M. CEMMEDO

PROTECTION OF SHIP FROM CORROSION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OFAPPLIED SCIENCES
OF
UNIVERSITY OF KYRENIA

by

MAHMUT CEMMEDO

Supervised by Assis . Prof. Dr.Gülsün BEKTAŞ

INPARTIALFULFILLMENTOFTHE REQUIREMENTS
FORTHEDEGREEOFMASTEROF SCIENCE
INMARITIME TRANSPORTATION AND
MANAGEMENTENGINEERING

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Mahmut Cemmedo : PROTECTION OF SHIP FROM CORROSION

Approval of Director of Graduate School of
Applied Sciences

Prof. Dr. İlkay SALİHOĞLU

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Maritime Transportation and Management Engineering

Examining Committee in Charge:

Prof. Dr. Mustafa Altunç	Chairman of the Commitee- Kyrenia University
Prof. Dr. Süleyman TOLUN	Kyrenia University
Prof. Dr. Deniz ÜNSALAN	Dokuz Eylül University
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ABSTRACT

All metal compounds exist in nature.Using information, generated metal or alloy by material and labor addition of these compounds.The produced compounds of metals and alloys again stable states reversion tendency is very high.Therefore metal reacts with the elements of the environment before they are in the ionic state then attempt to return to the compound which combines with other elements in the environment.Thus, they undergo chemical changes.As a result of this unwanted changes metals, chemical, physical, electrical and mechanical properties occur over time and consequently of these changes will cause great harm.Metal materials as well as the deterioration reaction caused by the reaction abrasion and corrosion damage is called corrosion.Corrosion can be also specified as the electrochemical and chemical corrosion occuring due to the effects of corrosion in metallic materials.

Corrosion can cause significant damage to property and the environment as well as causing great losses due to metal wear occurs in particular from energy and marine vessel construction. Decrease rate in energy due to corrosion, loss of material and labor to the annual value of the gross national income of the country is the level of 4-5%.This ratio means a serious economic harm.Especially,on ships and marine structures it has led to very serious environmental pollution and damage.

Therefore, prevention of corrosion and methods are particularly well known to be responsible for the technical staff and implemented.These methods are precise, timely and correct implementation of condition of corrosion losses can be reduced by between 30% and 60% of the technology currently implemented.This ratio may reach even higher levels in ships.

In this study, the corrosion on ship is discussed. By using photography the corrosion is indicated and the reason the precautions which should be taken was for corrosion is discussed. Unwanted changes on chemical, physical, electical and mechanical properties of metals occur over time.

Keywords: Corrosion, Marine Corrosion, Cathodic Protection, Paints and Coatings, Effects of Corrosion

ÖZET

Doğada tüm metaller bileşik halinde bulunurlar. Teknik bilgiyi kullanarak malzeme ve emek ilave edilerek bu bileşiklerden metal veya alaşım üretilir. Üretilen alaşım ve metaller ise tekrar kararlı durumları olan bileşik haline dönme eğilimleri çok yüksektir. Bu nedenle metaller içinde bulundukları ortamın elemanları ile reaksiyona girerek önce iyonik duruma sonra ortamdaki başka elementlerle birleşerek bileşik haline dönmeye çalışırlar.Böylece kimyasal değişime ve bozulmaya uğrarlar. Sonuç olarak metallerin kimyasal,fiziksel, elektriksel ve mekanik özelliklerinde zamanla istenmeyen değişiklikler meydana gelir ve sonuçta bu değişiklikler büyük zararlara neden olur. Metallerin malzemesinin bozulma reaksiyonuna hem de bu reaksiyonun sebep olduğu aşınmaya ve zarara korozyon denir. Korozyonu ayrıca elektrokimyasal ve kimyasal etkilerinden dolayı metalik malzemelerde meydana gelen aşınma olarak ta niteleyebiliriz.

Korozyon, hem çevrede hem de deniz yapılarında özellikle gemilerde meydana gelen enerji ve metal aşınmalarından dolayı büyük zararlara yol açarak önemli maddi zararlaraneden olur.Korozyon nedeniyle ortaya çıkan enerji, malzeme ve emek kaybının yıllık değeri ülkelerin gayri safi milli gelirlerinin yaklaşık %4-5'ler seviyesindedir. Bu oran ciddi bir ekonomik zarar demektir. Metalin kullanıldığı her yerde korozyon meydana gelir. Gemilerde ve deniz yapılarında korozyon çok ciddi çevre kirliliğine ve maddi zararlara yol açmıştır ve açmaktadır.

Bundan dolayı korozyonun önlenmesi ve metodları özellikle sorumlu teknik elemanlar tarafından çok iyi bilinmeli ve uygulanmalıdır. Bu metodlar kesin, zamanında ve doğru olarak uygulanmak şartıyla korozyon kayıpları şu anda uygulanan teknolojiyle %30 ile %60 arasında azaltılabilmektedir. Gemilerde bu oran daha da yüksek düzeye ulaşabilir.

Bu çalışmada da, gemilerdeki korozyon incelenmiş ve halen çalışmakta olan gemilerde korozyon fotoğraflarla gösterilmiştir. Korozyonun sebepleri hakkında da ayrıntılı tartışılmış ve alınabilecek önlemlerle ilgili önerilerde bulunulmuştur.

Anahtar Sözcükler: Korozyon, Gemide Korozyon, Katodik Koruma, Boyalar ve Kaplamalar, Korozyonun Etkileri

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CHAPTER 1

INTRODUCTION

The nature of the ore obtained from different metals and alloys, by using chemical or electrochemical ways in which they interact with the environment, the most stable states tend to turn to the compounds found in nature. Because of this trend, in metallic materials due to the changes that occurred corrosion or chemical is called corrosion. A result of corrosion of metal; there could be undesirable changes in the mechanical or electrical properties. Dissolved or corroded metal through the environment as an ion during corrosion, or oxide or like hydroxide which it does not dissolve, formed a compound that stays on metal.

There are various metal areas. They corrode over time if no action is taken. Atmosphere under the influence of all steel structures, bridges, poles and all motor vehicles, water and soil contact with port legs, ships, boilers, water pipes and so on. Metallic structures may become unusable in a short time due to corrosion. Wear and corrosion with the function of replacing lost materials, labor and material loss causes the job to be changed in case of accidents and greater losses. Losses caused by corrosion is not limited only to material and labor costs, the business during the replacement of the material corrodes pausing for a certain period, an underground tank or up to determine the damage caused by corrosion in the pipeline, the losses in time and food, the cations formed by corrosion in the pharmaceutical and textile industry product mingling contamination of products are examples of other corrosion losses.

Corrosion results expenditure of energy produced is converted into a portion of the metal former. This gives great damage to the national economy. Therefore, it should be taken into account in all areas of corrosion of the metal material is used. For example, increasing the corrosion resistance of the steel produced a coating to protect against corrosion in environments where, paint. Measures should be taken.

CHAPTER 2

CORROSION

2.1 Definition of Corrosion

Corrosion of materials due as a result of physical, chemical and electrochemical reactions leads to change in the chemical and mechanical properties. In general corrosion, electrochemical reactions causes environmental degradation of metals and alloys. Corrosion of metals and alloys are oxidation of gaseous environments. The decay in the wet areas of metals and alloys are called electrochemical or wet corrosion.

All metals except gold and platinum are present in the oxidized state in nature. It is a difficult process to separate the metal oxide and is carried out with large amounts of energy. From the thermodynamic point when moved to a higher energy level of metal at the end of this process, the entropy are reduced. The situation in the metals tend to return to nature is the driving force behind the corrosion.

We can sort forms of corrosion as follows.

2.1.1 Uniform corrosion

General corrosion or regular contact with all surface corrosion is characterized by progressive corrosion equal speed. General corrosion rate per unit time per unit weight which is the loss of surface area (mg / dm3.g) or average thickness reduction (mm / year) can be expressed as. Equations used to calculate the corrosion rates are based on the assumption that the corrosion walk uniform manner. General corrosion, metal leaching (anodic reaction) and reduction reaction of dissolved oxygen is hydrogen or her balance (cathodic reaction) occurs in specific regions on the surface (Schweitzer, P.A. 1996).

Naturally present on the metal protective oxide film that dissolves completely in a corrosive environment or the stick occurs when weak and not protective. Stainless steel, nickel containing alloys, for metals and alloys such as titanium oxide film is protective in stable and neutral solution. Metal is disabled in this case. And the protective oxide film is called passive film. The resolution of the passive film on the metal and its alloys can be increased in acid or alkaline solutions. Protective oxide film is not directly in contact time with the metal solution and substantially the entire surface corroded. In this case, the metal surface may be coated with corrosion products such as rust (Brasunas, A.de S.1984). Uniform corrosion of the ship hull is shown in Figure 2.1 – Figure 2.2.

Figure 2.1 Uniform corrosion of the ship hull,(Shangai Drydock, 2014).

Figure 2.2 Uniform corrosion of the ship hull (Shangai Drydock, 2014).

2.1.2 Crevice corrosion

Crevice corrosion occurs when the protective film cracks. This is the realization of cathodic reaction with regional fragmentation of the films leads to accelerated corrosion cracks. Passive protection of films, if the neutral aqueous environment (such as CI) is adversely affected by corrosive anions. These anions in the regions where mixing of the solution can be concentrated in the cracks in such junctions. Solution with restricted mass exchange between the cracks of the main cathodic reaction, that causes cracks to occur outside of the reduction of oxygen. Also passive dissolution of metal cations of small current CI- ions into the crack in the film to stabilize the load causes a movement. This results in a concentrated metal salt going to the pH value of the acidic hydrolysis of the solution increases, or metal cation. It may continue to dissolve the protective oxide film that traces of corrosion cracks (Revie, R.W.2000).

Crevice corrosion is not only crack in the metal surfaces, between the metal surface with a non-metallic material may occur. For example, at the points where the pipes with insulating flange connected to each other, crevice corrosion can occur between steel flanges. Corrosion is most effective is the place where the crack mouth region close to the cathode region. Even a small crack up about one micron is sufficient to initiate corrosion. The idle and low oxygen in the range of 2-3 mm in size can be said also crevice corrosion will occur in a region of this size. Crevice corrosion of sea water ballast pump impeller is shown in Figure 2.3.

Figure 2.3 Crevice corrosion of ballast pump impeller(YASA AYSEN,2014).

Crevice corrosion because of the formation is described as follows. Suppose that a bolt or rivet set with two steel plates connected to each other into the sea water. Normally, depending on the oxygen concentration contained in the solution in the solution-contact surfaces with metal, corrosion phenomenon occurs at a certain speed. Cathodic oxygen present in the solution by using two plates in the region that initially incoherent and anodic reactions begin. The formation of crevice corrosion is shown in Figure 2.4.

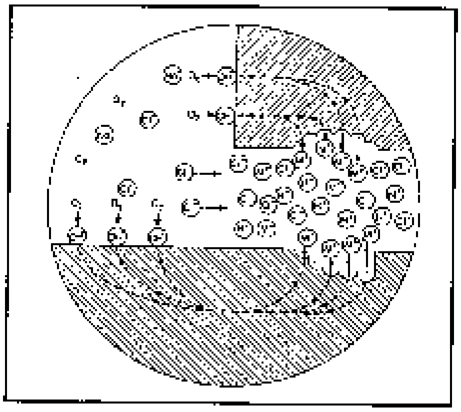

Figure 2.4 The formation of crevice corrosion(http://corrosion-in-rod-pumped-wells.wikispaces.com).

In practice the following precautions can be taken against crevice corrosion:

- Welding should be preferred instead of bolt and rivets.
- Welding or braze should be preferred at the joining surfaces.
- The design of the liquid carrying containers, care must be taken corner cabinet remains to be fully discharged and cannot be cleaned in the bowl.
- Board, which can remain in contact with the metal of wet materials such as plastic should be avoided.

2.1.3 Pitting corrosion

Corrosion event is the type of corrosion as a result of the very narrow focus on regions. A large number of pits formed in the metal surface generally give a tingling view. Diameter of the pit depth and frequency vary depending on the material and environment. Homogeneous distribution of the total metal loss is very small contrast corrosion. However, parts (e.g. condenser tubes) drilled as soon as they become available. Also, besides the loss of corrosion pits formed in the bottom fatigue strength and start events, defined as stress corrosion cracking. Distorting effect, due to difficulties in prevalence and control of pitting corrosion is among the most feared types of corrosion. The formation of pitting corrosion is shown in Figure 2.5.

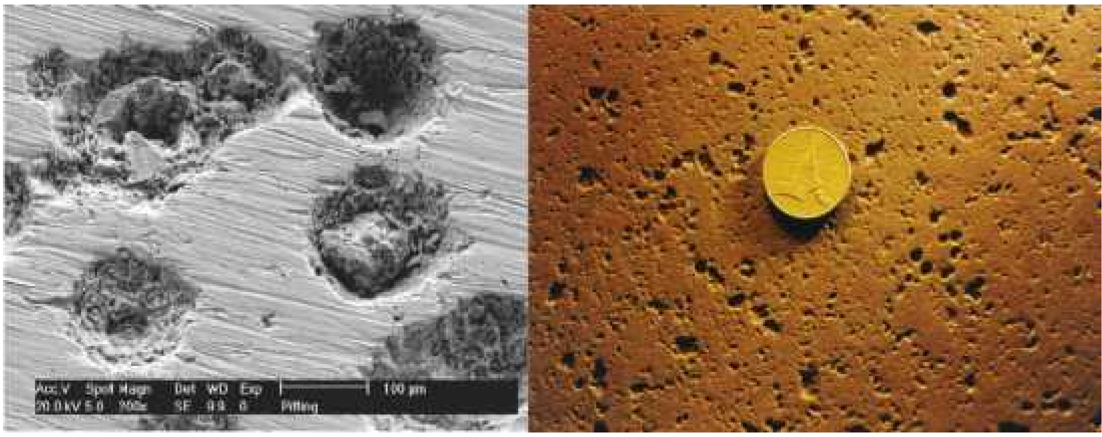

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Figure 2.5. The formation of pitting corrosion(http://www.forensic.cc/non-fire/machinery-breakdown/mechanical-&-material/corrosion).

Pitting corrosion can be seen in many metals and alloys. However, the technological and economic aspects of stainless steels and aluminum alloys must be given priority. Pitting corrosion usually occurs in neutral environments containing chlorine and bromine ions. NaCl and is very rich in oxygen, sea water, pitting environment is a factor that leads to corrosion. Sea water is left to decay in a short time with stainless steel deep pitting formation. Hypochlorite bleach-containing environments are difficult to control in terms of pitting corrosion. In terms of pitting corrosion, the pH of the media is an important indicator. Pitting corrosion occurs primarily in neutral environment. The pH of minimize the location leaves the general corrosion. In exchange for rising the pH will increase the effectiveness of the passive attitude of pitting corrosion it is defined as an attitude among the general corrosion resistance to corrosion. One of the salient features of the pitting corrosion is caused by too small amount of solution. Corrosion pharmaceutically spoke of the necessity of an obstruction between concentrated in the bottom of the wells with the large volume of media. This congestion relieving effects, e.g., conversion into an environment that forms stagnant flow may reduce the tendency of pitting corrosion substantially.

2.1.4 Galvanic corrosion

If dissimilar metals immersed in a conductive solution combined different voltages on the surface due to the transport of metal ions (corrosion potential) and electrons are produced along exposed. Metals are one noble metal (corrosion potential is more positive) the other metal less noble electrode potential, the conductivity increases depending on the area ratio and the solution. The active state is a less noble metal, accelerated corrosion generally occurs, and local corrosion occurs at the metal passive. Galvanic corrosion can be reduced by limiting the ratio of the area of the metal which is more strain to the metal less noble. However, the use of galvanic corrosion inhibitors is needed to fight many odd, metallic systems (Revie, R.W.,2000).

In a galvanic cell, corrosion rate, mainly the potential difference between anode and cathode player force depends on the ambient electrolyte conductivity. Apart from the cathode / anode surface area ratio is important in practice. The larger this ratio is, that a large cathode surface to the anode surface area to be smaller, causing an increase in the anode current density and severe corrosion to occur in a narrow area. The anode of the large, whereas if the cathode is small, corrosion has spread to a large surface area ineffective. In small cathode-anode great if the conductivity of the electrolyte is high, consisting of galvanic corrosion current cell manifests itself in a wide range. In case of low conductivity, in contact with the two metals occurs as severe in a narrow space region. A typical example is made of steel plate, copper rivets (small cathode-anode great) and made on the copper plate steel rivets (large-small anode cathode) is observed.

Another kind of galvanic corrosion occurs at concentrations as corrosion cell battery. These two electrodes having the same type and structure are formed by immersing the two different concentrations of the same solution. Practically metals usually absent in their solutions. For example, concentrated and the concentration cell in contact with a dilute salt solution of these two iron rods occurs. In this case in contact with the concentrated salt solution of iron corrodes the anode. The formation of galvanic corrosion is shown in Figure 2.6.

Figure 2.6 The formation of galvanic Corrosion (http://activerain.com/blogsview/1857467/galvanic-corrosion).

Another type of galvanic corrosion is found in the form of corrosion cells from different cell concentrations leading ventilation. For example, if a region of an iron bar which plunges into water ventilated to receive more oxygen than the other regions, it consists of a battery of oxygen between the two regions. More air space of the cathode, the anode becomes less air space. In this kind of corrosion inside the pile it is frequently observed sea. Pile close to the water level and would cathode from time to time it receive plenty of oxygen in the wet with sea water. The rest area just below the water level, the anode corrodes because it can get less oxygen. Galvanic corrosion of the boiler drain valves and pipes are shown in Figure 2.7.

Figure 2.7 Galvanic corrosion (Shanghai Drydock - M/V YASA AYSEN, 2014).

Another typical example of the galvanic corrosion is more strain on the flowing waters carrying metal ions of an active metal. For example, copper metal in contact with water, when flowing onto steel, copper ions dissolved in the minimum amount of water causes the corrosion of steel by the following reaction. Galvanic corrosion of the general service pump suction pipe is shown in Figure 2.8.

In practice, these measures can be taken against galvanic corrosion:

- Do not touch the metal away from each other in the galvanic series, which should be avoided.

- If it is necessary to use a combination of two metals should be avoided small anode-big cathode surface.
- Two metal contacts must be electrically isolated by isolated flange.

Figure 2.8 Galvanic corrosion [Shanghai Dry-dock - M/V YASA AYSEN, 2014].

2.1.5 Selective Corrosion

One of the elements in an alloy of this type of corrosion are removed as a result of electrochemical interaction with the environment. It consists of porous and brittle metal corrosion results (Schweitzer, P.A.1996).

The best example of this type of corrosion, before the zinc contained in the brass alloy is a copper corrosion. This optional corrosion in private "dezincifications" is called. Selective corrosion of the ship shell plate is shown in Figure 2.9 – Figure 2.10.

Figure 2.9 Selective corrosion of the ship shell plate [http://www.gard.no/web/updates/content/vessel-corrosion-in-stratified-river-systems].

Figure 2.10 Formation of the selective corrosion of the ship shell plate [http://www.chemistryexplained.com/Co-Di/Corrosion.html].

Brass alloy is an alloy consisting of about 70% copper + 30% zinc. This is initially yellow alloy; copper-red color gradually turns into after corrosion of zinc. Alloy loses its strength, winning a porous structure. The greater the percentage of zinc in the alloy, the corrosion resistance is less selective. Make of that solution is still more favorable for dezincification corrosion.

Dezincification corrosion formerly only found in the zinc alloy was described as a move away dissolve and remain in the copper skeleton. This assumption can not exactly bring clarity to acquire a porous structure of the alloy corrodes. The mechanism of recently dezincification corrosion is described as follows: soluble in the zinc and copper alloy surfaces, both the corrosion normally. While zinc added copper ions dissolving cathodic zinc metal reverts back to a reduction. This event can also walk in solution without oxygen. Copper ions accelerate the corrosion of zinc, so the event does not remain on the surface corrosion progresses towards deep to form a porous structure.

Another alternative corrosion phenomenon in common, "graphitization" is corrosion on the so-called gray cast iron. Gray cast iron has 2-4% carbon. Would cathode and graphite cast iron in iron anode. Thus, galvanic corrosion phenomenon occurs. Remain in soluble iron and graphite skeleton. White cast iron in carbon freely available. Therefore graphitizing event does not occur in the white cast iron.

2.1.6 Erosion corrosion

Type of corrosion is occurring in situations where high relative velocity between the fluid and metal materials in the environment. The formation of erosion corrosion is shown in Figure 2.11.

