

OVERVIEW ON CORROSION IN AUTOMOTIVE INDUSTRY AND THERMAL POWER PLANT

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ABSTRACT

Corrosion; Classification; Thermal Power Plant; Automotive Industry; Causes; Mechanism; Preventive Measures.



Corrosion implies to the irreparable damage or demolition of living tissues or materials due to electrochemical reactions. The automotive sector is rather bellicose and gives rise to metal corrosion in automotive parts due to high amount of pollution generated and due to de-icing salts. In power plants, corrosion is the principal agent leading to costly and critical downtimes. The water-steam circuits in fossil and nuclear power plants are inherently prone to corrosion, as metal components are constantly in contact with water. This review paper provides the overview of distinct types of corrosion in automotive and thermal power plant, their causes and measures to prevent them.

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1. INTRODUCTION

Corrosion is an irreversible interfacial reaction of a material (metal, ceramic, and polymer) with its environment which results in its consumption or dissolution into the material of a component of the environment (Belan, 2018; Natarajan, n.d.). The Society of Automotive Engineers (SAE) has predicted that the rate at which coating corrodes is about 8.5 micro-meter/year. Amidst the safety measures such as the existence of seat belts, airbags, crumple zone, and dampers, for passengers in cars, it should not be neglected that steel constitutes over 50% of the total weight of an average automobile globally. This steel is to be supervised on the regular basis to avoid vehicles from getting corroded and rusted that certainly would affect the safety of vehicles and increase life risk (Fentahun & Savaş, 2018).

Thermal power plants have components that operate at different pressures and temperatures, such as- boilers,

steel drums, feed water heaters, super heaters, turbine, pipes, cooling tower, etc. Corrosion at thermal power plants poses safety hazards that may be fatal if a worker is exposed to hot steam, gas, ash, or radioactive materials from a leaky component or welding failure. In addition to driving up maintenance costs, if corrosion prevents a plant from starting after scheduled maintenance, the operators may face non-delivery fees (Krishnan et al., 2003).

2. TYPES OF CORROSION

The various types of corrosion are shown in Figure 1 and discussed below.

2.1 Uniform Corrosion

It is the most common variety of corrosion such as rusting of iron. Other metals and alloys also corrode uniformly such as aluminium, copper, brass, and magnesium. However, depending upon the nature of the

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metal and the environment, some of them will form either protective or non-protective films on the surface. Since uniform corrosion of different metals and alloys has been studied at length, it is fairly predictable and controlling the same is relatively simple. Use of more corrosion-resistant metal for a given environment and adopting suitable surface protection measures such as painting, coating, anodizing, plating, cladding, and cathodic protection are commonly used for preventing a metal from uniform corrosion (Virgil, 2004).

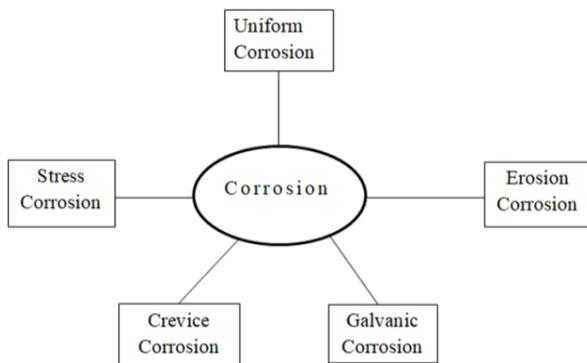


Figure 1. Various types of corrosion [5]

2.2 Erosion Corrosion

Erosion corrosion is the deterioration of metals and alloys due to relative movement between surfaces and the corrosive fluids. Depending on the rate of this movement, abrasion takes place. This type of corrosion is characterized by grooves and surface patterns having directionality. Typical examples are Stainless alloy pump impeller, Condenser tube walls. Erosion corrosion due to high velocity impingement occurs in steam condenser tubes, slide valves in petroleum refinery at high temperature, inlet pipes, cyclones and steam turbine blades (Okyere, 2019; Kumar et al., 2018a).

