Electrochemical Corrosion Phenomenon and Prospect of Materials Selection in Curtailing the Challenges

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Abstract
Corrosion evolution over time has caused severe damage to life; affects the economic, environmental, and mechanical aspects of materials services. Corrosion is an electrochemical reaction; it is a reaction that involves the movement of electrons from one place to another. Electrochemical reactions include both oxidation and reduction reactions; oxidation reactions increase the valence number of material by removing particles from the material, making it positively charged. In other ways, technological advancement has provided several attempts to understand this catastrophe, providing consistent mitigating measures and control toward attaining less cost. This overview study the electrochemical corrosion phenomena and the prospect of materials selection in curtailing the ranging challenges

Keywords: Electrochemical, oxidation, materials, challenges

1. Introduction
In the search for a solution to corrosion at the same time looking for a replacement of the inorganic inhibitors used to mitigate corrosion [1]. Organic inhibitors have proven to be a very worthy alternative [2]. The harmful effect of inorganic inhibitors to the environment and to our health has become a rising concern and does not support safety and sustainability drives [3]. Green corrosion inhibitors have been looked into recent years because of the problem’s inorganic inhibitors present [4]. Green corrosion inhibitors can either be inorganic that comes in the form of drugs or other eco-friendly inorganic material, or they can be organic such as plant extracts or extract oils [5-7]. Moreso, several researches is aimed at finding the inhibitive efficiency of extract oil on the stress corrosion cracking of mild steel by analyzing their potentials effect, the adsorption isotherms and the surface morphology when subjected to various environments [8-10]. This overview covered a general corrosion, its forms, methods of prevention and explicit of coating technologies for materials prevention.
2. **Corrosion is a Phenomena**

Corrosion is an unavoidable process which destroys materials and their properties. Corrosion is seen as the deterioration of a material and its properties due to an electrochemical reaction between the material and its environment [11-13]. Forms of destruction caused by corrosion are quite a number and they depend on a number of factors namely:

- The nature of the metal or alloy.
- Foreign matter or other inclusions on the surface of the metal.
- The homogeneity (similarity) of the metal structure.
- The corrosive medium used and its nature.
- Environmental factors of incidence such as: temperature, velocity movement, presence of oxygen etc.
- Presence of stress within the structure. It could be residual, applied, steady or cyclic.
- Presence of oxide scales (continuous or broken).
- Presence of built in crevices.
- The galvanic effect of two dissimilar metals in contact.
- The effect of stray currents etc [3].

Various corrosion phenomena can be categorized by 3 main factors according to ASME (2000):

- Appearance of corroded material.
- The mechanism of corrosion.
- The nature of the corroded material.

### 2.1. Electrochemical Basis of Corrosion

For corrosion to take place in a material there has to be a flow electricity from one point of the metal to another point in the metal through a solution capable of electrical conduction. The portion of metal from which current leaves to enter the solution is called the anode. This is the part of the metal that gets corroded. The part of metal the current from the solution penetrates is called the cathode. The anode and cathode are called corrosion reaction electrodes, and their polarities are negative and positive respectively. The electrodes can be from different metals or different places on the same piece of metal [4]. There are many factors that consider which metal or part of the metal is the negative electrode or positive electrode, some are listed below:

- The reactivity of the metals in contact with one another.
- Variation of oxygen concentration over the surfaces of the metal.
- Variation in the homogeneity of metal surface.
- Variation in the acid concentrations of the surfaces.

An electrolyte is an ionic solution capable of conducting electricity. Its ability to conduct electricity is because of the presence of ions in the solution. An electrolyte has ions in its solution and this gives it the ability to conduct electricity. The ions could be either positive or negative, and this is the solution that provides the corrosive environment for the electrodes [5]. For corrosion to occur there has to be electrodes, an electrolyte and an electric connection between the electrodes. Corrosion is an electrochemical reaction; it is a reaction that involves the movement of electrons from one place to another. Electrochemical reactions involve both oxidation and reduction reactions; oxidation reactions increase the valence number of a material by removing electrons from the material making it positively charged. While reduction reactions reduce the valence number of a material by adding electrons to the material. In corrosion both reduction and oxidation reactions occur at the same time and the
oxidation of the anode is what makes the anode corrode. Oxidation is the cause of the dissolution of the material as current leaves it to enter the solution.

2.2. The perspectives of corrosion and their forms

Stated below are the various ways in which corrosion can affect metals and their properties:
When wastage of metal occurs at much the same rate over large areas the corrosion said to be taking place is called uniform corrosion. In the situation of a particular metal in a particular environment the service life and rate of corrosion are easily measured or predicted. In order for corrosion to be completely uniform it is absolutely necessary that the material and the environment be homogeneous. Meaning that the environment should be the same across all areas of the metal and the metal should be of the same composition across the environment [6].

When two metals which are not similar are in contact directly or indirectly or chemical differences exist in the corroding medium galvanic corrosion can ensue. Different types of metals all have different tendencies to corrode, so when different metals are in contact electrons flow to the cathodic metal from the more anodic metal. When this happens in the presence of an ionic solution a complete circuit is created hence corrosion [4].

