys as close together as possible in the galvanic series.
- Avoid unfavourable area effect of a small anode and large cathode.
- Insulate dissimilar metals wherever practical
- Apply coatings with caution. Paint the cathode (or both) and keep the coatings in good repair on the anode.
- Avoid threaded joints for materials far apart in the galvanic series

3) Pitting Corrosion

This is a localized type of attack, with the rate of corrosion being greater at some areas than at others. If appreciable attack is confined to a relatively small, fixed area of metal, acting as anode, the resultant pits are described as deep. If the area of attack is relatively larger and not so deep, the pits are called shallow. Depth of pitting is sometimes expressed by the pitting factor, the ratio of deepest metal penetration to average metal penetration as determined by the weight loss of the specimen. A pitting factor of unity represents uniform attack. Iron buried in the soil corrodes with formation of shallow pits, whereas stainless steels immersed in seawater characteristically corrode with formation of deep pits. The Pitting corrosion shown in Figure.3



Fig. 3: Pitting corrosion

a) Prevention of Pitting Corrosion

- Proper selection of materials with known resistance to the service environment
- Control pH, chloride concentration and temperature
- Cathodic protection and/or Anodic Protection

- Use higher alloys (ASTM G48) for increased resistance to pitting corrosion

4) Crevice Correction

Refers to the localized attack on a metal surface at, or immediately adjacent to, the gap or crevice between two joining surfaces. The gap or crevice can be formed between two metals or a metal and non-metallic material. Outside the gap or without the gap, both metals are resistant to corrosion. The damage caused by crevice corrosion is normally confined to one metal at localized area within or close to the joining surfaces. The crevice corrosion shown in Figure.4

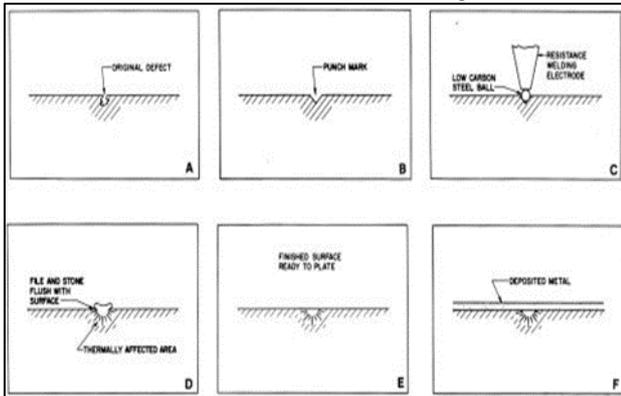


Fig. 4: Crevice correction

a) Prevention of Crevice Correction

- Use welded butt joints instead of riveted or bolted joints in new equipment
- Eliminate crevices in existing lap joints by continuous welding or soldering
- Avoid creating stagnant conditions and ensure complete drainage in vessels
- Use solid, non-absorbent gaskets such as Teflon.
- Use higher alloys (ASTM G48) for increased resistance to crevice corrosion

5) Filiform Corrosion

Filiform corrosion is a special form of corrosion that occurs under some thin coatings in the form of randomly distributed threadlike filaments. Filiform corrosion is also known as "underfilm Corrosion" or "filamentary corrosion". The crevice corrosion shown in Figure.5



Fig. 5: Filiform corrosion of a tin-coated steel

Filiform corrosion occurs on metallic surfaces coated with a thin organic film that is typically 0.1 mm thick. The pattern of corrosion attack is characterized by the appearance of fine filaments emanating from one or more sources in semi-random directions. The filaments are fine tunnels composed of corrosion products underneath the bulged and cracked coating. Filiform corrosion can be visually recognized without using a microscopy. Filiform corrosion has been

observed on surfaces of coated steel, magnesium, and aluminum with thin coatings of tin, silver, gold, phosphate, enamel, and lacquer. Filiform corrosion has also been observed on paper-backed aluminum foils.

a) Prevention of Filiform Correction

- control the relative humidity
- use brittle coatings

6) Microbiologically Influenced Corrosion

Microbiologically-Influenced Corrosion (MIC), also known as microbial corrosion or biological corrosion, is the deterioration of metals as a result of the metabolic activity of microorganisms. There are about a dozen of bacteria known to cause microbiologically influenced corrosion of carbon steels, stainless steels, aluminium alloys and copper alloys in waters and soils with pH 4- 9 and temperature 10oC-50oC. These bacteria can be broadly classified as aerobic (requires oxygen to become active) or anaerobic (oxygen is toxic to the bacteria). Sulphate reducing bacteria (SRB) is anaerobic and is responsible for most instances of accelerated corrosion damages to ships and offshore steel structures. Iron and manganese oxidizing bacteria are aerobic and are frequently associated with accelerated pitting attacks on stainless steels at welds. The Microbiologically Influenced Corrosion shown in Figure.6



