

A Review on Corrosion of Steel Structures

Gunda Sowmya, Gajula Rakesh, G. V. S. Karthik

Department of Mechanical Engineering, Vidya Jyothi Institute of Technology, Aziz Nagar, Hyderabad, India

ABSTRACT

Corrosion is degradation of material’s properties due to interactions with environment. Like other natural hazards such as earthquakes or severe weather disturbances, corrosion can cause dangerous and expensive damage to everything from automobiles, home appliances, and drinking water systems, pipelines, bridges, and public buildings. The current work reviews the phenomenon, impact, forms, consequences and preventive measures of corrosion with special emphasis on corrosion of steel structures. Different techniques like coating, painting, plating and Cathodic Protection are also reviewed in the current work.

Keywords: Corrosion, Impressed Current Cathodic Protection (ICCP), coatings, plating, Liquid phase inhibitors (LPis), Volatile Corrosion Inhibitors (VCIs).

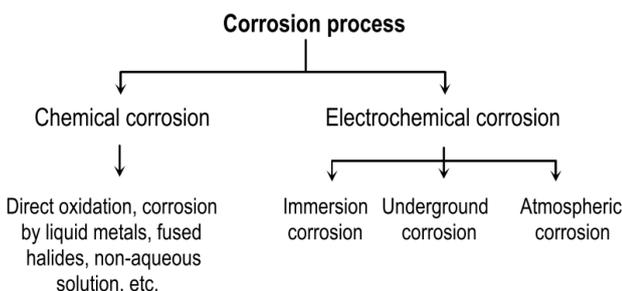
I. INTRODUCTION

Corrosion is the chemical or electrochemical reaction between a material and its environments that produces a deterioration of the material and its properties. Corrosion is degradation of material’s properties due to interactions with their environments, and corrosion of most metals (and many materials for that matter) is inevitable. While primarily associated with metallic materials, all material types are susceptible to degradation. Degradation of polymeric insulating coatings on wiring has been a concern in aging aircraft. Even ceramics can undergo degradation by selective dissolution. Like death and taxes, corrosion is something we hope to avoid; but ultimately it is something we must learn to deal with. The primary cause or driving force for all corrosion is the lowering of a system’s Gibbs energy. Corrosion process can be classified as follows [1];

Reaction of metals with dry air or oxygen is considered as a chemical corrosion. High temperature oxidation of metals and tarnishing of metals like copper, silver etc. fall in this category. Electrochemical corrosion occurs in the presence of electrolyte. The reaction is considered to take place at the metal-solution interface with the creation of local cathodic and anodic sides on the metal surface. Corrosion can be classified into eight forms [2];

II. METHODS AND MATERIAL

- a. **Uniform attack or, general corrosion:** It is the most common type of corrosion. It is normally characterized by chemical or electro chemical reaction which proceeds uniformly over the entire exposed surface. The metal becomes thinner and eventually fails. Uniform attack or general over-all corrosion represents the greatest destruction of metal on a tonnage basis. This form of corrosion, however, is not of too great concern from the technical standpoint because the life of equipment can be accurately estimated on the basis of comparatively simple tests or, experience.
- b. **Intergranular corrosion:** It consists of selective or localized attack at the boundaries of the metallic crystals. Sometimes whole grains are thereby loosened and fall away. Complete disintegration of the metal result even though a relatively small portion of it corrodes on a weight-loss basis. The



18-8 chromium-nickel stainless steels are particularly susceptible to intergranular corrosion when they are not properly heat treated or otherwise stabilized. If plain 18-8 stainless steel is subjected to a temperature in the range 900 to 1400°F for an appreciable time, this alloy becomes susceptible to inter-granular attack in many corrosive media.