2.3 Galvanic Corrosion

Galvanic corrosion often referred to as dissimilar metal corrosion occurs in galvanic couples where the active one corrodes. Galvanic corrosion can occur in multiphase alloys, like Copper containing precipitates in aluminium alloys. Impurities such as iron and copper in metallic zinc. When two metals come in contact in the presence of an electrolyte, the more reactive metal acts as an anode whereas the less reactive metal acts as a cathode. The electrolyte offers a channel for the movement of particles, which in turn leads to the rapid eroding of the anodic metal. Galvanic Corrosion can be used beneficially to protect a cathodic metal from corrosion. A good example of this would be the usage of zinc in batteries to promote the corrosion of zinc to create a potential difference (Balan, 2018).

2.4 Crevice Corrosion

When metal surfaces are exposed to corrosive environment, localized corrosion takes place within crevices or shielded areas. Small volume of stagnant solution getting trapped under gaskets, lap joints, and crevices under bolt and rivet heads cause this type of attack known as crevice corrosion. To function as a corrosion site, a crevice must be wide enough to permit liquid entry, but sufficiently narrow to maintain a stagnant zone. Metals which form a passive oxide film on their surfaces for corrosion resistance are particularly prone to crevice corrosion, for example stainless steels and aluminium alloys. Dissimilar metals in contact can aggravate crevice corrosion attack because galvanic corrosion may also add to the problem (Birbilis & Hinton, 2011).

2.5 Stress Corrosion

Stress corrosion cracking (SCC) refers to failure under simultaneous presence of a corrosive medium and tensile stress. Two classic examples of SCC are caustic embrittlement of steels occurring in riveted boilers of steam-driven locomotives and season cracking of brasses observed in brass cartridge cases due to ammonia in environment. Stress cracking of different alloys does occur depending on the type of corrosive environment. Stainless steels crack in chloride atmosphere. Major variables influencing SCC include solution composition, metal/alloy composition and structure, stress and temperature (Beavers & Bubenik, 2017).

3. CORROSION IN AUTOMOTIVE INDUSTRY

The amount and type of materials used in the construction of automotive vehicles are diverse, as the component parts. The problem of corrosion occurs at parts where the operation of the vehicle is compromised. Corrosion happens in many parts of the car (mostly invisible) it is not only undesirable for the problems it causes, but also reduces the vehicle's resale value and decreases the strength of the structure. The main cause of corrosion of the car body is the accumulation of dust in different closed parts, which stays for a long time by absorbing moisture, so that in these areas metal corrosion proceeds, while in the clean and dry external parts it does not occur. However, artificial intelligence may also help to solve various problems (Jindal et al., 2021; Valdez et al., 2012).

3.1 Corrosion in the cooling system

The cooling system of a car combustion engine consists of several components, constructed of a variety of metals: radiators are made of copper or aluminum, bronze and solder couplings with tin water pumps; motors are made of steel, cast iron or aluminum. Most

modern automobiles, with iron block engine and aluminum cylinder head, require inhibitor introduced into the cooling water to prevent corrosion in the cooling system. It is advisable to use only the inhibitor recommended in the automobile manual and not a mixture of inhibitors, since these may act in different ways and mechanisms.

3.2 Corrosion in exhaust pipes and batteries

The acidic environment which is generated on the surface of accumulators supplying the energy necessary for starting the engine, favors conducting corrosion processes in the lead terminals, where the cables are connected by bronze or steel clamps. Exhaust pipes made of SS (0.6 - 0.8 mm thick) have a better resistance to chemical corrosion at high temperatures, which is why we are now using SS in many popular models. This SS resists corrosion much more than conventional CS and thus their long life covers the higher price (Carrillo et al., 2012).