Fig. 6: Microbiologically Influenced Corrosion

a) Prevention of Microbiologically Influenced Corrosion

- Regular mechanical cleaning if possible
- Chemical treatment with biocides to control the population of bacteria
- Complete drainage and dry-storage

7) Inter Granular Corrosion

Intergranular corrosion is a chemical or electrochemical attack on the grain boundaries of a metal. It often occurs due to impurities in the metal, which tend to be present in higher contents near grain boundaries. These boundaries can be more vulnerable to corrosion than the bulk of the metal. Intergranular" or "intercrystalline" means between grains or crystals. As the name suggests, this is a form of corrosive attack that progresses preferentially along interdendritic paths (the grain boundaries). Positive identification of this type of corrosion usually requires microstructure examination under a microscopy although sometimes it is visually recognizable as in the case of weld decay. The Inter granular corrosion shown in Figure.7

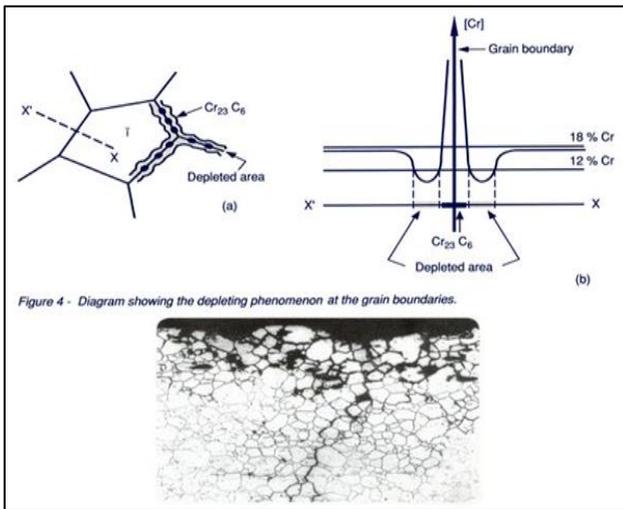


Figure 4 - Diagram showing the depleting phenomenon at the grain boundaries.

Fig. 7: Inter granular corrosion

a) Prevention of Inter Granular Corrosion

- Use low carbon grade of stainless steels
- Use stabilized grades alloyed with titanium or niobium. Titanium and niobium are strong carbide-formers. They react with the carbon to form the corresponding carbides thereby preventing chromium depletion.
- Use post-weld heat treatment.

8) Fretting Corrosion:

Fretting corrosion occurs as a result of repeated wearing, weight and/or vibration on an uneven, rough surface. Corrosion, resulting in pits and grooves, occurs on the surface. Fretting corrosion is often found in rotation and impact machinery, bolted assemblies and bearings, as well as to surfaces exposed to vibration during transportation. The Fretting corrosion shown in Figure.8



Fig. 8: Fretting corrosion

a) Prevention of Fretting corrosion

- Lubricate the surfaces
- Regularly inspect and maintain the lubrication

9) High-Temperature Corrosion:

Fuels used in gas turbines, diesel engines and other machinery, which contain vanadium or sulphates can, during combustion, form compounds with a low melting point. These compounds are very corrosive towards metal alloys normally resistant to high temperatures and corrosion, including stainless steel. High-temperature corrosion can also be caused by high-temperature oxidization, sulfidation, and carbonization. The high temperature corrosion shown in Figure.9



Fig. 9: High-Temperature Corrosion

10) Environmental Cracking Corrosion

Environmental cracking refers to a brittle fracture of a typical ductile material where the environment's corrosive effect is the actual causing agent. Cracking corrosion is caused by various conditions that can result in different forms of corrosion damage like:

- Stress Corrosion Cracking (SCC)
- Corrosion fatigue
- Hydrogen-induced cracking
- Caustic cracking
- Hydrogen blistering
- Hydrogen embrittlement
- Hydride embrittlement
- Hydrogen stress cracking
- Sulfide stress cracking
- Liquid metal cracking

a) Prevention of Environmental Cracking correction

- Control of stress level (residual or load) and hardness.
- Avoid the chemical species that causes environmental cracking.
- Use of materials known not to crack in the specified environment.
- Control temperature and/or potential

11) Flow Assisted Correction

Flow-assisted corrosion, or flow-accelerated corrosion, results when a protective layer of oxide on a metal surface is dissolved or removed by wind or water, exposing the underlying metal to further corroding and deteriorate.