- c. **Pitting:** It is perhaps the most destructive and insidious form of corrosion; containers fail because of perforation, yet only a small amount of metal is lost in the entire structure. In addition, pitting is difficult to evaluate on an experimental basis, and the service life of equipment is correspondingly uncertain. Pitting is probably responsible for more unexpected plant equipment failures than any one of the other seven forms of corrosion.
- d. **Galvanic or two-metal corrosion:** When two dissimilar metals are in contact with each other (or otherwise electrically connected) and exposed to a corrosive liquid or conductive solution, a potential is set up between these two metals and current flows. Corrosion of one metal is often accelerated and of the other reduced, as compared to the behaviour of these metals when they are not in contact. The historic voltaic cell and the ordinary dry cell battery are examples of such action, planned to produce current. Because of the electric currents and dissimilar metals involved, this form of corrosion is called "galvanic" or "two-metal" corrosion.
- e. **Concentration cell corrosion:** It is a similar situation as galvanic corrosion but occurs when only one metal is in contact with different concentrations in the environment. In other words, cells, current flow and potential difference exist on different areas of the same metal as this metal is in contact with different concentrations of a solution or liquid. For example, current will flow between two copper electrodes if one is placed in a solution of 5% hydrochloric acid and the other in 10% acid, the solutions being separated by porous cups. Localized attack resulting from these effects is designated concentration cell or solution cell corrosion.
- f. **Dezincification:** As the term implies, was first observed in brasses. Zinc is selectively leached out of brass to leave a weak porous mass of copper. Dezincification can be readily observed since the attacked areas show the red color of copper as compared to the distinct yellow of brass.

- g. **Erosion-Corrosion:** Erosion-Corrosion often causes unexpected and rapid deterioration of plant process equipment. The rate of corrosion can be greatly accelerated when mechanical or abrasive conditions are present, such as liquids moving at substantial velocities, presence of solids in suspension (that is, slurries), marked turbulence, and impingement of fluid streams. Examples of equipment that may be subject to erosion-corrosion are pumps, valves, centrifugals, measuring devices (such as an orifice), agitators, pipe lines, particularly at elbows and tees, and heat exchanger tubes. The corrosion effect known as "cavitation" is one type of erosion-corrosion. An excellent example of erosion-corrosion involves hard lead valves in hot, dilute sulphuric acid.
- h. **Stress-corrosion:** Stress-Corrosion is the general term describing corrosion accelerated by internal stresses or externally applied stresses. The stresses are sometimes complex, but tension stresses are generally if not always required. High internal or residual stresses are often produced during the forming of the part, by heat treatment, or other means such as locked, in stresses resulting from welding.

III. CONSEQUENCES OF CORROSION

The consequences of corrosion are many and varied and the effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than the simple loss of a mass of metal. Failures of various kinds and the need for expensive replacements may occur even though the amount of metal destroyed is quite small. Some of the major harmful effects of corrosion can be summarized as follows [3]:

- a. Reduction of metal thickness leading to loss of mechanical strength and structural failure or breakdown. When the metal is lost in localized zones so as to give a crack-like structure, very considerable weakening may result from quite a small amount of metal loss.
- b. Hazards or injuries to people arising from structural failure or breakdown (e.g. bridges, cars, aircraft).
- c. Loss of time in availability of profile-making industrial equipment.
- d. Reduced value of goods due to deterioration of appearance.

- e. Contamination of fluids in vessels and pipes (e.g. beer goes cloudy when small quantities of heavy metals are released by corrosion).
- f. Perforation of vessels and pipes allowing escape of their contents and possible harm to the surroundings. For example, a leaky domestic radiator can cause expensive damage to carpets and decorations, while corrosive sea water may enter the boilers of a power station if the condenser tubes perforate.
- g. Loss of technically important surface properties of a metallic component. These could include frictional and bearing properties, ease of fluid flow over a pipe surface, electrical conductivity of contacts, surface reflectivity or heat transfer across a surface.
- h. Mechanical damage to valves, pumps, etc., or blockage of pipes by solid corrosion products.
- i. Added complexity and expense of equipment which needs to be designed to withstand a certain amount of corrosion, and to allow corroded components to be conveniently replaced.