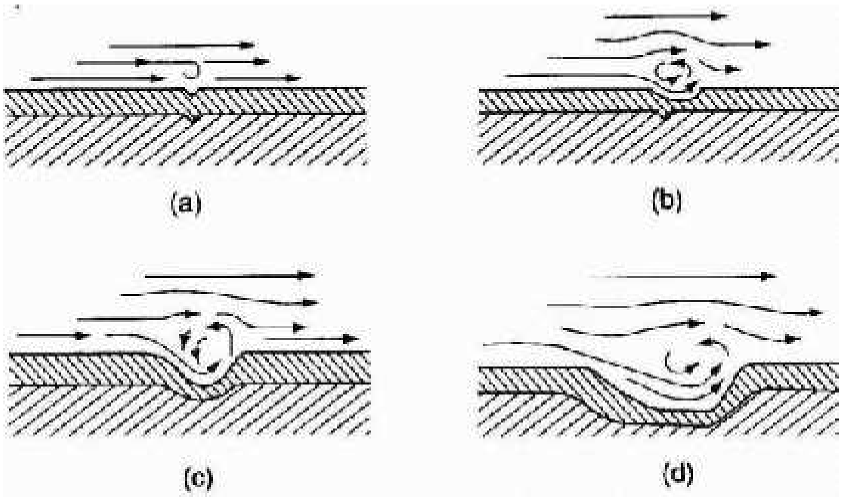


Figure 2.11 Formation of erosion corrosion [http://www.snipview.com/q/Applied_mechanics].

If solutions flow rapidly from the metal surface corrosion, erosion would occur next to corrosion. This causes an increase in the corrosion rate. The main reason is dragged away by the fluid of the corrosion products. Passivity feature which metals are more susceptible to erosion corrosion such as aluminum, lead and stainless steel. This metal surface erosion effect cannot occur in the remaining regions of the passivation layer and the metal corrosion protection in the rest of the region suffered severely. Erosion corrosion of the ship pipe is shown in Figure 2.12.

Figure 2.12 Erosion corrosion

Although erosion corrosion is seen in a metal, metal copper and copper alloys that are most susceptible to corrosion. All the equipment in the presence of moving fluid, such as pipes, elbows, valves, pumps, centrifuges, propellers, mixers, heat exchangers and turbine blades can be said erosion corrosion. The most important factors affecting the erosion corrosion phenomenon, the fluid flow rate is. The flow rate was increased erosion effect also increases. Solid particles present in fluids, increases the severity of the event. Corrosion, erosion corrosion result would be the initiator of the event with a small hollow factors resulting effect of turbulence. Erosion corrosion of ship ballast line is shown in Figure 2.13.

Figure 2.13 Erosion corrosion of ship ballast line (http://www.sacettinarsu.com/images/korozyon.jpg).

The main measures to be taken against corrosion, erosion can be listed as follows:

- The first measure to be taken, the erosion is to select a material with high corrosion resistance.
- Measures should be taken to reduce the effects of erosion during design. For example, the pipe diameter must be increased or the flow rate should be reduced.
- If the fluid carrying solid particles, they must be precipitated before the stream.

A special form of erosion corrosion phenomenon as “cavitation” stops. In case there is a gas or vapor bubbles in the fluid, this pressurized gas on the metal surface can cause wear and tear in that region explodes due to any obstacle. This event usually happens in hydraulic turbines, revealed in the ship’s propeller and pump pallet.

The mechanism of cavitation is: the formation of a vacuum in some areas can vaporize liquid at high flow rates and as a result thereof, or with dissolved gases in the liquid phase separated. Thus, low pressure gas bubbles occur in the liquid. The occurrence of cavitation events are shown in Figure 2.14.

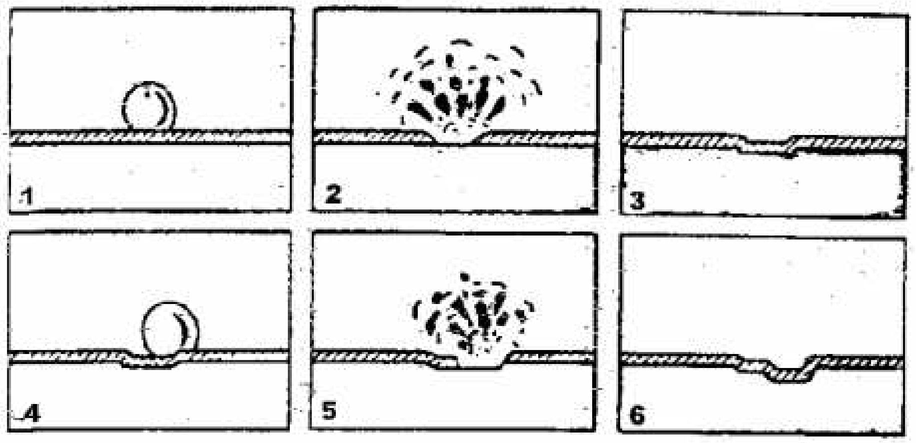


Figure 2.14 Occurrence of cavitation events (http://www.4cev.com/Documents/tebli%C4%9Fler/AATTUTblg.htm).

These bubbles are destroyed by hitting an obstacle in the flow surface. This event usually occurs abruptly metal surface on the metal surface and a strong suction (vacuum) is caused by the influence of the etched metal at that point. Resulting in the formation of new bubbles and the recess causes the recess to gradually grow.

2.1.7 Fretting corrosion

Floating above the other two surfaces is called erosion corrosion should be worn with walking to corrosion. This corrosion is realized only under certain circumstances. There are two different theories on this subject. Fretting corrosion is shown in Figure 2.15.

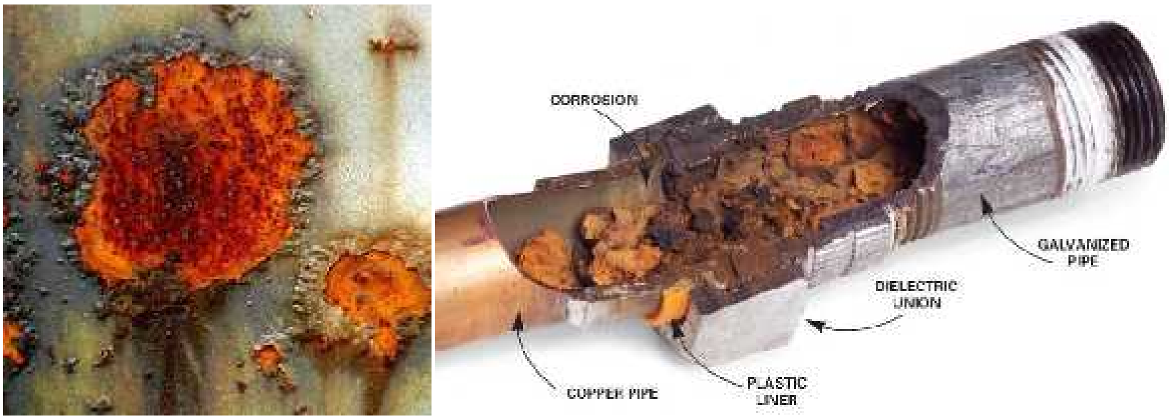


Figure 2.15 Fretting corrosion [http://metaltekkimya.com.tr/labaratuvar/korozyon].

- When the two metal surfaces’ friction is very small metal particles embedded break the surface. These metal particles suffer broken easily oxidized corrosion.
- The contact with oxygen the metal surface is coated with a thin oxide film. This oxide film on the metal surface is scraped and removed friction results.

Corrosion, abrasion during transport over long distances events more bulk metals and is seen in this second type of connection made between the soft elements. Vaccine corrosion as seen from this example is not required to have water to come. Fretting corrosion of diesel generator piston rod shell bearing is shown in Figure 2.16 – Figure 2.17.

Figure 2.16 Fretting corrosion of diesel generator piston rod shell bearing

Generally, aluminum alloys are very prone to corrosion. Therefore, packs must be lubricated and moved to aluminum plates that are shipped. During storage of the materials made of aluminum it is also encountered this problem. The result in many tremors cargo transported on ships damage can occur. Compressors, in cars, many problems arise as a result of friction in rail transport. These can be prevented by making lubrication.

Figure 2.17 Fretting corrosion of D/G piston rod shell bearing(M/V YASA AYSEN 2014).

2.1.8 Atmospheric corrosion

Atmospheric corrosion is a very common type of corrosion encountered. Research done has shown that all the metallic structures remained under atmospheric conditions effected approximately 80%. These structures are such as poles, bridges, guardrails, railways, warehouses, roofing, etc. and all kinds of vehicles. Many steel structure remains constantly under the influence of the atmosphere. Atmospheric corrosion of flange is shown in Figure

2.18.

Figure 2.18 Atmospheric corrosion of flange[http://www.apsonline.com/flange].

Especially under the influence of the atmosphere made industrially polluted state bare steel corrodes in a short time. The atmosphere in the corrosion rate of steel, although more or less water according to the underwater and underground corrosion rate, the losses caused by the atmospheric corrosion, constitute almost half of the total corrosion damage. A large part of the losses consist of the costs of corrosion to prevent corrosion. Nearly half of paints and corrosion protection of the zinc produced is used in the steel industry.

The atmosphere in order to prevent corrosion, material selection, starting from the project's design phase, surface cleaning and painting the determination of the life of scientific precautions structure can be increased as desired.

When the metal is left in the external environment as a result of rain and condensation cycle of wet and dry air can corrode. If sulfur dioxide in the air increases thus the chloride corrosion power is also. In the control of atmospheric corrosion inhibitor coatings in open systems, oils, water repellent liquids, volatile corrosion inhibitors are used in closed systems. Packaging and storage for temporary coating of the metal parts are made on the same application purpose (Schweitzer, P.A.,1996).

The causes of atmospheric corrosion in the following ways.

- *Effect of air humidity*

Compounds found in natural state in a clean atmosphere is another component that does not exist outside of water vapor corrosion. When the air saturated water vapor state to be less than it could cause corrosion. As temperature increases the relative humidity (the water vapor mass in the air per unit volume at the same temperature and the same volume of water vapor mass ratio contained in saturated air.) Decreases, whereas the temperature is reduced relative humidity rises. The temperature at which the relative humidity is 100%, said the dew point of the air. If there is up 70% due to the temperature difference between day and night is the result of condensation on the metal surface consists of a thin liquid film. Metal surface to a minimum relative humidity that causes the liquid film "Critical relative humidity" is called. Of moisture when the metal surface is less than this value will not appear in the liquid layer. However, very fine capillary cavities contain water in liquid state. If solid particles having capillary features such as dust and dirt on the metal surface is easier to concentrate the available water vapor.

- *Impact of industrial pollution*

The most important factor for the atmospheric corrosion of industrial pollution. At first combustion, namely, the atmosphere gas in many chemical industrial processes, vapor and solid particles are mixed. The most common and effective of sulfur oxides. These oxides combine with water vapor in the air acids, ammonia and chloride can be mixed into the atmosphere. Especially in the open sea atmosphere has microscopic salt particles carried by the wind. These salts of metal surfaces creates debris collapse.

- *Effect of temperature*

Atmospheric corrosion rate has a big impact on the corrosion is connected to the duration of the temperature on the surface of the liquid film formed on the metal surface. Temperature drying will occur in low and will continue as long as the metal surface corrosion. Therefore, the atmospheric corrosion rate was low in the northern regions the temperature is higher than in southern regions. Constantly changing temperature outside, it plays a role in enhancing the corrosion will facilitate the concentration of the metal surface.

- *Precipitation and wind effect*

Atmospheric corrosion is needed for absolute water away. Therefore, there is a direct relationship between the corrosion rate by the amount of annual precipitation. However, rainfall is up, the frequency and drying time is also important. Therefore, the wind speed and direction in the region 17 also plays an important role. Wind causes of dry dirt and dust collected on the surface dragged away as accelerate.

Corrosion of metal with the environment "at the interface" is an event that occurred. The basic principle of the interfacial reaction stop walking or methods of corrosion protection is intended to slow down. Methods used to protect them from atmospheric corrosion can be divided into three groups:

- To select more resistant to environmental conditions or the metal surface of a metal plate with another metal,
- To minimize the corrosion reaction speed with a conscious design,
- Paint and other organic coatings to fully isolate the metal environment. Which of these measures or decide which ones will be selected as a result of economic analysis. In fact, the main purpose is to provide economic benefits to combat corrosion. Therefore, for non-economic protection solution is not counted.

2.1.9 Intergranular corrosion

In one of the crystal structure of a metal corrosion occurring along the border line "intergranular corrosion" it is called. The solidification of a molten metal with a metal or solid form during the heat treatment undergone any metal atom crystals of weak boundary of some disorders may occur in terms of corrosion. Intergranular corrosion phenomenon in this region manifests itself when the metal into a corrosive environment.

Touched the limits of corrosion in metal particles is more sensitive. Particle integrity remains intact but intergranular bond is broken. After leaving the grains of the surface layer consists of a porous matrix (Schweitzer, P.A.,1996). Intergranular corrosion is shown in Figure 2.19.

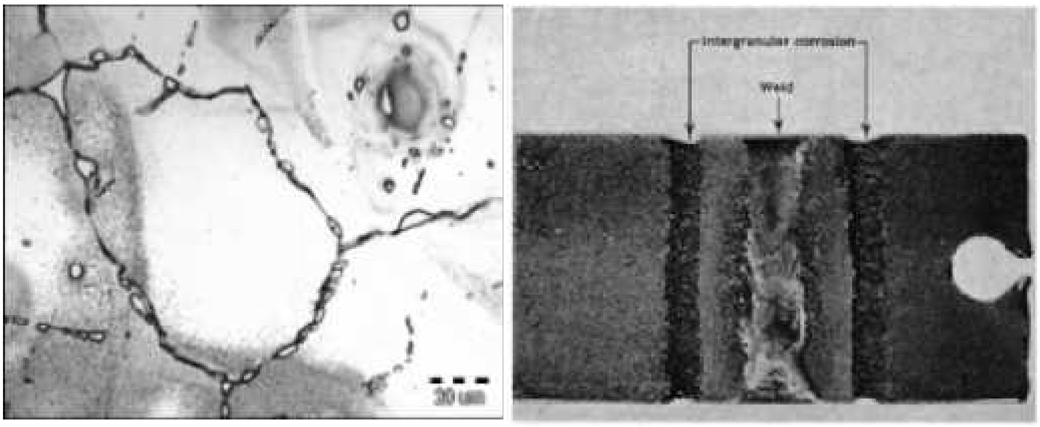


Figure 2.19. Intergranular corrosion (http://www.euro-nox.org/map/intergranular_corrosion).

Intergranular corrosion, from any impurities found in grains, such as is caused by the presence or absence of a more alloying elements. For example, it can cause corrosion of aluminum from iron grains in small amounts. Because aluminum is very slightly soluble in iron. 18-8 stainless steel represents a special case in terms of intergranular corrosion. This steel, although it is very resistant to corrosion in normal circumstances, 500-800°C when heated becomes susceptible to corrosion. The most severe temperature effect, steel 650°C for an hour when the show itself. The reason for this is the extremely decrease of intergranular chromium in at this temperature. Intergranular corrosion of sea water main sea chest suction valve is shown in Figure 2.20.

Figure 2.20. Intergranular corrosion of sea water main sea chest suction valve (M/V YASA AYSEN 2014).

To be corrosion resistant must have at least 12% chromium in stainless steel. If stainless steel is heated in the temperature as mentioned above, chromium in the alloy, carbon reacts with chromium carbide ($Cr_{23}C_6$) generates compound. Chromium carbide is a compound insoluble in steel. Collected along the line of demarcation between the grains. Located in the alloy during heating operation moves between the chromium grains. But the movement speed of the chrome is very small, so you will not be able to reach there in intergranular chromium deficiency. There must be at least 0.02% carbon in the steel to be connected in chromium carbides. A lower proportion of chromium carbide compound formed if there are not effective in terms of carbon corrosion. Chromium carbide itself does not corrode. However, in the area between the grains it becomes vulnerable to corrosion due to chromium deficiency this region. 304 0.06% in stainless steel - has carbon between 0.08. Therefore, it accumulates significant amounts of chromium carbides precipitate between the grains.

2.1.10 Stress corrosion

A metal in a corrosive environment at the same time under a static stress, the fracture is accelerated by cracking the metal. Any hole or crack under stress by becoming sensitive in the metal surface creates a favorable environment for the start of corrosion. Although the normal state of corrosion products on the metal surface to form a protective shell, the shell can not create when under stress. As a result, it causes cracking of the metal by continuing rapid corrosion. Stress corrosion of exposed metal and corrosion formation is shown in Figure 2.21.

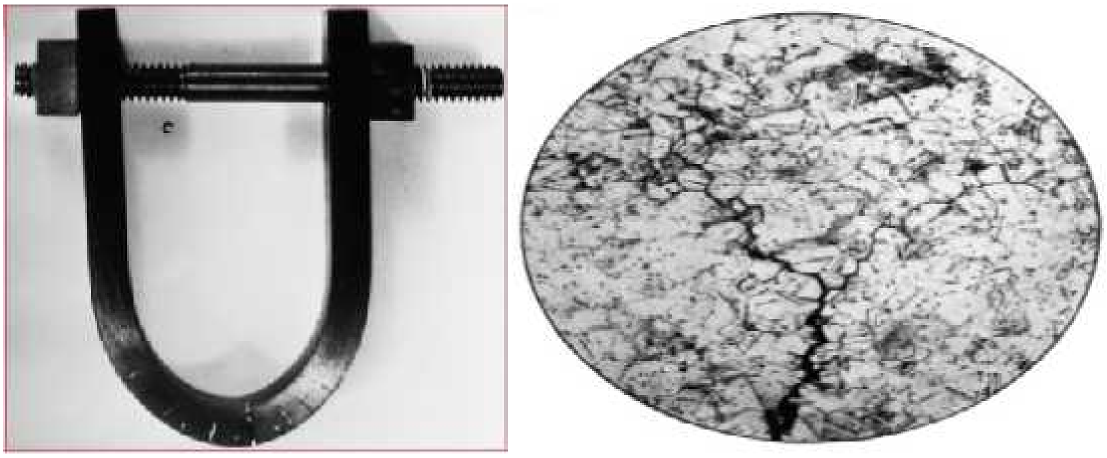


Figure 2.21. Stress corrosion of exposed metal and corrosion Formation (http://www2.aku.edu.tr/corrosion).

This type of very pure metals and alloys are susceptible to corrosion. What is important here is only a tensile stress. To increase the compressive stress corrosion is no effect. Corrosive environments, it helps the formation of stress corrosion. For example, ammonia atmosphere in copper and copper alloys, stainless steel and stress corrosion in chloride atmosphere of carbon steel in nitrate solutions walks more vigorously. Stress corrosion can also occur in other environments.

The most well known form of stress corrosion cracking is common in caustic win. Of water in order to reduce the corrosive effect of the boiler feed water for steam boilers it has prompted the alkaline. Some rivets caustic concentration increases as a result of the evaporation occurs in space and in this region, "caustic cracking" can be seen.

To avoid stress corrosion, or the tensile stress on the material to be removed or not corrosive environments. Or it would suit best to eliminate both the two factors. Heat treatment is recommended to make them more resistant to the tensile stress material. Appropriate temperature and time decreased the sensitivity of the material annealed tensile stress. For example, rice, if allowed to stand for 1 hour at 300°C temperature or stainless steel 500°C also become more resistant to stress corrosion when subjected to heat treatment. Best is to use a metal which is less sensitive to stress corrosion. For example, 304 stainless steel is susceptible to stress corrosion. Instead, inconel (nickel - chromium - iron alloy) is available. Much cheaper than the carbon steel, stainless steel is more resistant to stress corrosion.

2.1.11. Microbiological corrosion

Micro-organisms to increase microbial corrosion rate of corrosion, corrosion or microbiological effects resulting from bio-corrosion (microbially induced or influenced corrosion, MIC) could be described as. Microorganisms forming biofilms, producing adhesives, under producing deposits with a suitable environment for the development of crevice corrosion, creating corrosive acidic environment of metabolic products, by breaking down chemicals added to prevent corrosion environment and affect corrosion reactions directly (accelerating cathodic or anodic reactions) can accelerate corrosion [Videla, H.A.2001]. Microbiological corrosion is shown in Figure 2.22.

Figure 2.22. Microbiological corrosion (http://www.bushman.cc/corrosion_photos.html).