4. CORROSION IN THERMAL POWER PLANT

The three central equipment of a thermal power plant are the boiler, which converts the water into steam, the steam turbine to whom the pressure imparts a rotary motion and the condenser that condenses the vapor released by the turbine and the condensed water is returned to the boiler as feed water. Corrosion in steam plant equipment occurs in two parts of the boiler: on the water side and the steam side, with the fire temperature up to 700 ° C, depending on the type, size and capacity of the boiler. The flue gases and ash solid particles reach temperatures up to 1000 to 1200 °C, impinging on the outer surface of the boiler water tubes and preheater, creating an atmosphere for aggressive chemical corrosion. The damaged tubes lose its thickness generating metal corrosion products; they often are fractured, suffering a stress corrosion due to the combined effects of mechanical stress and corrosion. Corrosion occurs also in the combustion air preheater, by sulphurous gases which react with condense and form sulfuric acid. Metal components of the turbine rotor: disks and blades suffer from corrosion by salts, alkalis and solid particles entrained in the vapor (Amabogha, 2013). To overcome this various thermal sprayed coatings can be used. Among distinct thermal spray Ni-Cr and Ni-5Al based cold spray and wire arc spray gives better results to prevent hot corrosion of T22, T91 and SA516 boiler steels (Kumar et al., 2020a; Kumar et al., 2020b; Kumar et al., 2019a; Sharma et al., 2019).

5. CAUSES OF CORROSION

The various causes of corrosion are shown in Figure 2.

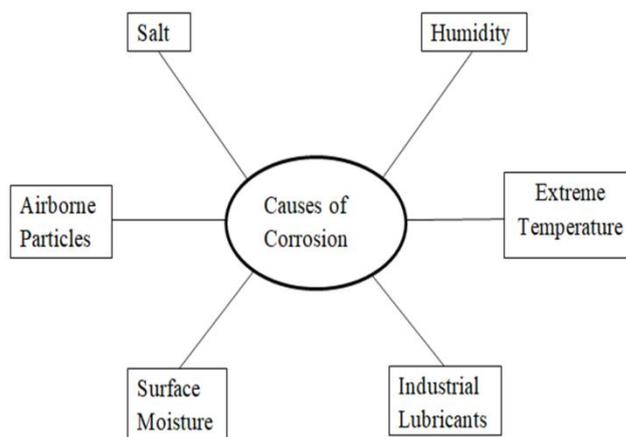


Figure 2. Various causes of corrosion (Parker South Africa Team, 2020)

5.1 Salt

Salt and water are known to cause corrosion. The presence of oxygen in water and salt can stimulate the process. Salts commonly act as carriers of electrons, allowing water to carry them through redox reactions. Water as a medium helps in the transfer of electrons and salt to the metal. This process, which is known as an electrochemical one, occurs when the iron gets oxidized by taking advantage of the presence of oxygen and hydroxide ions. After the iron gets oxidized, it forms metal oxide by reacting with the oxygen and the hydroxide ions. As metals get rusted, their electrons are lost and the water breaks into hydroxide ions and oxygen. This process triggers the formation of metal oxide (rust).

5.2 Humidity

Under humid conditions, metal corrodes at a much faster rate. This occurs as a result of moisture-saturated air reacting with oxygen and electrons on the metal's surface. Metal components corrode faster when exposed to humid air for an extended period of time. This type of atmospheric corrosion can occur when the amount of moisture in the air reaches critical humidity, which is the point at which water no longer evaporates or is absorbed from the atmosphere. At 80 percent relative humidity, this occurs in the majority of cases (RH). The greater the relative humidity, the smaller the temperature difference required for condensation to form, allowing corrosion to occur.

5.3 Extreme Temperatures

Temperature has a significant impact on atmospheric corrosion in two ways. The first is the normal increase in corrosion activity, which can theoretically double with every ten-degree increase in temperature. Second, a little-noticed effect is the temperature lag of metallic objects behind changes in ambient temperature due to their heat capacity. As the temperature drops in the

evening, metallic surfaces tend to stay warmer than the humid air around them and do not begin to collect condensation until the dew point is reached. As the temperature of the surrounding air rises, the lagging temperature of the metal structures causes them to act as condensers, retaining a film of moisture on their surfaces. Temperature cycling has caused severe corrosion on metal objects in the Tropics, unheated warehouses, and metal tools or other objects stored in plastic bags.

