

Corrosion of metals and polymers: A vital concern

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Abstract— Corrosion costs nearly \$4 Trillion worldwide each year. April 24, 2012 has been dedicated to raising awareness about what can be done to prevent the impact of corrosion on people, infrastructure, and the environment. Though Codes and standards on corrosion exist on the basis of physical parameters, there is little focus on performance criteria. The US is losing more than \$276 billion and India Rs 1 Lakh crore per annum on account of corrosion. The annual loss due to corrosion can be compared with that of other natural calamities like fire, floods, hurricanes, tornadoes, earthquakes and cyclones; only its impact is indirect. Corrosion destroys the objects made up of metals and their alloys but the modern world can not afford without the use of these materials. Around 80 per cent of the unscheduled shutdowns and breakdowns in industries are due to corrosion. Corrosion causes plant shut downs, waste of valuable resources, loss or contamination of products, reduction in efficiency and costly maintenance. Corrosion solutions are highly customized as standards must be created on the basis of prevailing local conditions as India is a tropical country and environment and climatic conditions differ from region to region. If this corrosion cannot be eliminated completely, industries can ensure the prevention at the design stage. Improved technology and awareness can only come through consistent research and development activities. While this has become a reality in some industries such as nuclear power, refineries, space, railways, shipping and defense, most medium and small-scale industries do not take up corrosion issues seriously or are simply not aware of them. Additionally, corrosion may lead to loss of metals and their strength which in turn can cause serious accidents, loss of manpower and human lives. Out of the total loss due to corrosion, 25 per cent of loss can be easily saved with pro-active approach and protecting the system by applying protective coatings. Creating awareness and propagating knowledge about corrosion is therefore very important. Corrosion needs to be addressed by all industries. The protection of assets and environment from effects of corrosion is a must.

I. INTRODUCTION

Corrosion costs nearly \$4 Trillion worldwide each year. April 24, 2012 has been dedicated to raising awareness about what can be done to prevent the impact of corrosion on people, infrastructure, and the environment. Though Codes and standards on corrosion exist on the basis of physical parameters, there is little focus on performance criteria. The US is losing more than \$276 billion and India Rs 1 Lakh crore per annum on account of corrosion. The annual loss due to corrosion can be compared with that of other natural calamities like fire, floods, hurricanes, tornadoes, earthquakes and cyclones; only its impact is indirect. In any case, corrosion represents a tremendous economic loss and much can be done to reduce it. (Fig 1,2) [1,5].



Fig-1: Rusting in a drainage water pipeline

2. DEFINITION

Corrosion is defined as the destruction or deterioration of a material because of reaction with its environment. These materials include metals like iron, copper etc and non metals like ceramics, plastics, rubber etc. Corrosion can be fast or slow. Where on one hand, sensitized steel is badly attacked in hours by polythionic acid while on the other hand Railroad tracks usually show slight rusting over many years. The Famous Iron pillar in Delhi was made

almost 2000 years ago and is almost as good as new.
(Fig 3a, 3b)



Fig-2 Corrosion of Railings



Fig-3 (a), (b) Iron pillar in Delhi

Corrosion destroys the objects made up of metals and their alloys but the modern world can not afford without the use of these materials. Around 80 per cent of the unscheduled shutdowns and breakdowns in industries are due to corrosion. Corrosion causes plant shut downs, waste of valuable resources, loss or contamination of products, reduction in efficiency and costly maintenance.

3.ELECTROCHEMISTRY OF CORROSION

The same metallic surface exposed to an aqueous electrolyte usually possesses sites for an oxidation (or anodic chemical reaction) that produces electrons in the metal, and a reduction (or cathodic reaction) that consumes the electrons produced by the anodic reaction. These "sites" together make up a "corrosion cell". The anodic reaction is the dissolution of the metal to form either soluble ionic products or an insoluble compound of the metal, usually an oxide. Several cathodic reactions are possible depending on what reducible species are present in the solution. Typical reactions are the reduction of dissolved oxygen gas, or the reduction of the solvent (water) to produce hydrogen gas. Because these anodic and cathodic reactions occur simultaneously on a metal surface, they create an electrochemical cell [2,4].

The sites where the anodic and cathodic reactions take place, the anodes and the cathodes of the corrosion cell, are determined by many factors: (i) they are not necessarily fixed in location; (ii) they can be adjacent or widely separated so that, for example, if two metals are in contact, one metal can be the anode and the other the cathode, leading to galvanic corrosion of the more anodic metal; (iii) there can exist variations those sites exposed to the environment containing the lower oxygen content – differential aeration corrosion; (iv) or similarly, variations in the concentration of metal ions or other species in the environment, arising because of the spatial orientation of the corroding metal and gravity; or finally, (v) variations in the homogeneity of the metal surface, due to the presence of inclusions, different phases, grain boundaries, disturbed metal, and other causes, can lead to the establishment of anodic and cathodic sites. The flow of electrons between the corroding anodes and the non-corroding cathodes forms the corrosion current, the value of which is determined by the rate of production of electrons by the anodic reaction and their consumption by the cathodic reaction. A driving force is necessary for electrons to flow between the anodes and the cathodes. This driving force is the difference in potential between the anodic

and cathodic sites which exists because each oxidation or reduction reaction has associated with it a potential determined by the tendency for the reaction to take place spontaneously [3].

3. RUSTING

Corrosion occurs in the presence of moisture. For example when iron is exposed to moist air, it reacts with oxygen to form rust. (Fig 4)

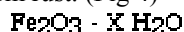
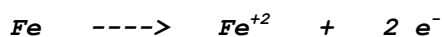
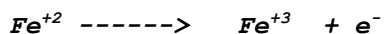


Fig-4 Rusting of Iron

The amount of water complexed with the iron (III) oxide (ferric oxide) varies as indicated by the letter "X". The amount of water present also determines the color of rust, which may vary from black to yellow to orange brown. The formation of rust is a very complex process which is thought to begin with the oxidation of iron to ferrous (iron "+2") ions.