As a result of development of microorganisms revealed some components, such as acids and sulfides. These components may play a role in increasing the rate of corrosion. Although some microbes can participate directly in the electrochemical reaction. Microbiological corrosion of main engine air cooler sea water inlet side cover is shown in Figure 2.23.

Figure 2.23. Microbiological corrosion of M/E air cooler cover (M/V YASA AYSEN 2014)

Aerobic bacteria such as Thiobacillus thiooxidans may oxides and sulfur compounds into elemental sulfur in sulfate of all kinds. Environment for the activity of such bacteria is obligatory oxygen. Reaction to oxidized sulfur turns into sulfuric acid.

We can explain the formation of short chain MIC.

- Physical presence and metabolic activity of microorganisms, modifies the electrochemical properties of the surface.
- Microorganisms reproduces and carries out a colony. Colonies can not cover the whole surface. Of the surface area of the colony space colony consists of no difference in oxygen content. These are called different concentrations of cells and is effective in corrosion.
- Also under the cathode area right next to a colony becomes the anode formed. Such differences occurring on metal surfaces causes a difference in electrical potential, and all these variations cause the formation MIC. Microbiological corrosion formation stages are shown in Figure 2.24.

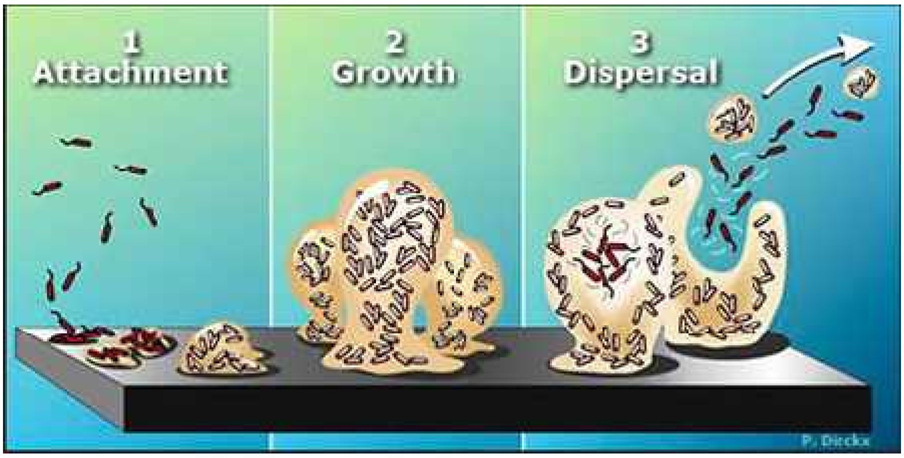


Figure 1: The biofilm life cycle [1]. 1) Free-floating bacteria could anchor to a surface within minutes of encounter, and start to produce slimy extracellular polymeric substances (EPS); 2) Self-organized, highly-structured 3D biofilm community could appear within hours of encounter; 3) Dynamic evolution of biofilm community via intercellular interaction and signaling, as well as interaction with environmental stimuli. Clumps of cells are released to colonize new surface.

Figure 2.24. Microbiological corrosion formation stages[http://www.biofilm.montana.edu/node/2390].

The efficiency of the system as a result of accumulation of corrosion products on surfaces is reduced. However, corrosion, cause damage to the tank surface, making it impossible to reuse the pipe or a system leads to losses.

Corrosion is in the most frequently used imaging scanning electron microscopy (SEM). Energy Dispersive X-ray Spectroscopy (EDS) and SEM determined using elemental composition of corrosion products together. Thus it does simultaneous analysis of both elements of both metal surface morphology. Other methods of X-ray diffraction (XRD) spectroscopy. Compounds of corrosion products identified by XRD.

2.1.12 Hydrogen embrittlement

Corrosion reactions on the metal surface results or cathodic protection applications are carried out hydrogen atoms. These adsorbed on the metal surface. This is a part of the atoms combine to form H + H → H2 into hydrogen molecule is released into the atmosphere. A portion of the hydrogen atoms, is placed into cavities contained therein enter the metal structure. Then the hydrogen atoms leads to a large increase in volume is converted into a molecule. The latter diffuses into hydrogen molecules does not feature. Therefore, hydrogen molecules are formed in a high pressure metal forming the metal cavity causes the metal to break. Hydrogen embrittlement corrosion of bollard is shown in Figure 2.25.

Figure 2.25. Hydrogen embrittlement corrosion of bollard (http://www.protectkimya.com.tr/yuzeyıslem/photos).

Iron (ferrite) which is a metal-centered cubic crystal structure interstitial. Intersititial crystalline metals that can accept foreign to an atom or ion in the crystal lattice. Such a foreign atom plays a role in increasing vulnerability. Hydrogen atom falling within particular steel increases the brittleness characteristic of the steel. Hydrogen embrittlement corrosion stages are shown in Figure 2.26.

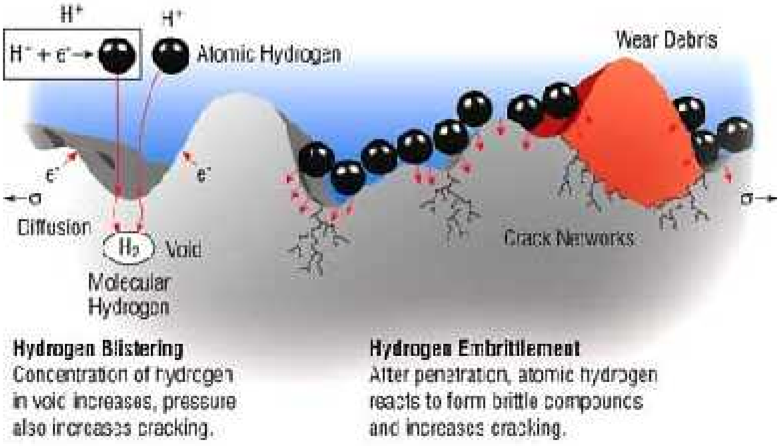


Figure 2.26. Hydrogen embrittlement corrosion stages[https://sgr20027784/degradation-ol/forms-of-corrosion].

Hydrogen embrittlement events frequently encountered in practice. Pikling especially with hydrogen formed in the surface cleaning or wet welding electrodes in various process creates problems for the metal. Hydrogen atoms have entered into the field to break the iron will cause some delay. This is clearly seen in tensile strength tests. If damage is hydrogen is subjected to a tensile strength test sample involved, not breaking even though an amount exceeding normal tensile strength. But with a few hours delay snap it occurs. This situation is caused by the diffusion of hydrogen atoms in the metal and there is no need for a certain period of time to turn into molecules. Hydrogen embrittlement is inside a steel is shown in Figure 2.27.

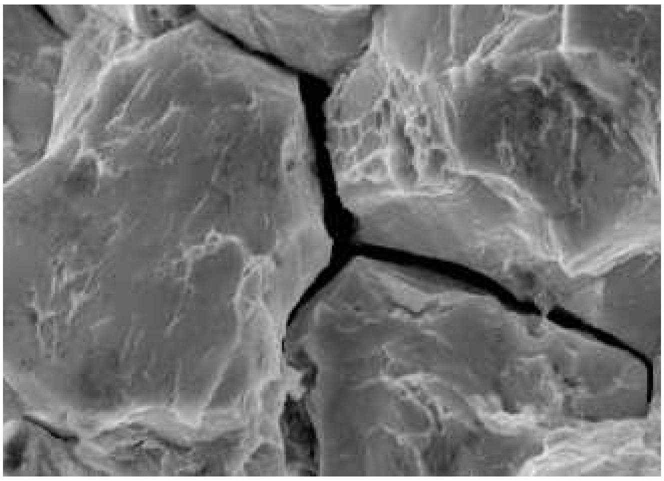


Figure 2.27. Hydrogen embrittlement is inside a steel[http://metassoc.com/site/2013/06/hydrogen-embrittlement].

Damage due to hydrogen, normal tensile stress of about 700 MPa steel after switching to manifest itself. This is rare event in low-strength material. In galvanized wood screws tightened strongly, especially if studies of the effects of hydrogen embrittlement may occur. Improper pikling and metal plating the hydrogen damage may occur. Metal surface such that a suitable environment for hydrogen hydrogen brittleness in all events with a high overvoltage may occur. The following measures can be taken to reduce or to eliminate the harmful effects of hydrogen penetration into the metal structure:

- Hydrogen atom, which has entered the metal, can be removed by heating to 100 - 150 °C temperature.
- Hydrogen embrittlement occurs in more high-strength steel. Resistance to hydrogen embrittlement or molibt joining the nickel into steel can be increased.
- As a general rule, it should not be allowed out of hydrogen in the metal surface. For example, resources should not be wet. Over-voltage should be avoided in cathodic

protection.

2.2 Other Losses Incurred Due to General Corrosion

Result of corrosion occurring, but clearly visible in several casualties as metal loss is concerned. This is the most typical example of a result of corrosion perforation of a pipeline carrying fuel or water. The other losses incurred outside of the drill pipe material due to corrosion are:

- Pipe loss of product to the environment escaping from the pipe as the understanding of the puncture,
- Pollution caused by fluid emitted into the environment or harmful effects,
- Fuel case of fire or explosion hazard,
- The danger of epidemics appeared in the city of water,
- Losses in profits and losses arising from a lack of business administration,,
- Labor spent on replacing old pipes with new pipes removed.

2.3 Corrosion Loss and Reduction Methods

Corrosion phenomenon manifests itself in all branches of industry. Located tanks open to the atmospheric conditions, tanks, racks, railings, vehicles, underground pipelines, concrete anchors, port legs, ships, chemicals containers filled factories, pipes, tanks and part of a machine are faced with corrosion. All this is done in a short time than expected due to corrosion in the business and stay out huge economic losses occur.

Account of the cost of corrosion loss is very difficult. In addition to these challenges due to the loss of material and labor caused corrosion, caused by the determination of some secondary invisible losses. Corrosion caused by direct loss of material and labor, must be included in other emerging losses due to corrosion. Indirect losses caused by corrosion can be grouped in five items:

2.3.1 Operation out of the service facility

Corrosion results for the repair of defects occurring plant will stop production remain off during the period. For example, a natural gas pipe or main water pipe corrosion due to losses occurring in the account being disabled for a few days can not be so great. In addition, the loss of prestige caused by the pause in operation at the plant in question must also be taken into account as losses caused by corrosion.

2.3.2 Loss of product

A receptacle, if a result of corrosion of the tank or drilling pipe, the loss of product during the period until the difference has been reached the event is concerned. These losses must be regarded as a loss to corrosion. Besides environmental pollution and loss of product if the product is also a fire hazard if flammable example is many fuel leak into the ground as a result of perforation of the fuel tanks in petrol stations.

2.3.3 Product contamination

Soluble corrosion products cause contamination into the resulting mixed substance. Especially food, quality products such as rust contamination with drugs and soap deteriorates. For example, lead pipes, causes mixing of toxic lead compounds into drinking water.

2.3.4 Paints and coatings

Coatings used to protect metals from corrosion, coatings made with tin and zinc can also be considered as a loss of corrosion. The paint being produced is used in order to prevent corrosion the most part.

2.4 Extreme Measures Taken To Corrosion

Most of the time what the size of the initial corrosion rate can not be fully known, is necessary during the design are made to the use of thicker materials or very expensive material.

In order to reduce as much as possible corrosion losses have been developed various methods outlined below.

2.4.1 Paints and coatings

Corrosion prevention in paints and other coatings which is the cheapest method is used in practice since ancient times. In the last few years it has been great advances in the paint type and quality. Even in the most severe corrosive environments that can withstand 15-20 years epoxy, polyurethane, rubber and so on. polymer coatings have been developed.

2.4.2 Stainless steels

In the beginning of this century into a certain percentage of chrome and iron alloy obtained by participating nickel it was found to be corrosion resistant. Iron initially contained in a stainless steel which is produced due to the high percentage of carbon has created several problems. Today, the percentage of carbon in the steel can be lowered to a very small value special methods have been developed, so have been able to produce outstanding feature stainless steel types. Presently, particularly medical instruments, food and chemical industries, including water and atmosphere under the influence of all structures in a variety of fully corrosion resistant stainless steel is used.

2.4.3. Inhibitor use

In the absence of the replacement cost of the metal species, it is made to use the inhibitor to reduce the corrosive nature of the environment. Especially in closed systems as well as cooling water, inhibitor is the most economical method to use in the fight against corrosion.

2.4.4 Anodic protection

The anodic protection, a metal, anodic passivation showing the property to be polarized in the direction based on the principle becomes inactive. Thus, the corrosion rate of metal in said environment can be reduced to about one-thousand level.

2.4.5 Cathodic protection

The first application of cathodic protection has been on the pipelines. Today, port legs, ships, water, and oil storage tanks, chemical carrying vessels, heat exchangers, reinforcing steel and so on. It is protected as a cathodic very metallic structures. Making, especially in high-pressure oil and gas pipelines can be operated safely, but it is possible cathodic protection.

2.5 The Consequences Of Corrosion

Corrosion effects are very diverse and secure these effects, a simple loss of equipment or building reliable and efficient operation of a metal mass usually more severe. Several failures and expensive replacement needs may occur even if the destruction of the metal amount is quite small. Some of the major detrimental effects of corrosion can be summarized as follows:

- Reduction of metal thickness leading to loss of mechanical strength and structural failure or breakdown. When the metal is lost in localised zones so as to give a cracklike structure, very considerable weakening may result from quite a small amount of metal loss.
- Hazards or injuries to people arising from structural failure or breakdown (e.g. bridges, cars, aircraft)
- Loss of time in availability of profile-making industrial equipment.
- Reduced value of goods due to deterioration of appearance.
- Contamination of fluids in vessels and pipes (e.g. beer goes cloudy when small quantities of heavy metals are released by corrosion)
- 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.
- 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.
- Mechanical damage to valves, pumps, etc, or blockage of pipes by solid corrosion products.
- 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 (http://www.npl.co.uk/upload/pdf/basics_of_corrosion_control.pdf).

CHAPTER 3

CAUSES OF CORROSION

3.1 Causes of Corrosion

Corrosion is a dynamic cycle process. So at any moment, with or without metal materials in any environment may be exposed to corrosion. Factors that cause corrosion and electrochemical, chemical, can be grouped under four main groups as physical and environmental.

3.1.1 Corrosion by physical factors

High pressure and temperature of the material provides a more favorable environment for corrosion. If getting more amount of load on the strength of a part or a versatile force is under the influence of the corrosion it is inevitable. The destruction of the protective surface of the friction material can be exposed to corrosion. For example, to address corrosion raises an environment where there are extreme differences in temperature during the day.

3.1.2 Corrosion by chemical factors

Common structural metals are obtained from their ores or naturally-occurring compounds by the expenditure of large amounts of energy. Therefore these metals can be regarded as being in a metastable state and will tend to lose their energy by reverting to compounds more or less similar to their original states. Since most metallic compounds, and especially corrosion products, have little mechanical strength a severely corroded piece of metal is quite useless for its original purpose.

Virtually all corrosion reactions are electrochemical in nature, at anodic sites on the surface the iron goes into solution as ferrous ions, this constituting the anodic reaction. As iron atoms undergo oxidation to ions they release electrons whose negative charge would quickly build up in the metal and prevent further anodic reaction, or corrosion. Thus this dissolution will only continue if the electrons released can pass to a site on the metal surface where a cathodic reaction is possible. At a cathodic site the electrons react with some reducible component of the electrolyte and are themselves removed from the metal. The rates of the anodic and cathodic reactions must be equivalent according to Faraday's Laws, being determined by the total flow of electrons from anodes to cathodes which is called the "corrosion current", Icor.

Since the corrosion current must also flow through the electrolyte by ionic conduction the conductivity of the electrolyte will influence the way in which corrosion cells operate. The corroding piece of metal is described as a “mixed electrode” since simultaneous anodic and cathodic reactions are proceeding on its surface. The mixed electrode is a complete electrochemical cell on one metal surface.

The most common and important electrochemical reactions in the corrosion of iron are thus

Anodic reaction (corrosion)

$$Fe \rightarrow Fe^{2+} + 2e \qquad \text{Formula 3.1}$$

Catthodic reactions (simplified)

$$2H^{+} + 2e \rightarrow H_2 \qquad \text{Formula 3.2}$$

3.1.3 Corrosion by environmental factors

Corrosion of materials in marine environments is dependent on various factors such as material composition, dissolved oxygen content, salinity, temperature, seawater chemistry, pH, biofouling, microbiological organisms, pollution and contamination, alloy surface films, geometry, surface roughness, galvanic interactions, fluid velocity characteristics, and heat transfer rate.

Atmospheric corrosion often incorporates a complex combination of chemical, electrochemical and physical processes in an interfacial domain from the gaseous phase to the liquid phase to the solid phase (Leygraf C., T. Graedel, 2000). The adsorption and absorption of water from the atmosphere is the initial step towards atmospheric corrosion and the degree of water adsorption is dependent on the relative humidity and the temperature. Adsorbed water acts as a solvent for atmospheric gases and particulates in the liquid layer which can alter the corrosion rate of the substrate alloy.

As a general rule, the corrosion reaction rate in seawater increases as the temperature is increased. However, other variables such as oxygen concentration and biological activity must also be considered. The dissolved oxygen decreases as the temperature is increased. Biological activity generally increases with increasing temperature, and calcareous deposits and other protective scales are also more likely to form/deposit on metal surfaces at higher temperatures. Temperature variations due to seasonal changes also affect metal corrosion rates in seawater.

In addition to the seawater variables listed above, the induction time dependence for initiation and subsequent propagation of many metal reactions will affect the corrosion occurring on metals and alloys in seawater. The composition of corrosion products and of calcareous deposits formed under cathodic polarization conditions will also influence metal corrosion.

Oxygen concentration cells can be created from deposits on a metal's surface or may be due to component design. Differences in oxygen content due to discrete films or deposits randomly scattered along a metal surface can cause pitting and/or crevice corrosion at these localized sites. In contrast, complete coverage of a surface by a film or a deposit can provide an effective barrier and reduce corrosion of the metal (Ifsseling, F.P.,1989).

The salinity of open ocean water at the surface typically varies from 32 to 37.5. Salinity variations influence the uniform corrosion rate of a material. Dilute seawater is under saturated in carbonates, which reduces the likelihood of forming protective calcareous films on metal surface. At the surface, the ocean waters throughout most of the world are supersaturated in calcium carbonates and precipitation of these carbonate scales will influence the corrosion reaction occurring at the metal surface. In deep ocean waters, calcareous deposits are not spontaneously formed in the ambient environment and are often not precipitated under cathodic protection conditions (Davis, J.R.,1987).

As the salinity is increased, the chloride ion activity increases and can result in increased pit and crevice corrosion inititation and propagation (Davis, J.R.,1987).

Marine biological organisms have both micro (bacterial) and macro (algae, barnacles) forms that can alter the corrosion behavior of metals and alloys in a number of ways including:

- influencing one or both of the anodic and cathodic reactions occurring,
- influencing the formation and/or maintenance of protective films,
- producing deposits on metal surfaces, and
- creating a corrosive environment. The items listed above can act singly or can be combined to alter a metal's corrosion behavior (Fontana, M.G. N.D.,1967).

Biological organisms can attach and multiply on any solid surface in seawater. Within two hours of immersion, a non-living organic conditioning film develops on a solid surface.

Within the first 1-2 days, a bacterial slime film develops over the conditioning film. The slime film creates a partial barrier to diffusion between the liquid/metal interface and the bulk seawater environment. These slime films are usually not continuous and can create oxygen or chemical concentration cells on the metal surface, which can result in accelerated localized corrosion. For a metal that normally has a relatively low corrosion rate in seawater, the slime film can alter the local environment at the liquid/metal interface to create conditions where the corrosion rate is accelerated (Davis, J.R.,1987).

Fluid velocity can significantly affect metal corrosion rates in seawater that can be further influenced by other significant variables. Corrosion rates and the type of corrosion are often dependent on environmental factors such as fluid flow and the availability of appropriate species required to drive electrochemical reactions (Fontana, M.G. N.D.,1967). A change in the motion of a corroding metal or alloy relative to its environment by fluid flow can increase corrosion rates by removing protective films or by increasing the diffusion or migration of deleterious species. On the other hand, and increase in fluid flow can decrease corrosion rates by eliminating aggressive ion concentration or enhancing passivation or inhibition by transporting the protective species to the fluid/metal interface. Under turbulent conditions, corrosion may take the form of impingement, erosion corrosion or cavitation (Boyd, W.K. F.W., 1978). The effect of seawater velocity on a metal’s corrosion rate varies with the particular alloy.