5.4 Industrial Lubricants

A dry film lubricant is defined as a solid substance that, when interposed between two mating surfaces subjected to relative movement, reduces friction and prevents wear and tear (as well as corrosion, preferably). Molybdenum disulfide (MoS₂) and graphite are two common solid lubricants that cause corrosion when used directly. MoS₂ acts as a cathode to some metals in moist environments, producing a voltage of up to 0.5 volts. MoS₂ can cause accelerated galvanic corrosion and rusting on ferrous metals when mixed into grease. Molybdenum (the metal) on the other hand, can be anti-corrosive. Graphite is corrosive in any case because it causes selective leaching of iron from gray cast iron as ferrous particles are removed and the graphite remains, causing weakening of the structure.

5.5 Surface Moisture

Moisture, whether in the form of dew, rain, or condensation, plays a significant role in corrosion. Although rain can wash away hazardous air pollutants in the atmosphere that have accumulated in exposed areas such as a marine environment, rain also collects in crevices and pockets. Rain can also hasten corrosion by keeping things wet, especially in areas with galvanized bolts and steel parts or structures. Furthermore, condensation and dew are some of the undesirable types of moisture that are not washed away by recurring rain, which could eliminate or dilute the contamination. Dew films that have become saturated with acid sulphates, sea salt, and other acids may create an aggressive electrolyte environment that promotes corrosion. Condensation can be found on surfaces in humid, tropical areas. On such surfaces, moisture can become stagnant, resulting in an alkaline reaction with metal or the absorption of carbon dioxide to produce a dilute acid.

5.6 Airborne Particles

Airborne salt particles deposited on metal surfaces dissolve into this water ad layer, forming thicker electrolyte layers or droplets. Oxygen (O₂), carbon dioxide (CO₂), and gaseous pollutants such as SO₂, O₃, and NO₂ dissolve into the ad layer and interfere with the corrosion process. Local electrochemical corrosion cells with spatially separated anodes and cathodes form as a

result of unevenly distributed water films. This will happen as a result of particle deposition on the surface. Chemical reactions between liquids and solids produce airborne contaminants such as corrosive particulate matter (PM). These same liquids and solids, such as salt and black carbon, can interact with metal molecules and speed up decay. Furthermore, gaseous acidic contaminants play an important role in material corrosion, either directly or indirectly as precursors of corrosive particulate matter (PM).

6. MECHANISM OF CORROSION IN AUTOMOTIVE INDUSTRIES

Corrosion in vehicles can be traced back to the manufacturing stage as well as roadside environmental conditions. Galvanic corrosion, for example, can occur as a result of the use of different metals in various automotive parts. The inherent microstructure of the metal is also important. The use of magnesium (Mg) in automobiles has increased significantly as a result of the recent light weighting trend. Mg is a good engineering material because of its high strength-to-weight ratio and good cast ability; however, it has poor corrosion characteristics. It has been reported, for example, that the β -phase of Mg is more prone to corrosion than the α -phase, which can result in galvanic corrosion between the phases. Grain boundaries within a metal can also generate forces that cause deterioration.

Vehicles on the road are subjected to a variety of environments, including extremely hot and cold temperatures, as well as operating in coastal areas and near chemical plants. All of these factors can contribute to atmospheric corrosion. Even a minor scratch during operation can result in the formation of a corrosion cell in the surface moisture film, with the use of de-icing salts in cold environments hastening the process. Meanwhile, crevice corrosion is caused by the accumulation of dirt and debris in confined spaces such as door flanges and wheel wells. Automotive exhaust systems are highly susceptible to pitting due to the presence of wet condensates and significant concentrations of chloride ions.

7. MECHANISM OF CORROSION IN THERMAL POWER PLANTS

When a thermal energy generating plant is not in use, its components are prone to corrosion. A plant may be shut down as a result of planned or unplanned maintenance, or as a result of low seasonal power demand. During the shutdown, corrosion can occur on all or part of the thermal energy generating plant parts where the ambient air, which always contains some water vapor, comes into contact with metal surfaces.

Many thermal energy generating plants corrode as a result of poor materials collection or ineffective corrosion awareness on the part of the plant engineer or

designer. Changes to the water treatment package component material, the plant operating conditions, or all three may be required. For particles to collect on boiler surfaces or blade surfaces, they must first be brought close to the surface itself and be of the proper size. This can be attributed to physical phenomenon including the reaction of particles to the forces to which they are subjected within the stream of gases passing near the surfaces.