- Erosion-assisted corrosion
- Impingement
- Cavitation

a) De-Alloying:

De-alloying, or selective leaching, is the selective corrosion of a specific element in an alloy. The most common type of de-alloying is de-zincification of unstabilized brass. The result of corrosion in such cases is a deteriorated and porous copper.

II. METHODS OF CORROSION CONTROL

A. Barrier Protection

Provided by a protective coating that acts as a barrier between corrosive elements and the metal substrate. The barrier protection system such as Paint, Powder Coatings, Galvanizing etc.

B. Cathodic Protection

Employs protecting one metal by connecting it to another metal that is more anodic, according to the galvanic series .the following methods are Cathodic Protection system.

1) Impressed Current

External source of direct current power is connected (or impressed) between the structure to be protected and the ground bed (anode) Ideal impressed current systems use ground bed material that can discharge large amounts of current and yet still have a long life expectancy.

2) Galvanic Sacrificial Anode

Pieces of an active metal such as magnesium or zinc are placed in contact with the corrosive environment and are electrically connected to the structure to be protected Example: Docked Naval Ships.

3) Zinc Metallizing (plating)

Feeding zinc into a heated gun, where it is melted and sprayed on a structure or part using combustion gases and/or auxiliary compressed air.

4) Zinc-rich Paints

Zinc-rich paints contain various amounts of metallic zinc dust and are applied by brush or spray to properly prepared steel.

5) Hot-dip Galvanizing

Complete immersion of steel into a kettle/vessel of molten zinc.

III. SURFACE PREPARATION

Zinc-iron metallurgical bond only occurs on clean steel

A. *Degreasing: Removes dirt, oils, organic residue*

B. *Pickling: Removes mill scale and oxides*

C. *Fluxing: Mild cleaning, provides protective layer*

D. *Galvanizing*

- Steel articles are immersed in a bath of molten zinc(≈ 830 F)
- Greater than 98% pure zinc, minor elements added forcoating properties (Al, Bi,Ni)
- Zinc reacts with iron in the steel to formgalvanized coating.

E. *Inspection*

- Steel articles are inspected after galvanizing to verify conformance to appropriate specs.
- Surface defects easily identified through visual inspection.
- Coating thickness verified through magnetic thickness gauge readings.

IV. THE ZINC PATINA

Forms as zinc reacts with the environment Consists of zinc oxide, zinc hydroxide, and zinc carbonate protects the galvanized coating by providing an additional layer of corrosion resistance.

V. FEATURES OF HDG COATINGS

- Zinc-iron intermetallic layers
- Harder than the substrate steel
- Zinc patina
- Barrier protection
- Cathodic protection

- Metallurgical bond to the substrate steel
- Paintable
- Edge and corner protection
- Zinc is a natural and healthy metal

VI. BENEFITS OF HDG COATINGS

- Maintenance-free for 50 – 100 years in most atmospheric environments
- Long term performance in soils, water, and chemical environments
- No touch-up required
- High & Low temperature performance
- Application independent of weather
- 100% recyclable

VII. CONCLUSION

- 1) Corrosion is a natural process, which converts a refined metal to a more chemically-stable form, corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases.
- 2) Many new reinforced concrete structures continue to suffer as a result of corrosion damage, which results from the corrosion of the steel reinforcing.
- 3) In a wet environment, aqueous corrosion can occur due to electrochemical processes which depend upon metal ion transport and reaction.
- 4) Based on the study made for this paper, it reveals that though Calcium palmitate and its combination with calcium nitrite reduces the concrete strength but inhibition to the corrosion of the rebar increases the service life of the Reinforced concrete by 8 to ten times.
- 5) From the literature study made for this overview of corrosion, it could be concluded that One of the important solutions for corrosion problems is Fiber Optic Systems Technology and Fiber-Optic wall thickness sensors with the networked monitoring instrumentation and a satellite- or cell-based modem.
- 6) The major application of advanced methods of corrosion prevention techniques, in Nano-Composite materials and Coatings for Reinforcement.

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