Polluted waters, like those found in coastal harbors and estuaries, contain sulfide and sulfate-containing compounds. Sulfides are known to adversely affect the corrosion rate of metals. Sulfates themselves are not usually harmful, however, sulfates can be reduced to harmful sulfides by sulfate-reducing bacteria. Sulfide pollutants can alter the corrosion rates of steels, stainless steels, copper, and aluminum alloys (Davis, J.R.,1987). For instance, sulfide corrosion has been found to occur on a number of different copper-base alloys. Wrought 90/10 copper-nickel can exhibit sulfide-induced attack in the form of accelerated pitting with as little as 0.01 ppm sulfide concentration wgile 70/30 copper-nickel is susceptible at sulfide concentrations of 0.05 ppm or greater (Gudas, J.P. H.P.,1977).

3.1.4 Corrosion by electrochemical corrosion

Corrosion can be one oxidation at the anode, the electrochemical reaction occurs in two other moving simultaneously as the reduction at the cathode. From this perspective, the corrosion phenomenon considered as a galvanic cell that produces spontaneous flow. Corrosion is not necessarily to be present for the two metal away. Found alone in the electrolyte in a metal corrosion can occur. A potential difference between the two zones may occur due to some differences in the metal structure or surface. Particular areas of the metal surface as a result of this anode, some of it will also cathode. The result is a micro or macro-scale corrosion cells. Electron flow between the cathode and the anode metal is carried out. Corrosion can occur in the anode metal goes into solution as ions by oxidation of the metal electrons.

$$Me \rightarrow Me_2+ + 2e- \qquad \text{Formula 3.3}$$

Instead of corrosion in metal reduction at the cathode, another kind of reduction reactions occur depending on the environment where the conditions. The cathode of the reaction medium depends on the pH and electrolyte concentration of dissolved oxygen in the electrolyte. One of the major events in the following two reactions at the cathode corrosion in walking becomes natural electrolytes in question.

- Cathode reaction takes place in an acidic environment with hydrogen ion reduction. pH of the electrolyte must be small for the hydrogen evolution.

$$2H+ + 2e- \rightarrow H_2 \qquad \text{Formula 3.4}$$

- Neutral and in the presence of dissolved oxygen by electrons of oxygen dissolved in the water cathode reaction walks transformation into the form of hydroxyl ions.

$$½O_2 + H_2O + 2e- \rightarrow 2OH- \qquad \text{Formula 3.5}$$

pH in natural waters are generally higher than 7. Therefore, in the event of natural waters cathode corrosion walks with oxygen reduction. To be spent cathode reaction anode reaction of the released electrons must continue the same time. Therefore, in neutral and alkaline solutions must have the absolute oxygen dissolved in the electrolyte in order to continue the corrosion.

Natural waters play a role because of electrolyte ions dissolved in them. Some of metal surfaces in contact with water anode corrosion cells occur in some magnitude. These cells from the surface of any impurities or slag cleaning process leading to the formation of the metal composition is sufficient or not crack the shell. Metal or the electrolyte resulting from this heterogeneous structure allows the formation of a potential difference on the surface. Off occurs as a result of this metal itself is corrosion cells. The potential difference between the anode and cathode to what extent it would be very much greater than the rate of corrosion. Moving the anode and cathode reactions in the corrosion cell is shown in Figure 3.1. It goes into solution as a result of corrosion of metal ions in the anode dissolves. If metallic iron, the anode reaction is as follows:

$$\mathrm{Fe} \rightarrow \mathrm{Fe}_2+ + 2e- \qquad \text{Formula 3.6}$$

This reaction is caused by electrons flowing through the metal structure of expenditures of the cathode. For more of corrosion, coming form a reduction reaction at the cathode using the electrons must.

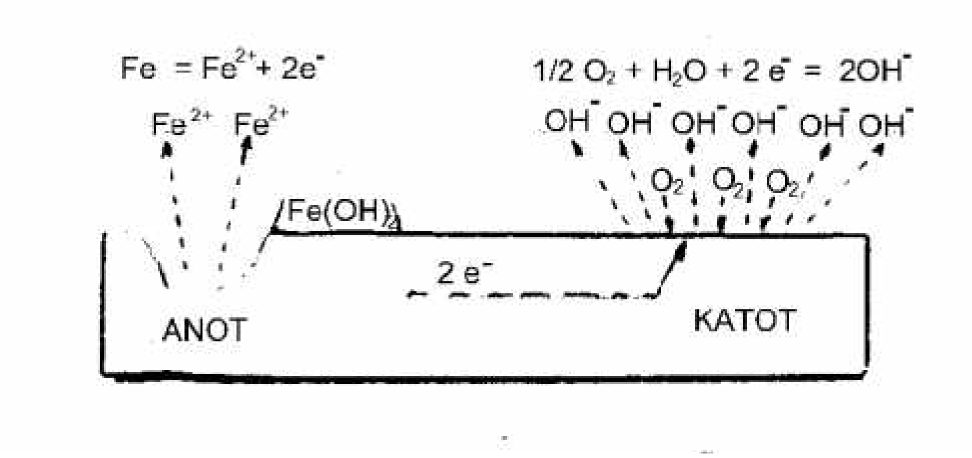


Figure 3.1. The anode and cathode reactions in the corrosion cell (http://www.amteccorrosion.co.uk/corrosionguide.html).

As explained above, the pH of the cathodic reaction medium and can be varied according to the oxygen concentration of the corrosion phenomenon. Neutral and electrons of oxygen dissolved in water according to the media which contains dissolved oxygen in the cathode reaction equations taking walks in the form of conversion into hydroxyl ions. In this case, the hydroxyl ions at the cathode by reduction of oxygen occurs. Natural water and the pH is usually 7 or corrosion phenomenon in natural waters is larger grounds usually work that way.

If the solution is acidic, the reduction of hydrogen ions at the cathode occurs. This reaction produces hydrogen at the cathode is observed. Released electrons at the anode by oxidation of the iron used for the reduction of hydrogen ions at the cathode. Figure 3.2

Fe 2+ ions released in the acidic environment in the event of walking through corrosion solution. Hydrogen atoms adsorbed in cathodes out into H_2 molecule.

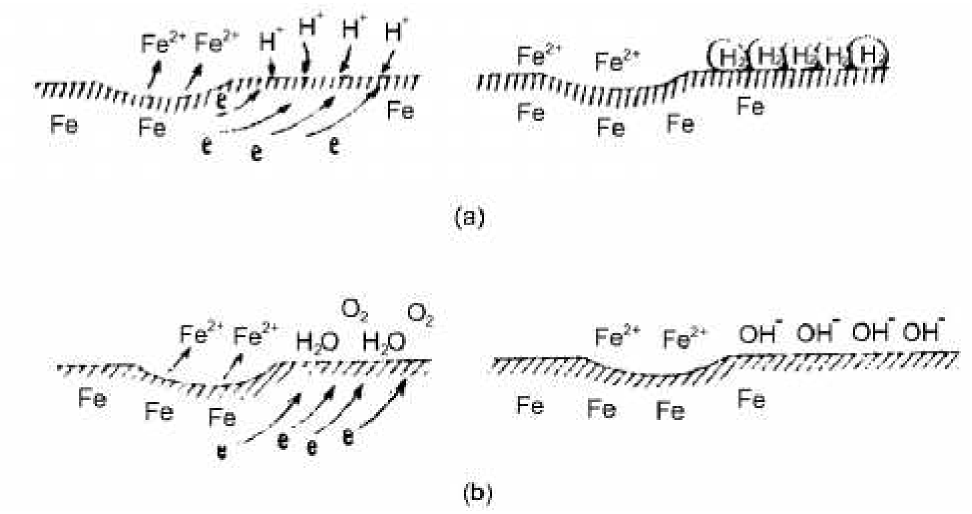


Figure 3.2. Corrosion of iron in aqueous environment corrosion in acidic environment , (b) dissolved oxygen created by corrosion (http://www.lifechem.co.id/CorrInfo.htm).

As it is shown in the figure, in a solution containing dissolved oxygen, as it is released at the anode of Fe 2+ ions are hydroxyl ions formed at the cathode. These ions combine in an area close to the metal surface into iron hydroxide (rust) deposits.

$$Fe_2+ + 2OH- \rightarrow Fe(OH)_2 \qquad \text{Formula 3.6}$$

Total corrosion reaction in an oxygenated environment,

$$Fe + ½ O_2 + H_2O \rightarrow Fe(OH)_2 \qquad \text{Formula 3.7}$$

It can be written as.

As can be seen from the reaction equation, neutral necessarily need the presence of dissolved oxygen in the water to continue the corrosion in natural waters. Corrosion rate is below the cathode reaction control. However, after a period of Fe_2 + ions occurring in the anode, the cathode consisting of (OH) - ions combine Fe (OH) 2 deposited on the metal surface as. If close to the anode and cathode regions, the iron hydroxide precipitate the metal surface adhering a crust. As a result of this, the anode reaction rate gradually slows down or even stopped altogether can be formed depending on the metal shell of the adhesion strength.

The formation of a protective shell on the metal surface in practice is of great importance for the prevention of corrosion. Slowing down one of the anode or cathode reaction will cause a slowdown in the rate of corrosion. Calcium carbonate the formation of a thin layer on the metal surface is also a reducing effect on the rate of corrosion. Especially ensuring that working in closed loop cooling water system capable of precipitated calcium carbonate in the water trying to reduce the corrosion rate.

Every region of the metal surface can equally take oxygen. Which can take more oxygen cathode regions, areas of low oxygen also becomes the anode. Thus likewise it consists of a corrosion cell to a cell concentration between two regions. It corrodes metal ions passing into the region of the anode corrosion cells. Reduction reaction in the cathode region not only comes from corrosion will occur.

Floor, concrete and so on. Ionic conductivity of porous structure, medium containing ions is weak. In such environments is facilitated formation of micro-corrosion cells. If the chloride ion, trough corrosion phenomenon may occur more easily. A corrosion cell formed in the concrete example schematic is shown in Figure 3.3.

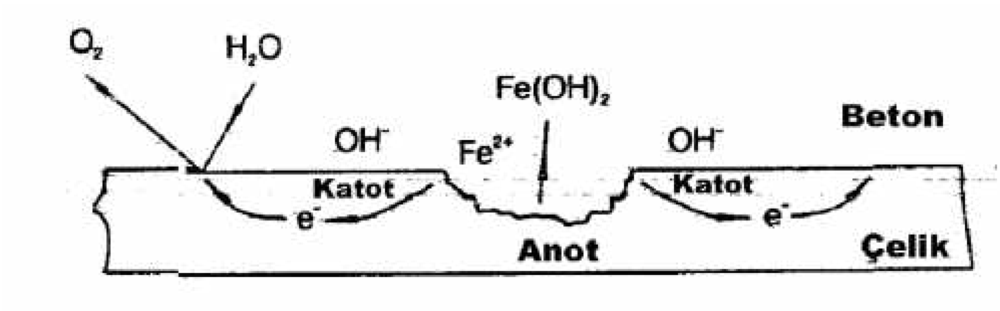


Figure 3.3. Formation of pit corrosion cell type [http://www.fgg.uni-.si/~/pmoze/ESDEP/master/wg04a/l0100.htm].

Any of the metal surfaces found in the concrete as shown in figure anode regions flanking this region also would cathode. Thus micro cell corrosion occurs. The anode reaction is carried to the results released electrons through the cathode metal is used in the reaction zone and there is reduction of oxygen. Corrosion of iron becomes ferric ions dissolving occurred in the anode region. Due to corrosion of the reinforcing steel passivation it is too slow. The iron ions dissolved in the medium because it is a concrete kalevi normal state becomes deposited on the metal hydroxide and form a crust on the surface of the anode region. If there is no chloride ions in the environment, this prevents the iron hydroxide precipitate more walking and reinforcing steel corrosion by filling the pit for the anode is passive in a short time.

3.1.5 Corrosion by cathodic events

And the coexistence of the two metals together without any other means is a single metal is not self-corrosion.

Cathodic corrosion occurs in four ways:

- From a faulty coating for protection against corrosion
- The lack of homogeneous structure of metal or alloy,
- The presence of foreign substances on metal surfaces,
- The stitching is different from the source point,

3.1.6 Corrosion by anodic events

Constantly eroded material to flow out no matter where a metal anode direct current to be passed. Wherein the event is the same as electrolysis. These ships directly to electricity in the form of corrosion is most common.

3.1.7 Corrosion by electric current

If the two metal contact points of a point touching each electrolyte with an electric current occurs. After the metal from the table before the electrochemical etching by that metal. Seen in metals and alloys by means of electric current is the most dangerous corrosion. Batteries shall consist of crystals with different electrochemical and material interferes with internal corrosion.

CHAPTER 4

CORRODED REGIONS ON SHIPS

As many of the world is still unstable in nature and tend to return to their natural thermodynamics of metal ores. This instability is the main factor causing corrosion. Corrosion is an electrochemical event and is partially known to occur from two reactions. Metal is oxidized, the metal ions and cathodic free electrons of the anodic to be transferred to the reaction solution and where the cathodic reaction pH of about 5, particularly on the most common type of reaction associated with corrosion of bulk carriers reactions. When the humidity in the environment, easier to transfer metal ions. Mild steel corrosion rate depends on the ratio of each reaction. Transfer of an electrochemical reaction electric charge and to collapse or melting (Walsh, F.C.1991). Corrosion in structural elements of the bulk carrier usually takes place in the presence of a non-acidic electrolyte. This external environment and the absence of a corrosion hydroxide is produced by the corrosion reaction that has a corrosive surface. This makes an impact on the corrosion process once.

Corrosion protection was crisp, occurs in rotten and rusty interior. Corrosion occurs with metal thickness reduction. This reduction does not clear itself up to extreme wear occurring in thickness. There is a lack of metal used in the construction of ships to forge services that can ship immediately possible corrosion can occur more quickly. Severe corrosion results in accumulation of this metal, makes it necessary to later be replaced. And as the thickness of the metal to uniformly reduce corrosion known as general or uniform corrosion mechanism may be found in the other types of marine structures. These are: pitting corrosion, crevice corrosion and is the source of metal corrosion.

Region most exposed to corrosion in ship ballast tanks are in place as well as sea water, humidity, are exposed to the salty atmosphere when the weather is empty. Also exposure to rising temperatures depending on the deck of the sun rays can cause corrosion. Corrosion in sea water ballast tank areas, fixed offshore diving (immersion) would be considered could be different from corrosion. The temperature of the water in the ballast tank is higher than the water in the marine environment. Trim during cargo loading and unloading operations at ports and freeboard and ballast may be necessary to adjust the ballast discharge process. Such ballast receiving and discharge operations can accelerate the corrosion process because the steel surfaces are wet and dry periodically. If there is this type of case, depending on the congestion due to the presence of anticorrosion coating corrosion can progress very quickly.

Corrosion behavior can be divided into three basic categories; the durability of the coating, corrosion and corrosion transition process. Convex curve of the corrosion rate increased at first, but then decreased by corrosion represents progress. Steel having the steel surface due to abraded material protects the corrosive environment and the corrosion process would have stopped. Electrochemical corrosion phenomenon consists of two partial reaction; anodic oxidation reaction (loss of electrons) and an electron receiver of electrons (usually oxygen) by reducing the cathodic reaction. Corrosion occurs only where adequate moisture and oxygen in the environment. Corrosion rate will depend on the temperature, because corrosion is a chemical reaction. If the temperature is for example oxygen and moisture, depending on the position of the working environment on board the ship in a bulk material cargo ships and corrosion will manifest itself. Shipping warehouse on the basis of operational parameters affecting the corrosion is partial frequency of cargo transported iron ore or coal. Coal is more corrosive than iron ore. Because it contains sulphates and chlorides. Corrosion that causes the formation of many factors to where the ship also shows commitment. For example, the paint on the side edges sweating and ballast tanks partially due to moisture degradation takes place in the inner volume. This corrosion on each point therefore hereby commitment to ship cruising because air and sea water temperatures, relative humidity and salinity of sea water is different from location to location in the world. When the surfaces and pressed steel structure in double bottom ballast tanks in ballast degradation seen.

4.1 Corrosion of The Ship’s Hull

Ships are faced with many chemical and physical phenomena. Chemical substances found in sea water, air, chemical structure, the sun, the rain, the cold, the ship under the influence of heat and boats ashore by waves more damage, worn with, they are faced with oxidised. Ships are determined by the situation and entering into the pool on the bottom of the tank with regular intervals and necessary repairs when the ships are allowed to campaign.

Figure 4.1. Corrosion of ship hull (Shanghai Drydock – M/V YASA AYSEN, 2014)

And the aging of the paint on the deck above the waterline will be scraped, to be taken by the new paint scraper and extend the life of the boat and placing it allows the deterioration of both the place and the beautiful view. It is not until more than twenty to thirty years, taking raw materials from the market while they paint on the ships was made in the paint and putty ship. Now almost all the ships ready-made paints and pastes are used. The one must remember that the paint and painting work and is a very expensive business and if well done, is driven as needed, the paint surface adhesion, can not do the tasks expected from the appreciation in the paint itself can not provide enough cover. Using more of the substance under the false idea that we better protect paint.

More on vertical surfaces such as paint flows will create a bad condition also causes unnecessary costs. Brush lightly dipped in paint box up to one in three, tin, then poured over the edge of the outbreak involves applying the paint surface thoroughly sharply, hovering ride should be done several times. If necessary, the brush not only from top to bottom, but also must be taken to ensure that allowed the horizontal movement of the brush. Corrosion of ship hull is shown in Figure 4.1 – Figure 4.2.

Figure 4.2. Corrosion of ship hull (Shangai Drydock – M/V YASA AYSEN, 2014)

Painting work if it takes a few days, painting brushes and paint when breaks were well protected until the next day is also important. Brush paint brushes leaving on freezing painted by brush can immobilize the job. For this reason, but not on the hair in place to stop after work ending washed thoroughly with brushes thinner must be held vertically. If the work can be continued in a container filled with water. May be kept wrapped in a newspaper. When the brush to be used in the water should be thoroughly with water newsprint. It will impair the quality of water flowing if the paint brush can remove unnecessary work. Of course, change in the color of old paint brush will do before using the brush remaining old paint discoloration should be completely cleaned. If possible, it is wise to use several kinds of brushes in such cases.

4.2 Corrosion of The Ship's Propeller

In the electrolyte (sea water) to the formation of corrosion, two elements must be present in the same environment of these two elements anode is the cathode. As is possible with a single metal surfaces found in two separate metal as the electrolyte. The substantial contribution of the propeller material is hardened with copper. Approximately it has the following ingredients in a propeller. 80.2% copper, aluminum 9.3%, 4.3% nickel, iron and 5%

Including processed which is called rudder is made of carbon steel. An ideal electrolyte in which seawater and steel boat propellers in two different potential; -Bronze propeller-manganese cathode. Steel boat-anode, located in the same environment and income galvanic battery occurred in such an environment. So the electric current form the corrosion of iron ions from the anode (the boat) Taking a cathode pass through the sea water (fan) passes. Thus, out of the current so that the anode sheet melts boat. Erosion corrosion undergone a propeller is shown in Figure 4.3.

Figure 4.3. Erosion corrosion undergone a propeller (M/V YASA AYSEN 2014**).**

If the current high potential for producing anodes help into this system (anodes) are added if they produce an electric current, corrosion, melting into the environment in which the cathode mix with all of these environments (protected) into the case. More specifically, the iron ions flow out of the boat stops. Current helping rescue boat Taking the case of the anode plate wearing the anodes of the anode to the cathode wear brings state. In other words, it will stop the flow of iron boat and the boat makes cathode sheets. Corroded propeller is shown in Figure 4.4.

Figure 4.4. Corroded propeller (http://www.boatdesign.net/forums/props/propeller-erosion-corrosion-42648.html).

If the iron and copper plates joined by a cable in seawater iron anode, copper (cathode) by corrodes. Tin boat is eroded. If a zinc piece are added to this system, electric current coming from iron and copper-zinc cathode that converts iron vessel corrosion state. Here is the essence of the protection of iron occurs in the cathodic protection system. Rudder and stern placed on aluminum anodes, anodes from steel vessel as it helps bring state from the anode to the cathode oxidize (dissolve) protects. We can say that is not associated with the iron and copper cable where continuous flow of sea water on duty cable.