IV. RESULTS AND DISCUSSION

1. Cost of Corrosion in Important Sectors

Corrosion costs society in three ways; viz, it is extremely expensive, it is extremely wasteful of natural resources at a time of increased concern over damage to the environment and it causes considerable inconvenience to human being and sometimes loss of life. Corrosion of industrial metal is one of the oldest problems that have ever challenged the industrial world. Its cost is quite enormous and translates into billions of dollars in many developed nations. Following figure shows costs of corrosion in five important sectors of industry.

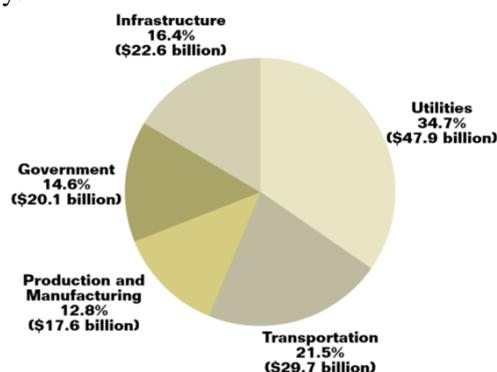


Figure 1. Percentage & dollar contribution to the total cost of corrosion for five important sectors

The above chart shows the enormous saving possible in different sectors if corrosion is avoided or controlled [4, 5].

2. Corrosion Protection Methods

There are many methods to reduce corrosion in all types of structures. Specifically, in steel pipelines there are three main types: coatings, corrosion inhibitors and cathodic protection [6].

2.1. Coatings

Coatings provide physical barriers that do not allow corrosive materials to come in contact with the structure that is being protected. Mainly, coatings are used on the exterior of pipelines to protect from external factors and are not used to directly protect the pipeline from CO₂ corrosion. The most common types of coating are painting and plating which both provide effective corrosion protection and aesthetic appearance. There are so many mechanisms of anti-corrosion coatings but generally, mechanism of coating can be differentiated into three, namely; barrier creation between substrate materials and environments, inhibition of the corrosion processes, and coating acting as sacrificial materials. However, recently one of the newest approaches is what is called “active-passive”. This involved the coating acting as barrier layers which will not allow permeation of corrosive agents to the metal surface (passive). While the active approach allows the formation of effective passive layer and this will impede the corrosion half reactions leading to Schottky barrier at the interface resulting in depletion of electrons [5].

2.1.1. Painting: Painting is an effective way to protect pipelines from external environmental factors. Although when looking at CO₂ corrosion on the interior of the pipeline, it is not ideal because painting the inside of a pipeline is impractical. The paint will breakdown over time, either through chemical reactions with the flowing fluid or the erosion due to turbulent or transient flow. Once the coating has broken down it leaves unprotected sections of the pipe when fluid induced localized corrosion occurs. Paint systems for steel bridges have developed over the years in response to technological advancements that have brought improved performance, and more recently to comply with industrial environmental legislation. Previous 5 and 6 coat systems have been replaced with 3 and 4 coat

alternatives, and the latest formulations have focused on application in even fewer numbers of coats, but with increasing individual film thickness. Examples of this are epoxy and polyester glass flake coatings that are designed for high build thickness in one or two coat applications.

2.1.2. Plating: Electroplating is one of the most popular methods employed to achieve corrosion control. Electroplating entails the electrode position of a metal onto the surface of a steel or iron product. This metal coating acts as a sacrificial barrier that can slow and even prevent corrosion from forming on the underlying material, which is referred to as the substrate. While zinc is frequently the metal of choice to provide corrosion protection, zinc-nickel alloys are also promising candidates for better corrosion resistance. Plating involves using electric currents to coat a metal with a thin layer of another metal that acts as a protective barrier. Plating an entire pipeline is very uncommon as it is expensive; however, it can be done when dealing with high pressures and high amounts of H₂S and CO₂. One drawback of plating is if the plating fails in a small section (either an imperfection or a scratch) then highly localized corrosion occurs. Another factor to consider is if the plating is more noble than the pipeline (for example, chromium on steel), the steel will act as a sacrificial anode for the chromium. This causes the exposed area to corrode much more rapidly than an un-plated surface [7].