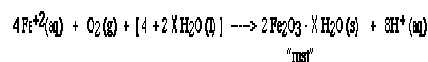
Both water and oxygen are required for the next sequence of reactions. The iron (+2) ions are further oxidized to form ferric ions (iron "+3") ions.



The electrons provided from both oxidation steps are used to reduce oxygen as shown.



The ferric ions then combine with oxygen to form ferric oxide [iron (III) oxide] which is then hydrated with varying amounts of water. The overall equation for the rust formation may be written as :



The formation of rust can occur at some distance away from the actual pitting or erosion of iron as illustrated below. This is possible because the electrons produced via the initial oxidation of iron can be conducted through the metal and the iron ions can diffuse through the water layer to another point on the metal surface where oxygen is available. This process results in an electrochemical cell in which iron serves as the anode, oxygen gas as the cathode, and the aqueous solution of ions serving as a "salt bridge" as shown below (Fig 5).

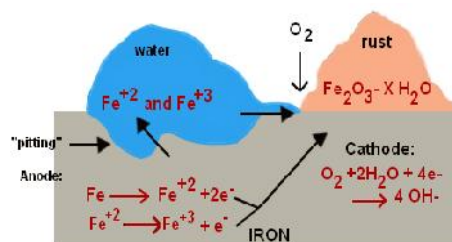


Fig-5 Mechanism of Rusting

The involvement of water accounts for the fact that rusting occurs much more rapidly in moist conditions as compared to a dry environment such as a desert. Many other factors affect the rate of corrosion. For example the presence of salt greatly enhances the rusting of metals. This is due to the fact that the dissolved salt increases the conductivity of the aqueous solution formed at the surface of the metal and enhances the rate of electrochemical corrosion. This is one reason why iron or steel tend to corrode much more quickly when exposed to salt (such as that used to melt snow or ice on roads) or moist salty air near the ocean [1-5].

4. FORMS OF CORROSION

The Table 1 below gives a detailed account of the example, corrosion testing and prevention techniques of the various forms of corrosion [1-5].

But there is another side of corrosion too. Our economy would drastically change if there was no corrosion. For example automobiles, ships,

underground pipelines and home appliances would not require coatings. The stainless steel industry would essentially disappear and copper would be used only for electrical purposes. Most metallic parts, as well as consumer products, would be made of cast iron or steel.

Although corrosion is inevitable, its cost can be considerably reduced. Keeping this in consideration Corrosion Engineering was introduced which is the application of science and art to prevent or control corrosion damage economically and safely [1-5].

TABLE 1- TESTING & PREVENTION OF CORROSION

S . N	Forms of Corrosion	Example	Corrosion Testing	Prevention
1	Galvanic Corrosion	The rusting of corrugated iron sheet, which becomes widespread when the protective zinc coating is broken and the underlying steel is attacked.	It consists of a large brass sheet with a steel nut bolted to the center of the sheet	Keep small anodes from contacting large cathodes, application of sacrificial coating, paint coatings, applying plastic, or other non-metallic barriers.
2	Pitting Corrosion	Pitting corrosion is common in passive metals above pitting potential (E_p) like Steel buried in the soil corrodes with the formation of pits.	Expose a large piece of specimen in a corrosive liquid for a fairly long period of time.	Reduce Cl ⁻ content in the electrolyte, Lower acidity of solution, lower O ₂ , Shot peen the surface. Avoid stagnant solutions in tanks, tubes, pipes & Redesign to ensure proper drainage
3	Uniform Corrosion	A piece of steel or zinc immersed in dilute sulfuric acid will normally dissolve at a uniform rate over its entire surface	A piece of steel or zinc dipped in sulphuric acid	Use thicker material for corrosion allowance, use paints or metallic coatings, cathodic & anodic protection
4	Erosion Corrosion	Characterized in appearance by grooves, gullies, waves, rounded holes, and valleys and usually exhibits a directional pattern	Spinning Disk test	Streamline the piping to reduce turbulence, control fluid velocity, using corrosion inhibitors or cathodic protection, using more resistant materials
5	Selective Leaching	Selective removal of zinc in brass alloys (dezincification)	Uniform dezincification of Brass pipe	Removing oxygen from the solution, Cathodic protection & appropriate selection of alloy
6	Stress Corrosion Cracking	Aluminum alloys crack in the presence of chlorides, mild steel cracks in the presence of alkali (boiler cracking) and nitrates, copper alloys crack in ammoniacal solutions (season cracking)	Bend Tests, Slow strain rate test	SCC is the result of a combination of three factors – a susceptible material, exposure to a corrosive environment, and tensile stresses above a threshold. Elimination any one of these factors SCC initiation becomes impossible.
7	Inter Granular Corrosion	Small amounts of iron in aluminum, wherein the solubility of iron is low, have been shown to segregate in the grain boundaries and cause intergranular corrosion	For stainless steels- Nitric acid test, Huey Test, Streicher Test & Warren Test	Use post weld heat treatment, use of low carbon grade of stainless steel.
8	Crevice Corrosion	Small volumes of stagnant solution caused by holes, gasket surfaces, lap joints, surface deposits, and crevices under bolt	Material's resistance to crevice corrosion is tested by wrapping the specimen with string, chord or rubber bands	Reduce crevices in design ,Use welding if possible instead of bolting two surfaces in contact Avoid electrolyte stagnation ,Use none-absorbent gaskets such as Teflon instead of absorbent gaskets such as fiber and wood gaskets & Cleaning to reduce local conc. of acids

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