In wide range of material properties expected of a fan varies depending on the ship's service life and mission. Overall are the most desired features of a propeller material:

- Corrosion-fatigue resistance in seawater.
- High resistance to cavitation.
- Good resistance to general corrosion.
- High resistance to crevice corrosion resistance against impact.
- High resistance to weight ratio.
- Characteristics of good repair, including resource availability, resistance to cracks will occur later.
- Good casting characteristics [http://www.gmo.org.tr/documents/gdt/sayi-157-ekim2002.pdf].

The impeller is obtained with the majority of casting. However, casting molding material varies from the size of different parts of the casting and foundry molding varies depending on the cooling rate increases, this difference increases. For example, the initial uniform temperature of the liquid metal is poured to the propeller and get in the mix of 15 mm in the blade tip cooling rate of the metal, may be greater than the propeller hub may occur around 1000 mm.

4.3 Corrosion in The Sea Water Circuit

Cooling water when immersed in seawater circuits that feature cast iron forming electro micropyle occurs if there is galvanic corrosion of metals such as copper and aluminum. By electrolysis of a portion of the seawater which case the electrolyte consists of oxygen and hydrogen. It goes to copper, zinc and alloys thereof in the form of oxide and oxygen combine with the positive pole nature. Therefore, corrosion due to the wear of the metal or metal alloy occurs. A plurality of additives to protect against corrosion, comprising the cooling surfaces of the galvanic oxygen carbon dioxide cavitation and vibration are made.

- **Dissolved solids in seawater**

Average sea water contains dissolved solids and total of around approximately 32 000 ppm. Sodium chloride that is salt, is the most important component of dissolved solids in seawater although rare in fresh water. Seawater PPM values in Table 4.1 are available.

Table 4.1. Seawater PPM values (http://content.cdlib.org/).

SALT	SYMBOL	%DISSOLVED SOLID	PPM
Calcium Bicarbonate	*Ca(HCO3)2*	*1*	*1200*
Calcium Sulfate	CaSO4	4	350
Magnesium Bicarbonate	Mg(HCO3)2	1	3000
Magnesium Chloride	MgCl2	110	2000
Magnesium Sulfate	MgSO4	6	25000
Sodium Chloride	NaCl	79	
TOTAL			**31500**

- **Calcium Sulfate ($CaSO4$):** Calcium sulfate is a dangerous chloride in steam boilers and it causes scab..
- **Magnesium bicarbonate ($Mg(HCO3)2$):** Magnesium bicarbonate is converted to magnesium hydroxide, magnesium hydroxide precipitates when heated to form soft scab. Magnesium hydroxide is a magnesium compound found in most gains are in low resolution. It creates scab due to low resolution. But stick to the boiler plate suitable breeding methods can be transformed into mud Blof to win. If hydrochloric acid causes corrosion.
- **Magnesium chloride ($MgCl2$):** Boiler creates hydrochloric acid, which is why the active corrosion in the metal scene.
- **Magnesium Sulfate ($MgSO4$):** It is soluble in normal conditions, but creates scab in high density.
- **Sodium Chloride ($NaCl$):** The chemical name of sodium chloride salt known. Sodium chloride has a very high solubility in water and increasing the concentration under normal operating conditions of pressure and temperature rises to very high values. They won chloride in solution under normal conditions..

  Sodium chloride and magnesium chloride, a sodium sulfate combine with magnesium sulfate. Causing the rising boiler water and the concentration of sodium chloride is a salt that remain in aqueous solution. Most of the time you can stay in solution in the form of a soft shell boiler and crash.

4.4 Heat Exchanger Corrosion in Ship Engines

Generally tubular part of the tube that the heat exchanger (aluminum brass, Al, Cu, Zn), a transom section (bronze, Al, Cu, Zn, Pb) and the body (cast iron and steel) constitute the elements. Corrosion in heat exchangers is shown in Figure 4.5.

Tube materials especially made of copper and zinc materials. Zinc and copper constitutes an excellent battery in sea water. An electric current of copper to zinc is formed. Zinc anode is out of the current, it would cathode copper enters.

Figure 4.5. Corrosion in heat exchangers (M/V YASA AYSEN, 2014).

Therefore, the current zinc copper alloy tube to be drilled out as a precaution we will need to provide reverse current system. Aluminum manganese - aluminum alloy anodes used mercury. Anodes are the source of seawater box. According to current anode poured their interests in various sizes. Anodes, zinc potential value of the sea water in the pipes by preventing current flow will be sending more powerful as manic electro chemical composition prevents the formation of zinc ions. Thus, cathodic pipes are protected. Steel or cast iron box painted with sea water paint is protected from seawater. Host exposed to corrosion of air cooler is shown in Figure 4.6.

Figure 4.6. Host exposed to corrosion of air cooler (M/V YASA AYSEN 2014).

4.5 Corrosion of ship steam turbine

Failure of turbine keys; formed by the condensation of steam and is caused by the accumulation of water can not be drained. Ship steam turbine corrosion is shown in Figure 4.7.

Figure 4.7. Ship steam turbine corrosion (http://www.powermag.com/optimizing-condenser-tube-selection/).

Corrosion can be seen in the rotor disk. The reason for low quality materials heat treatment may be weak. Measurement of the finest parts of the discs when severe corrosion should be made. 5% of the allowable design thickness loss of value in the disk 's should not exceed. If the loss of strength calculations must be made using the actual size of the larger disc.

Corrosion is the main damage in the blades. Steam and dust particles entering the turbine caused by oxygen. Oxygen is caused by the boiler feed water and air-borne corrosion of the turbine blade comes close to the inlet portion formed in the upper part of the wing. It found a large amount of alkaline and acid corrosion steam proliferate due to vapors. Corrosion event significantly affected by the surface of the wing and rotor wing links to their material. Less rust than polished surfaces unpolished surface.

It is seen in the most severe corrosion steam driven machine age. This is because the water in the water particles have centers is forging the separation of steam due to centrifugal force and wing tips. The greatest corrosion damage is seen moving wing 20-60 mm below the highest part of.

4.6. Bearing Corrosion in Ship Engines

Bearing cause corrosion of machine speed and operating temperatures cause oxidation of the organic acids formed by the oil when it is high.

This raises the temperature of the bed. The revenue load bearing surface of the metal lead and eliminated. This type of corrosion to minimize this type of detergent lubricating oil additives that prevent corrosion is rarely seen due to oxidation and corrosion inhibitors used. Corrosion of ship bearing is shown in Figure 4.8.

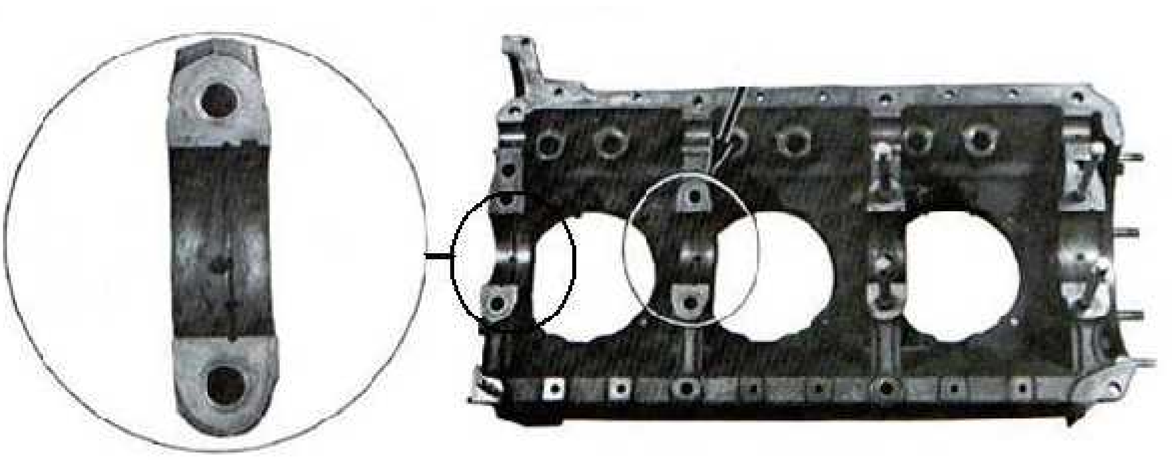


Figure 4.8. Corrosion of ship bearing (http://vintagetractors.com/casevaeng.html).

Lubricating oil in the sea water as a result of mixing bearing is supposed to shine the metal surface during operation surface, before it gets a gray or brownish color. As a result of very hard and black or brown surface of a layer of bearing. The acid layer causes damage to the crank journal and pin surface. But it develops very slowly. It can be noticed during the inspection of the bearing. Corrosion of the machine bearing is shown in Figure 4.9.

Figure 4.9. Corrosion of the machine bearing (M/V YASA AYSEN, 2014).

Bearings are not the only causes of these causes metal corrosion. In addition, air bubbles oil acid characteristic of high formed incorrectly during temperature increase lubrication and bearing the cause of the electrical potential of high-speed, for example, be grounded in turbocharger in the resulting static bearings or by contact with each other are of the potential difference between two metals. Diesel generator crank pin hardness control is shown in Figure 4.10.

Figure 4.10 D/G crank pin hardness control (M/V YASA AYSEN 2014).

4.7 Corrosion of The Hatch and Tanks

In bulk carriers; warehousing all internal and external surfaces and flat tank top areas with airborne mails and all internal surfaces of the cargo holds of the bracket of the roof comings and hatch, suitable as an effective protective coatings to manufacturers' recommendations (epoxy or equivalent) will be painted.

Ship hull unilaterally out board side in sea water. Board side is easy to maintain and no consideration for the permanent painted. Remaining in the ship hull side shell plating mails (frames) flags (brackets) and the base of construction (hold bottom plating) is still considered to be easy for maintenance. Section hatch is shown in Figure 4.11.

Figure 4.11 Section hatch (http://www.shipstructure.org/case_studies/carla/).

The protection against rust in the ballast tank is divided into two ways according to ship type. Preservation of ballast tanks of dry cargo vessels, on both sides of the shipbuilding yards of ballast tanks element in the construction of ship paint firm control on the side of epoxy- pure epoxy or solvent-free paints 300 microns, including two times (150/150) dry film thickness of paint is thrown. These elements are protected inside the tank thus close to ten years. Paint deterioration is performed by following strict maintenance by the ship's personnel. As a result of corrosion of ballast tanks as core elements in the annual classification to reduce the strength of ship hull inspection (annual survey) it causes a loss of time and costs charged for renewal of the hair from corrosion. Figure 4.15 painted in accordance with the procedure of a double bottom tank. Figure 4.12 also discarded if not well seen inside ballast tanks of paint and then not be maintained.

A ship cannot migrate the annual boat inspection in this case in any way and can not keep time. It can not take the seaworthiness document.

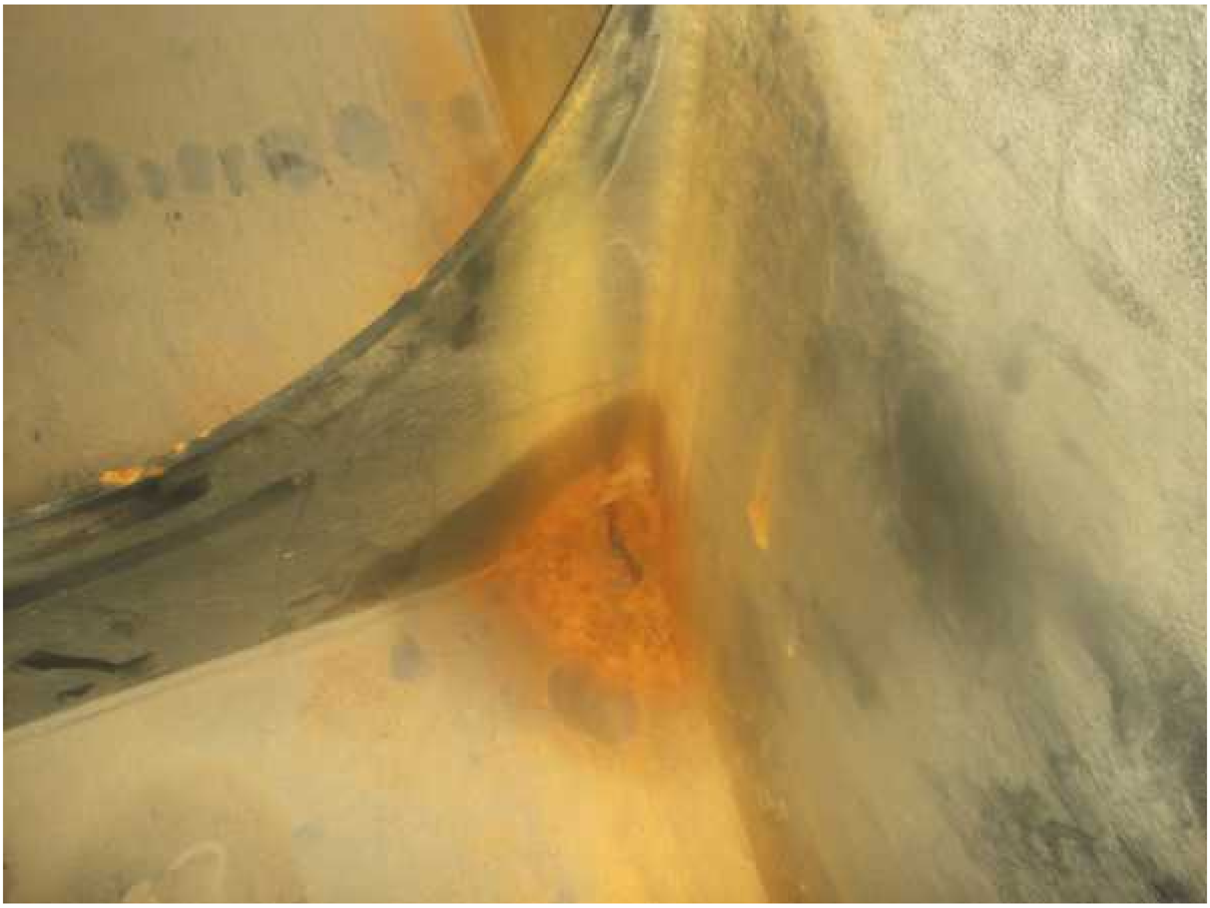


Figure 4.12 M/V YASA AYSEN No 4 Topside Tank

On the top deck from the bottom ballast tanks painted white. Very hot weather deck over hair dye will cause cracks disrupt bottom overheated. Using white radiation (radiation) and the extreme temperature (20-25 C) temperature is reduced. Excessive heat in the deck (deck) kept the sea water to the hair. Best paint regardless of the ballast tanks in the initial construction costs of the vessel (pure epoxy - solvent-free) and a very good surface preparation to be taken twice after the dry paint film thickness of 300 microns; ballast tanks elements and protects over 15 years.

4.7.1 Double-Walled tanks in ballast tank protection

According to OPA 90 decisions, need of 20,000 dwt and 30,000 dwt and above the finished fuel tanks with up crude carrier tankers will be double hull. The importance of the flow of crude oil into the sea at any sitting or collision of ships ballast corrosion protection of this double-walled tanks, but recommended a very good pure painted with epoxy paint. At least 1.5 m wide, this wall are the first boat building as places that are not considered in the operation of such tankers that double hull ballast tanks of pure epoxy paint more durable epoxy polyurethane or phenol epoxy paint and to put in twice 300 microns (150/150) pitinglen on top of the dry film of crude oil and inert gas will be resolved in this way. Double walled ballast tanks are showed in Figure 4.13.

Figure 4.13 Double-walled ballast tanks
[http://wgmather.nhlink.net/vt/dark_hold/fore_peak.html].

Ballast tanks, zinc or aluminum anodes for cathodic protection is used to do with painting. Recommended values are associated with known alloy of aluminum and zinc anodes in the table. Provided that the granting of cathodic protection quality of evidence used in the chemical composition of different zinc and aluminum anodes. Ballast tank corrosion is shown in Figure 4.14.

Figure 4.14. Ballast tank corrosion (http://marine.chemcoint.com/a-comprehensive-guide-to-marine-maintenance-and-repair.html).

60 ° C operating temperature 's zinc anodes used in the prescribed conditions pass. Ballast tanks channeled been current system (impressed current system) is not permitted to practice. The connection between the surface to be protected by anodes should demonstrate good conductive property. Therefore anodes must be connected to the source as possible. In special cases, it is mandatory to connect with bolts anodes, adequate and stable metallic conductive connection (eg. cable) must be provided. Anodes of them should be painted, must be free from dirt and other foreign matter.

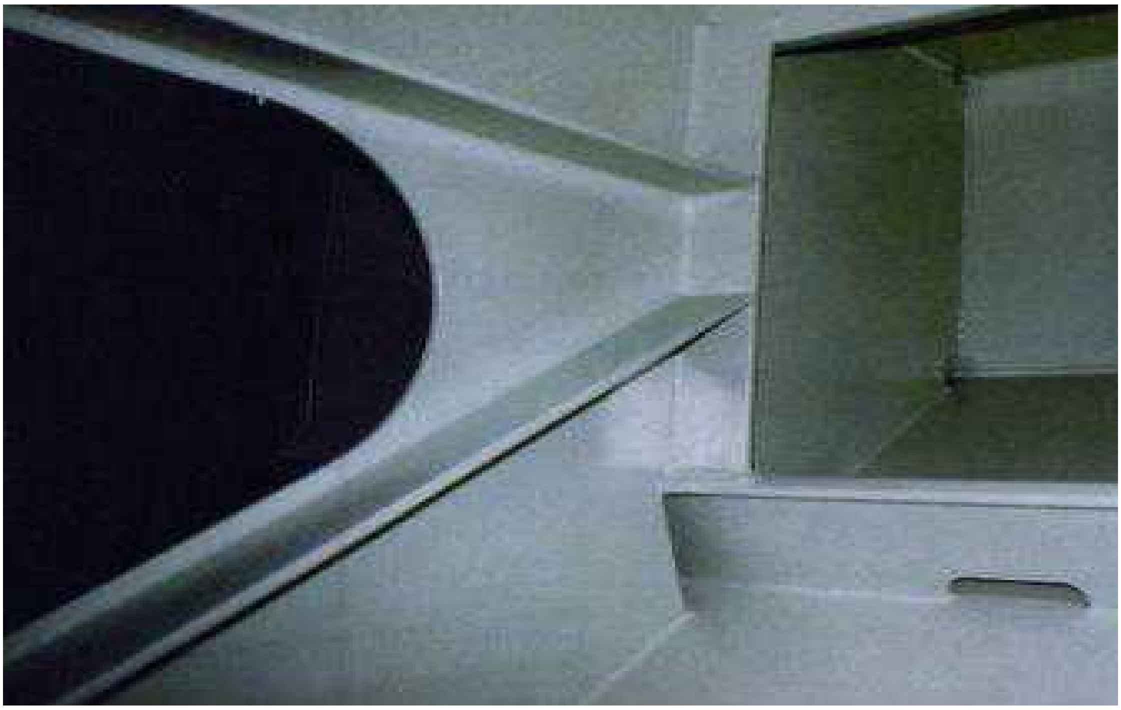


Figure 4.15 New painted double bottom tank (M/V YASA AYSEN, 2014).

4.7.2 Required protection movement

Painted surfaces to 0.02 A / m^2, a protective current density is applied. Which may be exposed to high temperatures (e.g., adjacent to the heated fuel tank) to the ballast tanks, the current density will be increased as follows: 25°C in excess of 1 mA per ° C / m^2 duration of protection will be designed for at least 5 years. Protective current density and the value specified in relation to the duration of protection, differences in case of a written consent of the ship owner is acceptable.

CHAPTER 5

CORROSION PROTECTION AND COATING TYPES

5.1 Cathodic Protection

Metal that has been extracted from its primary ore (metal oxides or other free radicals) has a natural tendency to revert to that state under the action of oxygen and water. This action is called corrosion and the most common example is the rusting of steel [Kean, R. L.1981]. Cathodic protection hull corrosion protection system is shown in Figure 5.1.

Figure 5.1. Cathodic hull corrosion protection system (M/V YASA AYSEN)

Corrosion is an electro-chemical process that involves the passage of electrical currents on a micro or macro scale.

The anode and cathode in a corrosion process may be on two different metals connected together forming a bimetallic couple, or, as with rusting of steel, they may be close together on the same metal surface. This corrosion process is initially caused by: Difference in natural potential in galvanic (bimetallic) couples. Metallurgical variations in the state of the metal at different points on the surface. Local differences in the environment, such as variations in the supply of oxygen at the surface (oxygen rich areas become the cathode and oxygen depleted areas become the anode) (Kean, R. L.,1981).