2.2. Corrosion Inhibitors

Corrosion inhibitors offer corrosion protection that is similar to coatings as they act as a barrier between the oxidizing agents and the metal surface. The inhibitor adsorbs onto the steel surface and slows down or eliminates one or more of the electrochemical reactions by blocking the reaction site. The degree of protection that a corrosion inhibitor provides is heavily dependent on the properties of the inhibitor, the properties of the steel and the fraction of the steel surface that is blocked by the inhibitor.

2.2.1. Liquid phase inhibitors (LPis): LPis are in wide scale use to combat CO₂ corrosion in pipelines. The inhibitor is that is injected into the pipeline is transported in low concentrations and adsorbs onto the surface of the steel. Because the inhibitor is in the liquid phase only the interior of the pipeline needs to be in contact with the liquid either continuously or semi-

continuously. One of the main benefits in using inhibitors to protect from CO₂ corrosion is that it can continuously be added to the flow to provide continuous protection.

2.2.2. Volatile corrosion inhibitors (VCIs): VCIs are similar to liquid phase inhibitors in that they are present in low concentrations in the pipeline. Because they are a volatile compound they can easily enter the vapour phase if one is present. VCIs can adsorb onto the steel directly from the vapour phase and can penetrate into complex shapes and imperfections better than LPis. Any condensate that may form on the inside of the pipe may contain water and CO₂ which will contribute to corrosion in the pipe. If VCIs are present in the vapour phase they will also condense and provide a protective film. The volatility of the inhibitor is dependent on the vapour pressure of the compound. For the prevention of CO₂ corrosion on steel, amines are used as the VCI. The vapour pressure of amines is ideal so that the VCI will be present in both phases and provide ideal coverage for the pipeline.

2.3. Cathodic Protection

2.3.1. Sacrificial Anode

A sacrificial anode is used to protect metal structures, mainly iron, from corrosion. A sacrificial anode is a substance that is easier to oxidize than the structure being protected, typically it is a relatively small and easy to replace piece of metal. Sacrificial anodes are used when the pipeline is temporary or where there is not access to a power supply.

2.3.2. Impressed Current Cathodic Protection (ICCP):

This form of corrosion protection is applied by connecting the negative terminal of a DC power source to the iron structure and the positive terminal to an anode. Because the driving voltage is provided from a DC source and not electric potentials the anode does not need to oxidize and an inert anode can be used. There are 3 main advantages to using ICCP, one being that the DC power sources can provide much higher driving voltages than sacrificial anodes (100 to 10,000 times higher) and can protect larger areas. The second main advantage is that the anodes that are used, such as graphite, are inert and don't need to be continuously replaced. The final advantage is the degree of control over the electron transfer that ICCP has, the current can be increased or decreased as need be. ICCP is what is

typically found on all pipelines as it does not have to be continuously monitored like the sacrificial anode and there is more control over the electron flow.

In order to prevent corrosion using cathodic protection, current must flow from the electrolyte onto the structure at all locations. If a portion of the structure does not receive current, the normal corrosion activity will continue at that point. If any of the cathodic protection current picked up by the structure leaves that structure to flow back into the electrolyte, corrosion will be accelerated at the location where the current is discharged. Cathodic protection is a highly adaptable and effective means of preventing corrosion on a variety of underground or underwater structures. Cathodic protection designs can differ considerably depending upon the coating, the configuration of the structure, the environment and the presence of neighbouring structures. When a system is designed, installed and maintained properly, cathodic protection is one of the most effective and economical methods of preventing corrosion.

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