A particle may collide with and then bounce off the surface. Erosion will occur if it strikes or rubs the surface with enough force. If, on the other hand, the particle is physically or chemically captured by the surface, a deposit is formed whose growth appears to be aerodynamically unavoidable. Due to the high temperatures, reactions can occur between the various particles deposited as well as with the gases passing nearby, particularly SO₃ and SO₂. The resulting compounds may then react with the metal structure to which they are attached via diffusion, causing accelerated corrosion (Amabogha, 2013).

8. MEASURES TO PREVENT CORROSION

The main methods to prevent the corrosion are shown in Figure 3.

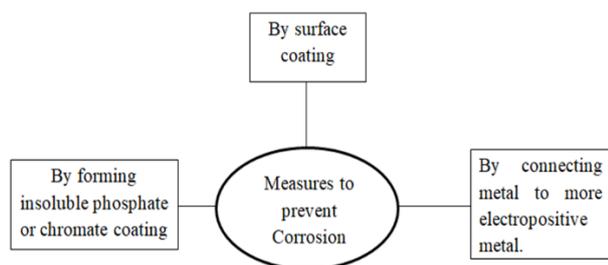


Figure 3. Various methods to prevent the corrosion (Singh et al., 2021)

8.1 By surface coating

We can prevent the corrosion of the metal by coating their surface using any of the following:

- By applying oil, grease, paint or varnish on the surface.
- By coating/depositing a thin layer of any other metal which does not corrode (Kumar & Kumar, 2018a; Toppr, n.d.).

The performance of distinct coatings on distinct boiler steel has already reviewed by various authors (Kumar et al., 2021; Kumar et al. 2020c; Kumar et al., 2019b; Kumar et al., 2019c; Kumar et al., 2019d; Kumar et al., 2018b) and reported that Ni-20Cr coating deposited by thermal spray processes offered better corrosion resistance in air, molten salt and actual boiler environment. This may be due to the formation of protective oxide phase of chromium. In addition, some

authors have studied the corrosion behavior of hydroxyapaite and hydroxyapaite/titania bond coating for biomedical applications and concluded that coating is an effective way to enhance the corrosion resistance and mechanical properties (Bedi et al., 2019; Tangestani, 2021). Some authors also investigated the corrosion behaviour of Alumina and Titanium Oxide Reinforced Alumina Coatings on boiler steels and reported positive results (Singh et al., 2020a; Sahil et al., 2021; Kumar & Kumar, 2018b). The parabolic rate, mechanical properties of distinct coatings and finishing processes are summarized by some authors (Kumar & Kumar, 2018c; Kumar et al., 218c; Sidhu & Kumar, 2019; Sidhu et al., 2020; Singh et al., 2020b) and also concluded Ni-Cr based coating gives better result for hot corrosion resistance.

8.2 By connecting metal to more electropositive metal

The given metal will not corrode as long as the more electropositive metal is present. For example, you can protect iron from corrosion by connecting it to a zinc or magnesium plate. Cathodic protection is the name given to this method of protection.

8.3 By forming insoluble phosphate or chromate coating

Treat the metal surfaces with phosphoric acid since it forms an insoluble phosphate coating on the surface which protects the metal from corrosion. We can also form a thin chromate layer to prevent the metals from corrosion. In addition, productivity of any sector can be enhanced by using DMAIC approach and by 3D printing techniques (Chandel & Kumar, 2016; Kumar & Kumar, 2020; Kumar et al., 2020c).

However, the extent of corrosion could be typically decreased by tailoring the microstructure, composition, and architecture of the coatings as indicated in Figure 4.