The principle of cathodic protection is in connecting an external anode to the metal to be protected and the passing of an electrical dc current so that all areas of the metal surface become cathodic and therefore do not corrode. The external anode may be a galvanic anode, where the current is a result of the potential difference between the two metals, or it may be an impressed current anode, where the current is impressed from an external dc power source. In electro-chemical terms, the electrical potential between the metal and the electrolyte solution with which it is in contact is made more negative, by the supply of negative charged electrons, to a value at which the corroding (anodic) reactions are stifled and only cathodic reactions can take place. In the discussion that follows it is assumed that the metal to be protected is carbon steel, which is the most common material used in construction. The cathodic protection of reinforcing carbon steel in reinforced concrete structures can be applied in a similar manner (Kean, R. L.,1981).

Cathodic protection can be achieved in two ways:

- by the use of galvanic (sacrificial) anodes, or
- by “impressed” current (Kean, R. L.,1981).

Galvanic anode systems employ reactive metals as auxiliary anodes that are directly electrically connected to the steel to be protected. The difference in natural potentials between the anode and the steel, as indicated by their relative positions in the electro-chemical series, causes a positive current to flow in the electrolyte, from the anode to the steel. Thus, the whole surface of the steel becomes more negatively charged and becomes the cathode. The metals commonly used, as sacrificial anodes are aluminium, zinc and magnesium. These metals are alloyed to improve the long-term performance and dissolution characteristics.

Impressed-current systems employ inert (zero or low dissolution) anodes and use an external source of dc power (rectified ac) to impress a current from an external anode onto the cathode surface (Kean, R. L.,1981).

The connections are similar for the application of cathodic protection to metallic storage tanks, jetties, offshore structures and reinforced concrete structures (Kean, R. L.,1981).

Excessive negative potentials can cause accelerated corrosion of lead and aluminium because of the alkaline environments created at the cathode. These alkaline conditions may also be detrimental to certain paint systems, and may cause loss of the paint film. Hydrogen evolution at the cathode surface may, on high-strength steels, result in hydrogen embrittlement of the steel, with subsequent loss of strength. It may also cause disbanding of any insulating coating: the coating would then act as an insulating shield to the cathodic protection currents (http://www.npl.co.uk/upload/pdf). Stern tube outboard propeller side with Zn anode is shown in Figure 5.2.

Cathodic protection can protect all types of buried and submerged metallic structures including:

- Cross country pipelines
- In plant piping
- Aboveground storage tank bases
- Buried tanks and vessels
- Internal surfaces of tanks, vessels, condensers and pipes
- Well casings
- Piling – tubular, sheet steel and foundation
- Marine structures including jetties, wharfs, harbours, piers, platforms
- Ships Reinforcing steel in concrete
- The cath
-

Figure 5.2. Stern tube outboard propeller side (M/V YASA AYSEN, 201)].

The cathodic protection system can be designed to prevent both oxygen controlled and microbiologically controlled corrosion. Each cathodic protection system tends to be of bespoke design and the main materials are manufactured to order as every location has it's own variation in environment and current demand.

In addition to providing protective current each cathodic protection system design must consider:

- Electrical continuity – structures must be electrical continuous to allow the protective current to return to the power source.
- Electrical isolation – structures must be electrically isolated from other buried metallic structures to prevent current loss and under protection of the structure under consideration.
- Testing facilities – must be installed to monitor the effectiveness of the cathodic protection system. Adjacent cathodic protection and buried metallic structures should also be monitored to ensure no detrimental effects [http://www.npl.co.uk/upload/pdf].

Marine structures are commonly cathodically protected by either impressed current or sacrificial anodes. Cathodic protection is effective for the embedded and submerged sections of the pile. It becomes less effective in increasing height of the splash zone where coatings need to be considered.

Sacrificial (or galvanic) anode cathodic protection systems are normally of either aluminium or zinc anodes and less commonly magnesium. The anode size is determined by current required and lifetime. Typical lifetime is around 10 to 20 years. The anodes can be directly welded to the structure (stand-off or flush mounted), mounted on a sled or on the seabed and allowed to silt up. If the anodes are not directly connected then continuity to the structure must be completed by a cable (http://www.npl.co.uk/upload/pdf). Applying zinc anode is shown in Figure 5.3.

Figure 5.3. Applying zinc anode (M/V YASA AYSEN Shangai Drydock 201)**].**

Impressed current cathodic protection (ICCP) systems consist of a power source, normally transformer rectifiers, located on deck level and submerged anodes. The anodes can be mounted on the structure, placed on a sled on the seabed or buried in the seabed. Anode types can be mixed metal oxide (MMO) coated titanium – wire or tubular type, platinised titanium or silicon iron (if buried). Typical lifetime is 20 plus years. The anodes are connected to the transformer rectifier and in turn to the structure via series of suitably rated (for immersion etc) and sized cables and junction boxes which must be suitable for the marine environment. Junction boxes can be plastic, aluminium, steel or stainless steel and be certified for hazardous areas as required [http://www.npl.co.uk/upload/pdf]. Diagram of cathodic protection using the impressed-current is shown in Figure 5.4.

5.1.1 Impressed current cathodic protection

With an impressed current system the current is “impressed” or forced by a power supply. The power source must be able to deliver direct current (DC) and examples are transformer rectifier units, solar generating units or thermo-electric generators (http://www.cathodic.co.uk/files/1246442149Cathodic%20Protection%20Overview.pdf).

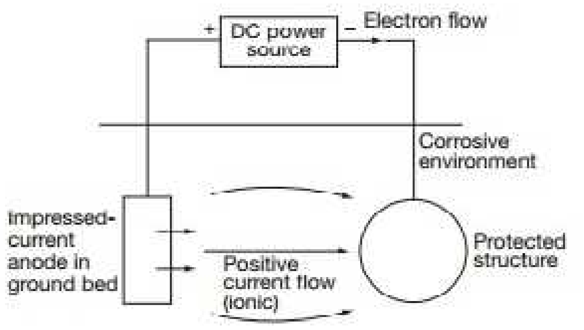


Figure 5.4. Diagram of cathodic protection using the impressed-current (http://www.mdpi.com/1424-8220/7/1/75/htm).

A range of materials have been used as non-consumable anodes for impressed-current systems. The sort of properties required by these anodes are

- Good electrical conduction,
- Low rate of corrosion,
- Good mechanical properties, able to stand the stresses which they may be subjected to during installation and in service,
- Readily fabricated into a variety of shapes,
- Low cost,
- Able to withstand high current densities at their surfaces without forming resistive barrier oxide layers, etc. [http://www.npl.co.uk/upload/pdf].

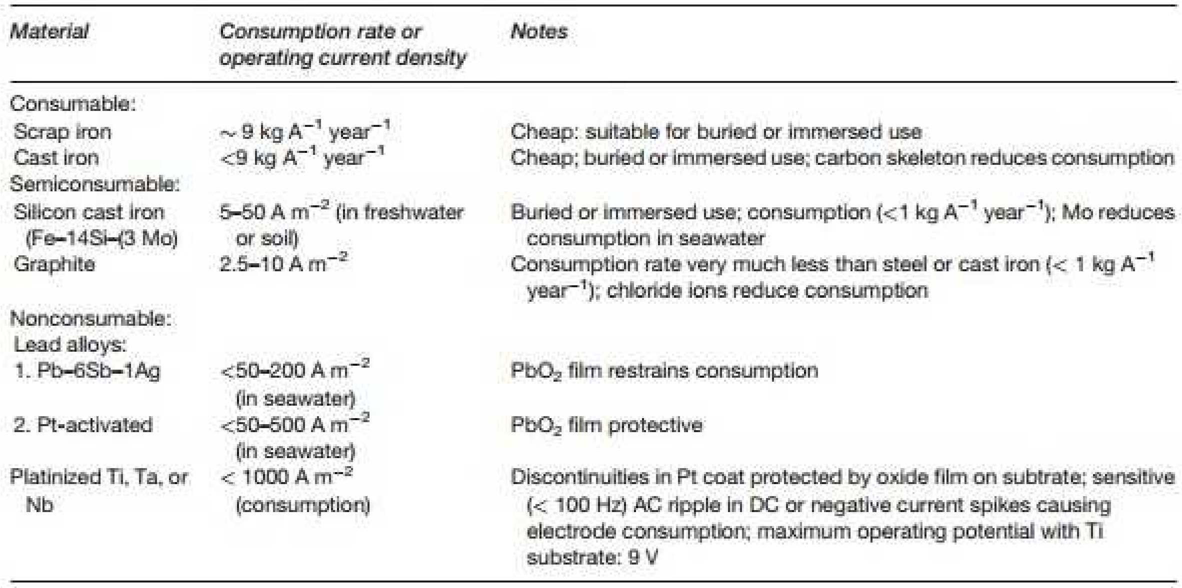
The following materials have been used as anodes: magnetite, carbonaceous materials (graphite), high silicon iron (14-18% Si), lead/lead oxide, lead alloys, platinised materials (such as tantalum, niobium, titanium). Platinum, with its high resistance to corrosion, would be an ideal anode material but has the major disadvantage of very high cost. (http://www.npl.co.uk/upload/pdf).

Although the anodes are described as non consumable, they do suffer some loss of the thin (2.5–10 mg) platinized coating. This loss, which unfortunately has become known as the wear rate although there is no question of the loss being due to mechanical wear, is usually small, related to the total current passed, and increased if the applied current has an AC component. Typically, values for the loss rate are 8 mg.

A 1 year 1 for platinized titanium, which may be increased 10-fold if an AC component of device, even given otherwise clean DC, can produce a 100-fold increase in the rate of loss. The semiconsumable electrodes, as the name implies, suffer rather less dissolution than Faraday's law would predict and substantially more than the non consumable electrodes. This is because the anodic reaction is shared between oxidizing the anode material (causing consumption) and oxidizing the environment (with no concomitant loss of metal). Electrodes made from silicon–iron, chromium– silicon–iron and graphite fall into this category.

Table 5-1 gives a brief summary of the behavior of some impressed current anodes, and protection by impressed current is discussed in more detail elsewhere (http://www.elsevierdirect.com/brochures/shreir/PDF).

Table 5.1. Impressed-current anode materials (https://www.corrosionpedia.com/2/1546/prevention/coatings/).



Material	*Consumption rate or operating current density*	*Notes*
Consumable:		
Scrap iron	~ 9 kg A^{-1} $year^{-1}$	Cheap: suitable for buried or immersed use
Cast iron	<9 kg A^{-1} $year^{-1}$	Cheap; buried or immersed use; carbon skeleton reduces consumption
Semiconsumable:		
Silicon cast iron (Fe–14Si–(3 Mo)	5–50 A m^{-2} (in freshwater or soil)	Buried or immersed use; consumption (<1 kg A^{-1} $year^{-1}$); Mo reduces consumption in seawater
Graphite	2.5–10 A m^{-2}	Consumption rate very much less than steel or cast iron (< 1 kg A^{-1} $year^{-1}$); chloride ions reduce consumption
Nonconsumable:		
Lead alloys:		
1. Pb–6Sb–1Ag	<50–200 A m^{-2} (in seawater)	PbO_2 film restrains consumption
2. Pt-activated	<50–500 A m^{-2} (in seawater)	PbO_2 film protective
Platinized Ti, Ta, or Nb	< 1000 A m^{-2} (consumption)	Discontinuities in Pt coat protected by oxide film on subtrate; sensitive (< 100 Hz) AC ripple in DC or negative current spikes causing electrode consumption; maximum operating potential with Ti substrate: 9 V

5.1.2 Galvanic (Sacrificial) anodes

Sacrificial anode cathodic protection system in the desired metal structure protection is less negative potential from which a metal (anode) by creating galvanic cell. Thus, the metal structure is turned into the cathode. Galvanic anodes on their own dissolving produce the same current as the battery. The dissolution of the anode results released electrons to the cathode from the outer link (protected metal structures) provides the electrons needed for the cathodic reaction moved. Zn anode is shown in Figure 5.5.

Figure 5.5. Zn anode (https://shipcare.be/ship-maintenance/anodes)].

The current capacity and galvanic anode current efficiency is certain. Cathodic protection sufficient period of time to the amount and number of galvanic circuit by connecting the anode surface of the metal structure to be protected can be kept as cathode. Applying zn anode is shown in Figure 5.6.

Figure 5.6. Applying zn anode (M/V YASA AYSEN Shanghai Drydock, 2014).

Cathodic protection practice areas include:

- **Pipelines:** Drinking water pipelines, gas pipelines, sewage pipes seabed pipes, fire hydrants pipelines, oil pipelines.
- **Inner sea constructions and vehicles:** Ships, ferries, sea buses, submarine ships, yachts, harbor, pier, platform, stake legs, float, etc.
- **Tanks:** Underground LPG and fuel tanks, aboveground fuel tanks, waste water tanks, potable water storage tanks, etc.
- **Water systems:** Heat Exchanger cooling and heating systems, water heaters, steam boilers, boiler tanks etc.
- **Zinc anodes:** Zinc anodes environment of less than 2000 ohm.cm Resistivity It is salt water, fresh water and earth ground in iron and steel structures They are used in cathodic protection.

Cathodic protection is often used in the following places;

- Ships, boats, yachts and tugs.
- Ballast tanks of ships
- Scaffolding and piles
- Heat exchanger

Cathodic protection applications in ships is shown in Figure 5.7.

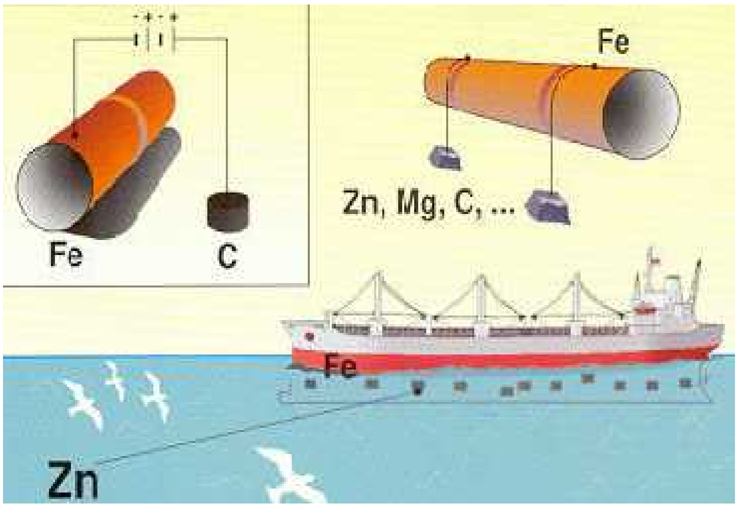


Figure 5.7 Cathodic protection applications in ships (http://old.iupac.org/didac/Didac%20Eng/Didac03/Content/R14.htm).

Some metals, such as aluminum, magnesium, and zinc, are anodic in comparison to steel. The electrical potential of these metals allows them to protect steel by galvanically supplying cathodic protection current without the aid of an outside power source. The driving voltage, and therefore the amount of protective current that is supplied by galvanic anodes in limited by the potential of that metal. For example, thermally sprayed zinc has been able to galvanically protect concrete in splash and tidal zones in seawater, but the anode must be periodically wet to supply adequate protection current. A problem with sacrificial anodes is that their protection current decreases with time, and they eventually become passive, so most systems have a relatively short useful life (Virmani, Yash Paul and Clemena, Gerardo G., 1998).

To understand the action of sacrificial anodes for cathodic protection it is necessary to have in mind the galvanic series of metals. When the tendency for metal to go into solution as metal ions increases (leaving an excess of electrons on the metal surface), i.e. (http://www.npl.co.uk/upload/pdf).

the metal becomes more electronegative. Thus, since zinc, aluminium and magnesium are more electronegative than steel they are increasingly able to supply electrons to the more electropositive steel when in electrical contact in water, and will effect cathodic protection of the steel surface. Clearly, if steel was coupled to copper ins ea water, steel would supply electrons to copper which would become cathodically protected, and the corrosion of the steel would be enhanced (http://www.npl.co.uk/upload/pdf).

Sacrificial anode cathodic protection systems are generally restricted to submerged structures, but have recently begun to be used on bridge substructures exposed to the atmosphere. Impressed current cathodic protection systems have an advantage in the fact that the power output can be controlled, but impressed current 124 systems can sometimes overprotect a structure, reducing the life of the anode and causing hydrogen embrittlement. In contrast to impressed current systems, which require a relatively large number of electrical components and have increased monitoring and maintenance requirements, sacrificial anode systems do not require an external power source. The use of most sacrificial anode systems is limited to substructure members when used on bridges, but a few methods have been tested on bridge decks as well (Kepler, J. L., Darwin, D. Jr. Locke, Carl E.,2000).

Sacrificial anodes for bridge decks — In 1977, sacrificial anodes were first tested on a bridge deck in Illinois as part of a National Cooperative Highway Research Program study. Two types of anodes were tested: perforated zinc sheets fastened to the deck with mortar and covered with a concrete overlay, and conventional zinc alloy ribbons embedded into grooves in the concrete surface. The concrete overlay on the zinc sheet system failed early on, and both overlays were replaced with freedraining asphalt overlays. These systems had to be removed in 1991 because of failure of the overlays. The researchers estimated that both anodes still had enough mass left to keep operating for many more years had the overlay held up (Virmani, Yash Paul and Clemena, Gerardo G., 1998).

A laboratory study was conducted to continue the effort to identify the most promising anodes, using aluminum, magnesium, and zinc alloys [Whiting, D. A., Nagi, M. A., and Broomfield, J. P.1995]. After screening tests, three anodes were selected for further evaluation in concrete slabs. An aluminum mesh anode was tested on a bridge deck in a northern exposure area, but the system did not perform satisfactorily (Kepler, J. L., Darwin, D. Jr. Locke, Carl E.,2000).

Zinc-hydrogel anode systems — A 1996 FHWA study investigated the ability of aluminum, aluminum alloy, and zinc sacrificial anodes in contact with several different commercial conductive hydrogel adhesives to deliver galvanic current to a cathodic protection system for bridge substructure members (Bennett, Jack E. and Schue, T. J., 1996). The zinc anodes were included in the study because zinc has good current efficiency and is relatively inexpensive, while the aluminum and aluminum alloy anodes were included because they could, potentially, be 30% thinner, 74% lighter, and 65% less expensive than zinc. The study identified zinc as the best candidate for a hydrogel anode system. The tests indicated that the aluminum and aluminum alloy anodes either had unstable behavior or were not able to provide a high enough working potential when used with the hydrogel adhesives, and thus were not appropriate for this use.

The best combination of a conductive adhesive and a zinc sacrificial anode was installed in three structures for field testing. The three installations used zinc sheets, ranging in thickness from 10 to 20 mm (0.4 to 0.8 in.). The hydrogel used was a special formulation by 3M that had indicated in accelerated testing that it would be capable of passing a cathodic protection charge for about 11 years (Bennett, Jack E. and Schue, T. J., 1996])

The first field system was installed in 1995 on the South Bridge Fishing Pier in Ft. Pierce, Florida. The zinc/hydrogel anode was placed on about 300 m2 (360 yd2) of the concrete surface, including 4 piles, 4 pile caps, and 2 double-tee beams. For the first 20 months of operation, the system met the cathodic protection polarization requirement of 100 mV, but between 9 and 20 months, the polarization of the system decreased from 120 mV to 108 mV. Another zinc/hydrogel anode system was installed on the Cape Perpetua Bridge in Yachats, Oregon in 1998. No data is available on this installation (Virmani, Yash Paul and Clemena, Gerardo G. ,1998).

In 1996, an experimental installation of zinc/hydrogel anodes was placed on 5 piers on the Long Key Bridge in the Florida Keys (Kessler, Richard J., Powers, Rodney G., and Lasa, Ivan R.,1998a). The bridge was built in 1979 using epoxy-coated steel and had begun to exhibit signs of corrosion, especially on the pier caps, which sat on top of bearing pads that separated them from the piers. In most cases, it is impractical to provide cathodic protection to structures with epoxy-coated reinforcing steel, because electrical continuity is generally nonexistent. A sacrificial zinc sheet anode (zinc-hydrogel) was designed that could be slipped in-between the pier caps and the bearing pads to prevent further damage to the concrete in the pier caps. The pad was put into place by jacking up the pier caps about 1 inch. The bearing pads were replaced and a zinc anode was put in place between the new bearing pad and the pier cap concrete. A conductive adhesive gel was used to keep the sheet in place and to ensure contact with the concrete to be protected. Copper wires were run from the zinc sheet to the reinforcing bars to complete the circuit. The wires were coated with epoxy and the groves in the concrete were filled with mortar (Kepler, J. L., Darwin, D. Jr. Locke, Carl E.,2000).

After about 5 months, the system appeared to be performing satisfactorily. The average current density was 10.8 mA/m2 (1.01 mA/ft2), calculated using the entire surface area of the protected reinforcement (Kessler, Richard J., Powers, Rodney G., and Lasa, Ivan R., 1998a). According to Ivan Lasa with the Florida Department of Transportation (Lasa, Ivan R., 2000), this system is still in place, but is no longer working. The failure of the system is attributed to errors made during installation. At that time, a good seal around the edges of the plates was not obtained, allowing water to get into the system and dissolve the hydrogel during a hurricane in 1999.

The Missouri Department of Transportation installed 3M zinc-hydrogel anodes to about 200 m2 (240 yd2) of concrete on four pier caps and three abutment beams on two bridges in Franklin County in November of 1999. As of February 2000, the measured current generated at each site was about 0.1 A (Wenzlick, J. D., (1999, 2000)).

Field studies of zinc/hydrogel anode systems show that the systems are relatively easy to install, without requiring a specialty contractor, and appear to be in good condition and well adhered to the concrete at ages up to 3 years. For the systems to work, the adhesive must be protected from direct exposure to water. This is achieved by caulking the edges of the plates (Virmani, Yash Paul and Clemena, Gerardo G., 1998).

5.1.3 Comparison of sacrificial anodes and impressed current system

The impressed current system is more expensive to install than sacrificial anodes but as the latter must be renewed, the eventual cost of both systems would appear to be similar. The impressed current method requires trained personnel to supervise the power units. Log sheets containing the daily readings of volts, millivolts, and the current in amps must be maintained and the reference reading of millivolts should be compared with the predetermined value. Although the units are automatic, they must be put on manual control when alongside in port as the system may attempt to protect the jetty structure. The anodes and reference cells must be inspected frequently for damage and also to ensure that they have not been painted over.

- **Ignoble and Noble Metals**

Metals which corrode rapidly are known as anodic or ignoble metals and those which resist corrosion are termed cathodic or noble.

Ignoble : Magnesium, Zinc, Aluminium, Iron, steel, lead, tin, nickel, mill scale, copper, titanium

Noble : Platinum

Any metal in the above series will therefore be subjected to accelerated corrosion when located in an adjacent position to a more noble metal.

- **Bimetallic Corrosion**

Any two different metals which are in electrical contact and are bridged by an electrolyte are liable to bimetallic corrosion. Thus, such corrosion will occur between metals which are not in direct contact with each other. However, many mariners use the term to describe the reaction which occurs when two different metals are in direct contact. Many corrosion and breakdown problems occur on board ship because metallic parts have been coupled without adequate insulation or protection being provided. The rate of corrosion in the ignoble metal will depend upon the relative sizes of the anodic and cathodic materials. A small anode attached to a large cathode, e.g. a steel flange in a copper pipe, will result in rapid corrosion of the anode. If design requirements are such that two dissimilar metals are in close proximity to one another the following procedures should be observed:

- The more noble metal should be used for actual connections.
- Both metals should be covered by a paint film to a very high standard.
- The metals must be efficiently insulated from each other.

Arias liable to bimetallic corrosion are:

- Valve fittings in tanks.
- Aluminium superstructures attached to steel decks.
- Steel lifting hooks in aluminium lifeboats.
- Openings in superstructures, such as portholes and windows.
- Inlets and outlets to tanks and to engine-room piping, systems.
- Zinc and aluminium drainage channels.

- Boiled joints.

5.2 Coating and Coating Types

This chapter covers the major types of coatings that are currently available for use on vessels and includes general information on the composition of coatings. It is intended to give basic information on coatings and is not a comprehensive guide to paint selection. The coating manufacturer is to be consulted if information on a specific product, or coatings suitable for particular areas on the vessel, is required (American Bureau of Shipping, 2007).

Coatings for ships are often divided into two broad categories:

- products for application at new building and;
- products suited for maintenance and repair, which would include both major refurbishments either at sea or in port and on board maintenance (OBM).

The types of paint used for on board maintenance (OBM) are often single pack products as this avoids the difficulties of measuring and mixing small quantities of two pack products, although small quantities of two pack products are sometimes available from paint manufacturers. Repairs carried out by the crew of vessels in service are rarely successful in the long term, due to the difficulties of preparing the surfaces to a sufficiently high standard as shown by the example in. It may be noted that guidelines for the maintenance of protective coatings are planned to be developed by IMO (American Bureau of Shipping, 2007). Localized repair in this coating has failed again at the same site is shown in Figure 5.8.

Figure 5.8. Localized repair in this coating has failed again at the same site (http://blog.theartofpaddling.com/tag/fiberglass-repair/).

In general, paints are either targeted for specific vessel areas and for specific functions for best performance, or universal coatings are available for all areas with a compromise in performance. In all cases, a balance between cost, performance and difficulty of maintenance has to be achieved. For example, anti-corrosive coatings used on the outside of the accommodation area have different performance requirements from anti-corrosion paints used in sea water ballast tanks as the corrosion stress placed on the latter is far greater. Ballast tanks are also much more difficult to maintain due to access difficulties and therefore the use of a highly effective (and often more expensive) coating is preferred to keep the steel in good condition.

In contrast, the holds of bulk carriers suffer from abrasion damage due to cargo impact and grab damage, which often leads to corrosion. Cargo holds used as ballast tanks during heavy weather can be particularly susceptible to corrosion at damage sites and a different coating is sometimes used for this cargo hold. This also applies to cargo tanks for oil carriers with a class notation for ‘Clean Products’, where any cargo tank may be used for heavy weather ballast (American Bureau of Shipping, 2007).

5.3 Paint Composotion

Paint can be described as a liquid material capable of being applied or spread over a solid surface on which it subsequently dries or hardens to form a continuous, adherent, film.

Paints basically consist of three major components and many additives which are included in minor quantities. The major components are:

- Binder (also called vehicle, medium, resin, film or polymer)
- Pigment and extender
- Solvent Of these, only the first two form the final dry paint film. Solvent is necessary only to aid paint application and the initial film formation, but inevitably, some solvent is always retained in practice depending upon the level of ventilation (American Bureau of Shipping, 2007).

5.4 Binders

Binders are the film forming components of paint which determine the principal characteristics of the coating, both physical and chemical. Paints are generally named after their binder component (e.g. epoxy paints, chlorinated rubber paints, alkyd paints, etc.). The binder forms a permanent continuous film which is responsible for adhesion to the surface and which will contribute to the overall resistance of the coating to the environment.

Binders used in the manufacture of paints fall into two classes, thermoset and thermoplastic. A thermoset coating when dry will be chemically different from the paint in the can. Thermoset coatings are not affected by solvents once cured. With a Thermoplastic coating, the dry film and the wet paint differ only in solvent content and chemically, these remain essentially the same. If the solvent originally used is applied to a thermoplastic coating, it will soften and can be redissolved in that solvent (American Bureau of Shipping, 2007).

5.5 Cross-linked (Thermoset) Coatings

These paints are usually supplied in two separate packs which are mixed together immediately before application. In liquid paints where solvent is involved, drying is considered a two stage process. Both stages actually occur together but at different rates.

Stage One: Solvent is lost from the film by evaporation and the film becomes dry to touch.

Stage Two: The film progressively becomes more chemically complex by one of the following four methods:

- Reaction with atmospheric oxygen, known as oxidation.
- Reaction with an added chemical curing agent.
- Reaction with water (moisture in the atmosphere).
- Artificial heating. This transformation in the paint is known as drying or curing. The films formed by the above methods are chemically different from the original binders and will not re-dissolve in their original solvent (American Bureau of Shipping, 2007).

5.5.1 Epoxy resins

These resins are particularly important and their development for use as binders was one of the most significant advances in paint technology. The rate of cross-linking or curing is dependent on temperature. Below 5°C the curing rate of standard epoxies is considerably reduced and to obtain optimal film properties full cure is essential. Epoxies with special curing agents will cure or set at temperatures down to –5°C. It is essential that the coating manufacturer's recommendations on application temperatures are strictly followed, to ensure that the coatings are effective in service (American Bureau of Shipping, 2007).

The choice of curing agent is very important as with the base, this determines the properties of the film. There is a wide choice of both resins and curing agents which allows for formulation of products to suit most applications (American Bureau of Shipping, 2007).

Epoxies are used in both underwater and above water situations and show good resistance to many marine environments, including cathodic protection utilizing zinc or other anodes, but they have a tendency to chalk in sunlight. This process occurs when the binder is degraded by ultra violet light to produce a loose and friable surface, with the pigment particles remaining on the surface (American Bureau of Shipping, 2007).

5.5.2 Polyurethane resins

These are polymers formed by reaction between hydroxyl compounds and compounds containing isocyanates.

In two-pack systems a special polyether or polyester resin with free hydroxyl groups is reacted with a high molecular weight isocyanate curing agent. A possible problem with these materials is their water sensitivity on storage and on application. Transport and storage should be in strict compliance with the manufacturers' recommendations. Due to their poor curing properties at low temperatures manufacturers' recommendations must be followed during application.

Polyurethane resins have excellent chemical and solvent resistance and are superior to standard epoxies in acid resistance. Epoxies are more resistant to alkaline than polyurethanes. Polyurethane finish coats are very hard and have extremely good gloss, gloss retention, and can be formulated to be non-yellowing. However in some instances, they can be difficult to overcoat after ageing and require very clean surfaces for optimum adhesion. Because of the isocyanate curing agent, there is also a potential health hazard when sprayed which can be overcome with the appropriate protective equipment (American Bureau of Shipping, 2007).

5.5.3 Alkyd resins

Alkyd resins are formed by the reaction between a special organic acid (e.g. phthalic acid), a special alcohol (e.g. glycerol or pentaerythritol) and a vegetable oil or its fatty acids. The final properties of the alkyd depend on the percentage of oil (termed ‘oil length’) and also on the alcohol and organic acid used.

Alkyds are not resistant to acids or alkalis and many of the modifications given below are aimed at improving this weakness, however, none provide complete resistance. Alkyd resins can be further modified with different resins for specific purposes (American Bureau of Shipping, 2007).

5.5.4 Inorganic resins

These types comprise the silicates which are almost always used in conjunction with zinc dust. There are water-based inorganic silicates based on lithium, potassium, or sodium silicate and solvent based inorganic silicates normally based on ethyl silicate. Coatings based on these resins are very hard, corrosion resistant and temperature resistant. They require a good standard of surface preparation and are often repaired using organic coatings.

The zinc in the inorganic resins can dissolve under acid or alkali conditions, but the coatings perform well under neutral pH and are often used as tank coatings (American Bureau of Shipping, 2007).

5.6 Thermoplastic Coatings

These types of paint binders are simple solutions of various resins or polymers dissolved in suitable solvent(s) and are usually supplied as one pack products, making them especially suitable for maintenance work. Drying is simply effected by the loss of the solvent by evaporation. This is termed physical drying as no chemical change takes place. The resulting film is therefore always readily soluble in the original solvent and can also be softened by heat. Since these coatings, by definition, require the presence of significant amounts of solvent, they are disappearing from markets where volatile organic content is regulated, particularly the USA and the EU. (American Bureau of Shipping, 2007)

Generic types of binders in this category include:

5.6.1 Chlorinated rubber resins

Chlorinated rubber resins have good acid and water resistance on well-prepared surfaces. Their temperature sensitivity can lead to various film defects when used in very hot climates. In addition, white and pale colors have a pronounced tendency to yellow when exposed to bright sunlight. Chlorinated rubber paints will dry at low temperatures and give good inter-coat adhesion in both freshly applied and aged systems, making them suitable for maintenance purposes (American Bureau of Shipping, 2000).

5.6.2 Vinyl resins

Vinyl resins are based on film forming polymers consisting of varying ratios of polyvinyl chloride, polyvinyl acetate and polyvinyl alcohol. Plasticizer types used are tricresyl phosphate or dioctyl phthalate.

Higher volume solid materials can be produced by blending the vinyl resin with other materials such as acrylic resins. Generally the film properties and weathering characteristics also show good low temperature drying and inter-coat adhesion characteristics. Coal tar can be added to increase water resistance (American Bureau of Shipping, 2007).

5.7 Pigments and Extenders

Pigments and extenders are used in paints in the form of fine powders. These are dispersed into the binder to particle sizes of about 5-10 microns for finishing paints and approximately 50 microns for primers (American Bureau of Shipping, 2007).

These materials can be divided into the following types:

Type	Purpose
Anti-corrosive pigments	To prevent corrosion of metals by chemical and electrochemical means, in above-water areas.

Barrier pigments	To increase impermeability of the paint film.
Coloring pigments	To give permanent color.
Extending pigments	To help give film properties required

5.7.1 Anti-Corrosive pigments

- **Zinc**

Metallic zinc is widely used in primers giving resistance to corrosion of steel. Initial protection is by galvanic action. However, as the coating is exposed to the atmosphere, a progressive build up of zinc corrosion product occurs, producing an impermeable barrier with little or no galvanic protection. To give good galvanic and barrier protection, high levels of zinc are required, about 85 percent of zinc in the dry film by weight (American Bureau of Shipping, 2007).

- **Aluminum pigments**

Metallic aluminum flake is commonly used as an anti-corrosive pigment and acts as an anti-corrosive by producing a circuitous pathway for water and ions around the lamellar flakes, as well as absorbing oxygen to give aluminum oxides, which block pores in the coating. Where the aluminum is in contact with steel, a limited cathodic protection mechanism will also operate, although when used on tankers and product carriers, the aluminum content in the dry film should not exceed 10 percent to avoid possible spark hazards where flammable gases build up (American Bureau of Shipping, 2007).

- **Zinc Phosphate**

This is also a widely used anti-corrosive pigment and it is thought that under normal exposure condition protection is afforded by a barrier effect, since high pigmentation levels are needed to give adequate anti-corrosion protection. Zinc phosphate can be incorporated into almost any binder and, because of its low opacity or transparent nature, paints of any color can be produced (American Bureau of Shipping, 2007).

5.7.2 Barrier pigments

The most common types of these pigments are aluminum (leafing aluminum) and Micaceous Iron Oxide (MIO). Both have particle shapes which are termed lamellar (plate-like). These materials can be used in combination, the aluminum lightening the almost black shade of MIO. (American Bureau of Shipping, 2007.

MIO pigmented films have durability, but to achieve this, high levels of MIO are necessary in the order of 80 percent of the total pigment. Aluminum has been used for many years as the principal pigment in paints for use underwater. The lamellar shape helps to make the film more water impermeable. Glass flake is also used as a barrier pigment (American Bureau of Shipping, 2007).

5.7.3 Coloring pigments

These pigments provide both color and opacity and can be divided into either inorganic or organic types. The most common coloring pigment is titanium dioxide, which is white. In paint, all pigments are normally dispersed to a very fine particle size in order to give maximum color and opacity (hiding power). Traditionally, bright colors were obtained using lead and chrome pigments. However due to health and safety concerns, these are less common. Now organic pigments are used instead but the opacity is not as high with these products (American Bureau of Shipping, 2007).

Where the International Maritime Organization (IMO) PSPC for ballast or other tanks is applicable and a multi-coat system is required, it is recommended that each coat be of contrasting color. The top coat should be a lighter color to facilitate in-service inspection.

5.7.4 Extender pigments

As the name suggests, they basically adjust or “extend” the pigmentation of the paint until the required pigment volume concentration (PVC) is achieved. Extender pigments are inorganic powders with various particle shapes and sizes. Although making little or no contribution to the color opacity of the paint, they can have significant influence on physical properties. These include flow, degree of gloss, anti-settling properties, spray-ability, water and chemical resistance, mechanical strength, hardness and firm build (volume solids, hold up thixotropy). Mixtures of extenders are often used to obtain the desired properties. They are relatively inexpensive when compared to resins, anticorrosive pigments and coloring pigments.

5.8 Solvents

Solvents are used in paints principally to facilitate application. Their function is to dissolve the binder and reduce the viscosity of the paint to a level which is suitable for the various methods of application, such as brush, roller, conventional spray, airless spray, etc. After application, the solvent evaporates and plays no further part in the final paint film. Liquids used as solvents in paints can be described in one of three ways:

5.8.1 True solvents

A liquid which will dissolve the binder and is completely compatible with it (American Bureau of Shipping, 2007).

5.8.2 Latent solvent

A liquid which is not a true solvent. However, when mixed with a true solvent, the mix has stronger dissolving properties than the true solvent alone (American Bureau of Shipping, 2007).

5.8.3 Diluent solvent

A liquid which is not a true solvent. Normally used as a blend with true solvent/latent solvent mixes to reduce the cost. Binders will only tolerate a limited quantity of diluent.

There are numerous solvents used in the paint industry and this is partly due to the number of different properties which have to be considered when selecting a solvent or solvent mixture. In addition to commercial factors such as price and availability, properties include toxicity, volatility, flammability, odor, compatibility and suitability.

In some countries, certain types of solvents are not allowed. This is especially true in the USA, where the Hazardous Air Pollutant Substances Act, (HAPS) dictates a timeline for removing many solvents and extenders from coatings. Application properties, dry times and overcoat windows will most likely be affected as this Act is implemented (American Bureau of Shipping, 2007).

5.9 Anti-Corrosion Paints

With few exceptions (such as anti-fouling paints, cosmetic effects, fire retardants, etc.), the majority of coatings applied to a vessel are used for anti-corrosion protection. There are many types of anti-corrosion coatings, but epoxy paints generally cover the greatest area on a vessel, particularly when they are used in sea water ballast tanks. In recent years there has been debate about the terminology used for epoxy coatings and the following are in common usage:

5.9.1 Pure epoxy

Pure epoxy coatings are generally regarded as paints which contain only epoxy polymers, the cross linking agent, pigments, extenders and solvents. The coatings contain high levels of epoxy binder and are therefore expected to provide the maximum possible performance from a coating in terms of anti-corrosion protection, long life and low maintenance. In addition, some products also claim abrasion-resistance properties. Other pigments such as aluminum can be added to pure epoxy coatings to provide additional anti-corrosion performance. Epoxy paint application is shown in Figure 5.9.

Figure 5.9. Epoxy paint application (M/V YASA AYSEN Shanghai Drydock, 2014).

Epoxy Phenolic coatings can be used in cargo tanks where a high level of additional cargo resistance is required, such as on oil-product and chemical carriers. Special care needs to be taken with the surface preparation; curing the coating by heating the tanks may be necessary.

Coating manufacturers will advise on the specific requirements for each tank. (American Bureau of Shipping, 2007).

5.9.2 Modified epoxy

Also known as epoxy mastic, tar-free epoxy and bleached tar epoxy, this group covers a wide range of products and anticorrosion performance capabilities. In service, modified epoxies can be effective. However, as there are many possible modified epoxy formulations it is not possible to make generalizations on their anti-corrosion performance. Epoxy paint application is shown in Figure 5.10.

Figure 5.10 Epoxy Paint Application (M/V YASA AYSEN Engine Room).

Modified epoxies can contain non-epoxy materials which are capable of cross-linking into the final film. They may also contain non-reactive materials, either solid or liquid, which do not take part in film formation, but remain like pigments or extenders in the final coating. If these materials are water (or cargo) soluble, they can leach out over an extended time period leaving a porous or brittle film with reduced anti-corrosive properties (American Bureau of Shipping, 2007).

5.9.3 Coal tar epoxy

Coal tar is a naturally occurring product. Coal tars are available in a wide range of types from liquid to solid. The inclusion of coal tars in a coating results in a very dark brown or black color to the coating, which can be slightly lightened by the addition of aluminum flake pigment for lighter colored paints. However it is unlikely that coal tar epoxies will be sufficiently light in color to be used in compliance with the International Maritime Organization (IMO), PSPC requirements for the final coat. A light colored, non-tar based epoxy top coat can be used over a tar based first coat. However, tar “bleed through” may discolor the top coat.

Certain constituents of the coating can leach out over long periods of time, leaving a more brittle and less protective coating. Coal tar epoxies have a long track record in service and generally have performed well. Since the 1990s they have been phased out of ballast tanks due to health and safety issues for the coating applicators and the recommendation for light colored coatings to aid inspections in ballast tanks (American Bureau of Shipping, 2007).

5.9.4 Solvent-free epoxy

Solvent-free (sometimes referred to as 100 percent solids) paints are, as the name implies, formulated and applied without the need for additional solvents, thereby overcoming the problems of retained solvents in the coating. The viscosity required to spray the paint is obtained from the selection of low molecular weight raw materials or by heating and the use of plural component systems. Typical applications include ballast and cargo tanks. They are sometimes used where volatile organic components (VOC) removal is difficult due to poor ventilation, although it should be noted that the VOC for solvent-free systems is not necessarily zero.