However, the alloying elements such as nickel or protective scale-forming elements (aluminium, chromium) can change mechanism of corrosion (Fauchais et al., 2014). In addition, the microstructural features of the as sprayed coating (pores and splat boundaries), can also have a major effect on the corrosion performance (Souza & Neville, 2003). The microstructure of the as sprayed coating can be changed depending on the spraying parameters, selection of the spraying process or post-spray treatment process (Rodriguez et al., 2000; Saedi et al., 2010). Except this another potential way would be changing the architecture of the coating. This may be done by, either through a new coating design (Sidhu et al., 2005), or by including a certain oxygen-active elements into the coatings, to fabricate composite structures (Unocic et al., 2018). There are a few microstructural properties (pores, splat boundaries, and surface roughness) that

directly influence the corrosion behavior/ performance of thermal spray coatings (Zhang et al., 2017). Except microstructure, the coatings chemistry is also important

to attain high resistance against corrosion. The role of splat boundaries and the corrosion path is shown in Figure 5 (a) and (b) respectively.

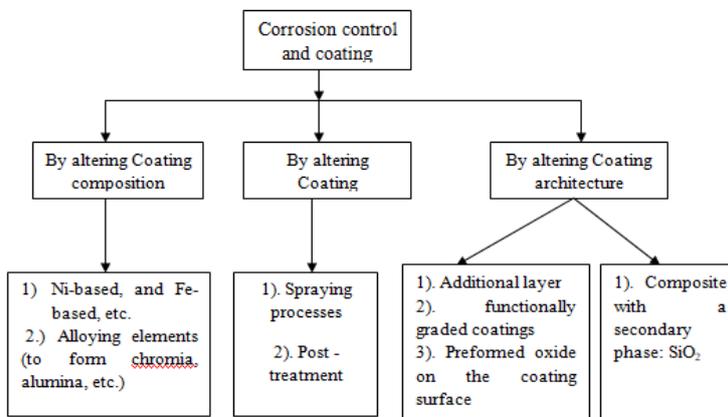


Figure 4. Distinct way to control the corrosion by utilizing coatings (Sadeghi et al., 2019)

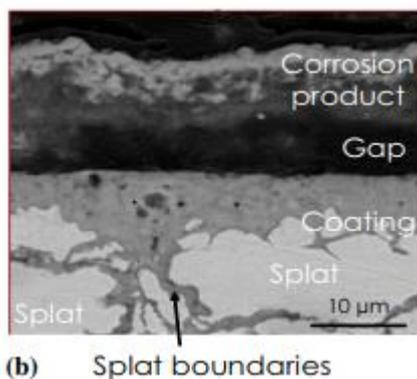
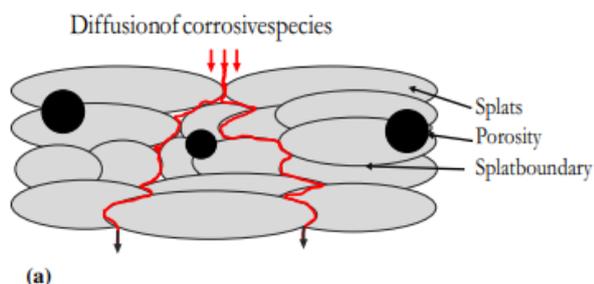


Figure 5. (a). Role of splat boundaries in the coatings (Sadeghimeresht, 2018) (b). The corrosion path primarily relating to the splat boundaries (Jafari et al., 2018)

Various authors (Bender & Schütze, 2003a; Bender & Schütze, 2003b; Guerin et al., 2017) concluded that chromium, aluminium and silicon are the most significant elements for developing protective oxide layers at elevated temperatures. However, in addition to these alloying elements, molybdenum has also significant effect on hot corrosion performance in aggressive environment (Cl containing environment).

9. CONCLUSION

To combat corrosion in automobile cooling systems, novel corrosion inhibitor mixtures have been developed. A wet car should not be left in a hot garage, as this causes accelerated corrosion because the water does not dry and can condense on the cold parts of the vehicle. To prevent battery acid spillage, clean the battery terminals on a regular basis (using a wire brush or a special instrument), and coat them with petroleum jelly to prevent corrosion in these contact areas. Acidic solutions containing corrosion inhibitors, passivating ammoniacal solutions, and solutions are used to chemically clean surfaces in contact with water and steam. Corrosion in power plants can be controlled by using corrosion engineering and technology knowledge, methods, standards, and materials.

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