Typical applications for solvent-free coatings include the inside of pipe work, some tanks and other areas where adequate ventilation cannot be provided or for areas where stringent VOC controls are in force (American Bureau of Shipping, 2007).

5.10 Impact and Abrasion-Resistant Coatings

This type of coating is generally applied to the areas of ships which are most susceptible to damage, such as boot-tops and decks, and are sometimes used for the holds of bulk carriers.

The regions around suction pipe ends and bell mouths are occasionally coated with abrasion-resistant coatings as these areas can be subjected to damage from the high flow rates of the cargo or ballast water and may suffer from erosion due to the presence of sand or small particles of debris in ballast water.

Coatings which are described as abrasion- or damage-resistant exhibit an increased resistance to cargo damage, but will not be able to withstand the severe impact of grabs and hold cleaning equipment which results in deformation of the steel itself (American Bureau of Shipping, 2007).

5.11 Shop Primers

Shop primers, also referred to as pre-construction primers, are anti-corrosive coatings designed for application in automated plants to plates or profiles prior to assembly, or construction, at the new building of vessels. Shop primers application is shown in Figure 5.11

Figure 5.11. Shop primers application (M/V YASA AYSEN, 2014).

Shop primers must:

- Provide protection against corrosion during the construction period
- Be spray applicable in a variety of automatic installations

- Permit a very short time between application and being dry to handle
- Not significantly influence the speed of welding or cutting
- Not produce noxious or toxic fumes during the welding or cutting process
- Not influence the strength of the welds or induce weld porosity
- Be able to withstand comparatively rough handling during vessel construction
- Form a suitable base for the widest possible range of coating systems
- Be capable of remaining on the steel and be over-coated or they may be partially removed prior to coating

Shop primers possess properties not normally found in paints designed for other marine purposes. They are applied at low film thicknesses, (typically 15m to 20m) so as to cause minimal interference to the speed of cutting or welding. The most common type of shop primer is zinc silicate. Anticorrosion paint application is shown in Figure 5.12.

Inherent in the formulation of shop primers are fast drying and retarded flow properties. A side effect of this is low cohesive strength. Shop primers that are applied with excessive dry film thickness (DFT) have a pronounced tendency to crack and split when over-coated.

Figure 5.12. Anticorrosion paint application (M/V YASA AYSEN Shanghai Drydock)**.**

To achieve the desired protection and avoid immediate or subsequent cracking, the dry film thickness of the primer must be closely monitored and the manufacturer’s specification followed closely. Shop priming usually occurs in automated paint facilities and regular checks on the efficiency of the abrasive cleaning and shop primer application lines should be carried out.

The weathering characteristics of zinc silicate shop primers depend upon the type of binder, the level of zinc in the primer and the local weather conditions. Longer lifetimes are achieved with higher levels of zinc but the zinc salts caused by atmospheric corrosion must be removed from the surface before subsequent coatings are applied. Iron oxide epoxy shop primers are also used successfully in some parts of the world, but generally do not have a long weathering period. The weathering time will depend upon the local climate.

Where a temporary protection to blast cleaned steel is applied by hand spray, as in a maintenance situation, a suitable anticorrosive holding primer with a reasonably long re-coating interval is often applied at relatively low film thickness. Anti-corrosive primers used for this purpose are referred to as holding primers. They are generally epoxy-based materials capable of accepting other generic top coats (American Bureau of Shipping, 2007).

5.11.1 Antifouling paint

Fuel consumption of vessel increases because of growing organisms in the water clinging to the surface of the ship's surface, the kind of inter-regional transport and so on. undesirable because of the negative consequences. Antifouling agents are used to remove these organisms. Sea chest antifouling paint application is shown in Figure 5.13.

Figure 5.13. Sea chest antifouling paint application (M/V YASA AYSEN).

Tributyltin (TBT) including past tin of today used antifouling agent and their derivatives designated permanent damage to its marine ecosystem and, therefore, by IMO-International Maritime Organization has introduced restrictions and bans on TBT use to be. TBT to be used instead of TBT in accordance with the new antifouling less harmful substances were released.

However, studies with DCM from alternative Irgarol 1051 and showed high toxicity of these substances on algae. Therefore TBT rather than as an alternative market driven / expulsion plan antifouling compounds of potential losses will leave on marine ecosystems and prediction of risks and in various matrices in these chemicals in the marine environment (water, sediment, organisms) measured should be followed. Alternative antifouling paint systems are as follows:

- **Copper-based paints**

It is effective for organisms (fauna), live alone at sea.

- **Tin-free paints**

It is not very effective against fouling, so it is suitable for ships.

- **Coating for preventing adhesion**

Antifouling compounds contain, but when they are applied to prevent the adhesion of organisms by creating a very slippery surface. The surface is easy to clean when fouling occurs due to very slippery.

Fouling watercraft in the water clinging onto the surface of the growing shellfish, algae, as is the layer consisting of live microorganisms.

Fouling has many negative effects. The most important ones are as follows:

- **Fuel consumption**

Very less amounts fouling on ship’s hull can cause significant increase fuel consumption. For example, 6 months unprotected against fouling as a ship sailing over 150 kg / m^2 fouling build up, which reaches a value of 40 000 m^2 of water to be considered when a ship with 6000 tons under the surface. In this case, if the ship’s fuel consumption can cause an increase up to 50%.

- **Air pollution**

CO_2 atmosphere due to the excessive fuel consumption, SO_2, increased levels of NO_x. When considered globally it has been estimated at 22 million tonnes of CO2 in such a case and 0.6 million tons of SO_2 into the atmosphere.

Also used during the removal of antifouling paints on ships solvents also cause contamination of harmful chemicals into the atmosphere.

- **Transport of invasive species**

Invading species are organisms inadvertently transported in various ways from one natural water ecosystems. One of the ways the transportation of these fouling organisms. Invasive species can pose a great threat to ecologically and economically. Economically important species in the region of transfer loss, a reduction in biological diversity and / or may result in the transport of various diseases and invasion.

5.11.2 Synthetic surface paint

Alkyd resin, rosin reinforced, air-drying topcoat is a bright surface paint. Exposed to the harsh conditions at sea surface is a very good guard. Very good adhesion to the substrate. Water, oil and abrasion resistant. Green, red-brown color is a shiny, alkyd-based topcoat phenolic surface paint. 1:21 to 1:41 kg / l having a density of. Before applying, hit the surface of the primer dry, must be free from dust and other contaminants sure. Once applied anticorrosion primers should be applied to the damaged surface. Applied at ambient temperatures above 5°C. + 15°C ’ increases drying times 70-100%.

5.11.3. Synthetic paint superstructure board

On board the ships, which can be applied to the bodywork and interior, alkyd based, air-drying topcoat paint. Excellent durability, has good gloss and color retention. Board paint application is shown in Figure 5.14.

Figure 5.14. Board paint (http://www.scubatr.com/scubaforum).

It must be applied on alkyd-based primers. In the liner surface to be applied to oil, dirt, salt should be cleaned thoroughly by wiping with thinner if necessary. The application surface should be dry and free of moisture. 2-layer synthetic lining, interlining second layer is applied on the first floor. + Applied at ambient temperatures above 5°C. + 15°C ’n longer drying times under 70-100%.

5.11.4 Deck paint

To be resistant to seawater to sink periodically modified, high-quality, alkyd based topcoat deck. Besides the very good color and gloss retention, it is resistant to wear walking in the area. It has good flexibility and adhesion to a variety of anti-corrosive primer. However, the concrete should not be applied directly to inorganic zinc and galvanized surfaces. The ship’s deck paint is shown in Figure 5.15.

Figure 5.15. The Ship’s deck paint (http://cmsas.com.tr/gemi-insaa/).

Before applying, hit the surface of the primer dry, must be free from dust and other contaminants sure. Once applied anticorrosion primers should be applied to the damaged surface. Deck paint should be applied over alkyd or oil-based anti-corrosive primer. In the liner surface to be applied; oil, dirt, salt should be cleaned thoroughly by wiping with thinner if necessary. The application surface should be dry and free of moisture. Very cold weather delayed drying of the application to be avoided. Applied at ambient temperatures above 5°C. + 15°C increases drying times 70-100%.

5.11.5 Synthetic aluminium paint (Interior Department) for warehouse

Synthetic resin, dry air hardening, suitable for use in warehouses in the watercraft, which can be a very good adhesion to metal surfaces, heat-resistant coat.

CHAPTER 6

THE IMPACT ON THE ENVIRONMENT AND THE ECONOMIC IMPACT OF CORROSION

6.1 The Effects of Corrosion on the Environment

Corrosion, starting from the chemical and electrochemical reactions as a result of the material surface, the material depth and the correct action by the ongoing degradation processes that lead to changes in the material properties. This process constitutes one of the major waste item causing great harm.

The most dangerous of all is corrosion that occurs in major industrial plants, such as electrical power or chemical processing plant shutdown can occur as a result of corrosion. This is just one of its many direct and indirect consequences some consequences of corrosion are economic and cause the following;

- **Loss Of Efficiency-** Such as when overdesign and forming pist on the material constructed. If it is a corrosive material/product it will decrease the heat-transfer rate; this could lead to short down of equipment due to corrosion failure.
- **Contamination of a Product-** Example in pipes made with lead (Pb) which is very toxic & dangerous to health. As the lead molecules dissolve in water, thereby contaminating the water that passes through it. E.g. fluid, beer goes cloudy when small quantity of heavy metal is released.
- Damage of equipment adjacent to that in which corrosion failure occurs.
- In ability to use desirable materials due to corrosion.
- It could also lead to loss of valuable material which also include mechanical damage to values, pumps, etc or blockage of pipes by solid corrosion products.
- Hazard or injures to people arising from structural failure or beaked down (e.g. bridges, cars, aircraft etc.) (http://articlesng.com/effects-corrosion-environment/).

Some consequences could be social:

- **Safety:** For example, fire explosion, release of toxic product and construction collapse.

- **Health:** Pollution due to escaping products from corroded equipment or due to a corrosion product itself.
- **Depletion of Natural Resources:** Metal and the fuels used to manufacture them, even the appearance as when corroded material is unpleasing to the eye of course; all the preceding social items have economic aspects also. (http://articlesng.com/effects-corrosion-environment/).

This also could lead to single catastrophic failures, for example a corrosion as mentioned in contamination above induced leak in an oil pipe line, with resulting loss of product and environmental contamination can result, in costly damage that is difficult to either assess or repair as well as massive legal penalties as punitive damage perforation of vessels and pipes allowing escape of their contents and possible harm to the surroundings. For instance, a leaky domestic radiator can cause expensive damage to carpet and decorations. Due to this hazards some methods have been designed to control corrosion (http://articlesng.com/effects-corrosion-environment).

6.2 The Economic Impact Of Corrosion

Corrosion of metals costs the U.S. economy almost $300 billion per year at current prices. Approximately one-third of these costs could be reduced by broader application of corrosion-resistant materials and the application of best corrosion-related technical practices. These estimates result from a recent update of findings of the 1978 study Economic Effects of Metallic Corrosion in the United States. The study was performed by Battelle Columbus Laboratories and the National Institute of Standards and Technology (NIST) and published in April 1995(Davis, J.R., 2000).

The original work, based upon an elaborate model of more than 130 economic sectors, found that in 1975, metallic corrosion cost the United States $82 billion, or 4.9% of its gross national product (GNP). It was also found that 60% of that cost was unavoidable. The remaining $33 billion (40%) was incurred by failure to use the best practices then known. These were called “avoidable” costs (Davis, J.R. 2000).

Over the last two decades, economic growth and price inflation have increased the GNP more than fourfold. If nothing else had changed, the costs of metallic corrosion would have risen to almost $350 billion annually by 1995, $139 billion of which would have been avoidable.

However, 20 years of scientific research and technological change, much of which was initiated because of the 1978 study, have affected these costs (Davis, J.R., 2000).

hese costs. The Battelle panel updated the earlier results by judgmentally evaluating two decades of corrosion-related changes in scientific knowledge and industrial practices. In the original study, almost 40% of the 1975 metallic corrosion costs were incurred in the production, use, and maintenance of motor vehicles. No other sector accounted for as much as 4% of the total, and most sectors contributed less than 1%. The aircraft sector, for instance, was one of the next largest contributors and accounted for just more than 3%. Pipelines, a sector to which corrosion is a recognized problem, accounted for less than 1% of the total cost (Davis, J.R., 2000).

The panel found that the automotive sector probably had made the greatest anticorrosion effort of any single industry. Advances have been made in the use of stainless steels, coated metals, and more protective finishes. Moreover, several substitutions of materials made primarily for reasons of weight reduction have also reduced corrosion. Also, the panel estimates that 15% of previously unavoidable corrosion costs can be reclassified as avoidable. The industry is estimated to have eliminated some 35% of avoidable corrosion by improved practices (Davis, J.R., 2000).

In examining the aircraft, pipeline, and shipbuilding sectors, the panel reported that both gains and losses have occurred, most of them tending to offset each other. For instance, in many cases, the use of more expensive materials has reduced the need for corrosion-related repairs or repainting. Overall, it was thought that for the U.S. economy other than in motor vehicle and aircraft applications, total corrosion costs have been reduced by no more than 5% with a further reduction of unavoidable costs by about 2% (Davis, J.R., 2000).

Corrosion caused by material, energy and labor on the basis of the annual loss rate countries, is approximately 5% of the gross national revenue. This rate of GDP in the United States with $ 444 billion corresponds to 3,1’%.(Figure 6.1) (Webster.,2010). The US Navy, Navy corrosion prevention and control department in the year 2010 report prepared by the total cost of corrosion is described as 7.36 billion dollars. Of this amount $ 3.2 billion in first place (43%) it is located by ship Navy.(Figure 6.2) (Thomas, Dail E.,2010). Data is seen as an important part in the fight against corrosion in the light of the ship industry.

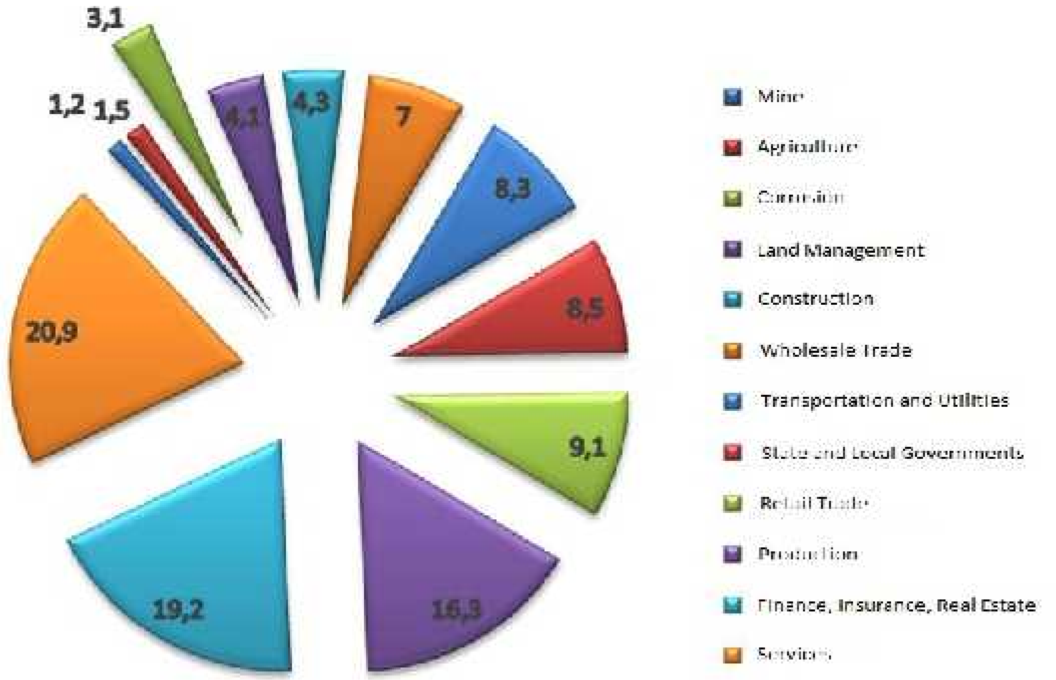


Figure 6.1. US GDP share in the cost of corrosion [http://focusafrica.gov.in/Sector_Profile_Ghana.html].

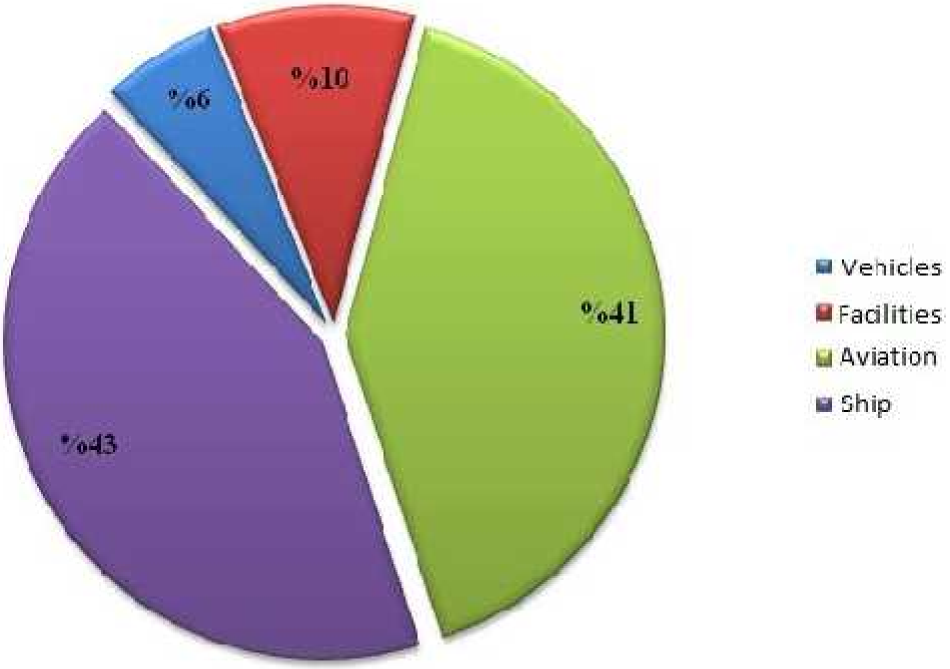


Figure 6.2. Proportional representation total cost of corrosion in US Navy (http://web.firat.edu.tr/iats/cd/subjects/Metallurgy&Material/MSM-87.pdf).

In addition to the financial losses caused by corrosion, as the effects of polluting the environment and endangering human life poses serious damage. A survey result, 67% of buildings were destroyed in the Izmit earthquake was determined that occurrence of corrosion damage. According to official figures the damage, 58 thousand of our citizens lost their lives and 122 thousand 411 thousand of our citizens and caused injuries or severe damage to the building's collapse. The 1999 earthquake occurred due to corrosion damage to the property, roughly the size calculation is made, is reported to be around 168 billion.

Corrosion costs are reduced by the application of available corrosion technology, which is supported by technology transfer. New and improved corrosion technology results from research and development. The proper application of methods to control corrosion (e.g., coatings, inhibitors, and cathodic protection) reduces the cost of corrosion. The costs of corrosion tend to increase with such factors as deferred maintenance and extended useful lives of buildings and equipment. Increased corrosion costs are often realized when higher-performance specifications and more hostile environments are encountered (Davis, J.R., 2000).

Finally, increased corrosion costs result from government regulations that prohibit the use of time-honored methods of protection because of safety or environmental damage. For example, in an effort to reduce smog, the elimination of lead-based paints on houses and bridges, chromate inhibiting paints on aircraft, and oil-based paints throughout industry has had severe repercussions. Substitute water-based paints have not, in many cases, afforded equivalent corrosion protection (Davis, J.R., 2000).

CHAPTER 7

CONCLUSION

Corrosion costs are reduced by the application of available corrosion technology for ships, which is supported and application by technology transfer. New and improved corrosion technology results from research and development. The proper application of methods to control corrosion (coating, inhibitors and cathodic protection) reduces the cost of corrosion.

Finally, prevention of corrosion and methods are particularly well known to be responsible for the technical staff and implemented. These methods are precise, timely and correct implementation of condition of corrosion losses can be reduced by between 30% and 60% of the technology currently implemented. This ratio may reach even higher levels for ships. In my future life I would like work on this subject.

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