Pitting corrosion is a strong form of corrosion which is localized and which with time will perforate the metal by the formation of deep narrow pits. Pitting attack is usually found with metals that passivate particularly austenitic stainless steels [7]. Pitting usually initiates when a local surface heterogeneity leads to the local failure of the passive film. This failure makes that place an active anode surrounded by a passive cathode which leads either to passivation or the rapid pitting corrosion of the small active area [8]. On the surfaces of metals in their openings or otherwise called crevices, crevice corrosion occurs which narrows down for different solutions to crack and get trapped in which could either be alkaline or acidic. The cracked in parts posses a characteristic of anodism and are surrounded by parts which inevitably become cathodic. The crevice regions are extremely corrosive due to the mismatch of the effects of both the anode and cathode and contribute to material decomposition [9].

Intergranular corrosion entails increased rust or disintegration around the product’s grain borders, even as the metal surface is not corroded. Intergranular corrosion affects the material’s microstructural fibers, resulting in decreased hardness, becomes unable to resist tensile stress, and may crack without warning. This can be induced by galvanic components [4]. The corrosion of some alloys of metals occurs by the selective dissolution of the more reactive component of the alloy leaving the more noble component as a porous residue [10]. The most common example known for selective leaching is the dezincification of brass. Brass is an alloy of zinc and copper, and zinc is the more reactive component in the alloy. At high temperatures zinc dissolves to leave copper as a residue. In high concentrations of zinc, the attack is uniform and is localized at lower concentrations.

Erosion corrosion is a collection of processes of corrosion that exhibit the properties of materials affected by reduction and oxidation reactions as well as being exposed to the effects of gradual wear and tear of the material [11]. Modeling of erosion applies to material design which can be used to prevent the erosion of a material by flowing fluids which have both effects of wearing of the material and also providing a means for corrosion [12]. It is dependent on three things namely:

- Nature of the protective film, and its environment
- Flow rate of the flowing liquid.
• Whether or not the liquid carries suspended solids.

On the other hand, fretting corrosion, is the type of corrosion that occurs at areas subject to vibration and slip together with the effect of corrosion. It is caused by the protective oxide layer of metals undergoing mechanical destruction on the fretting surfaces which lead to the rapid corrosion of the bare metal surfaces [13]. In a situation where alternating stresses are applied to a metal that is corroding fracture to that metal due to fatigue would occur. Corrosion fatigue differs from the normal failure due to mechanical fatigue in the fact that firstly it fails in a fewer number of cycles and there is no relationship between the tensile strength and the corrosion fatigue strength. Even if the tensile strength of a particular material is increased it will still fail at the same corrosion fatigue limit [13].

With hydrogen embrittlement corrosion happens at the positive electrode, because this is the area that corrosion effects are usually absent, the hardened component. Hydrogen molecules are produced in the cathode utilizing reduced hydrogen ions and these molecules bubble out as hydrogen gas [14]. Vital corrosion propagation is the stress corrosion cracking which is the spontaneous fracture of a metal due to the combined effects of a tensile stress and a specific corrosive medium. In the absence of any of the factors that cause this phenomenon stress corrosion cracking would not take place. It can lead to the sudden unexpected failure of metals [15]. The stresses that can cause stress corrosion cracking can be externally applied loads or they can be internal. Internal stresses are residual stresses gotten from processes such as cold working, welding or heat treatment. The corrosive medium that causes stress corrosion cracking is different from metal to metal [16].

3. Corrosion Control Measures in Engineering Science
Practically it is not possible to eradicate the effect of corrosion completely but it can be reduced to the barest minimum. Corrosion control includes all the processes, techniques and methods used to mitigate the effect of corrosion and its damages on a metal (Revie, 2008). The feasibility of corrosion control methods depends on the material’s nature and its surrounding environment it is exposed to during service. The corrosion control methods listed below can be divided into active and passive corrosion control techniques. Active corrosion control entails taking active control of the effect of corrosion in the system while passive corrosion control involves hampering the effect of the environment on the metal by removing one of the components from the process. Methods of corrosion control are listed below:
• Material selection for design and applications,
• Proper system design,
• Alteration of environment,
• Surface coating,
• Electrical protection
• Application of inhibitors [18].

3.1. Material Selection for Design and Applications
Material selection is the most common method used to mitigate the effect of corrosion on a metal. Proper material selection process saves the use of needless stress over devising any of the other methods used in the mitigation of corrosion. A popular misconception is the corrosion resistance of stainless steel. The aimless selection of stainless steel has been the cause of countless failures caused by corrosion because it has been based on the false notion that it has the best corrosion resistance at a reasonable cost [19].
Listed below are some natural metal-corrosive combinations; that is combinations in which the material has a natural resistance to the environment. These combinations can be coupled with other corrosion control techniques:

- Stainless steels - Nitric acids
- Aluminum - non staining atmospheric exposure
- Hastelloy (Chlorimets) - Hot hydrochloric acid
- Monel - Hydrofluoric acid
- Nickel and its alloys - Caustic solutions.
- Lead - Dilute sulphuric acid
- Steel - Sulfuric acid (concentrated)
- Tin - water (distilled)
- Titanium - Oxidizing solutions that are hot and strong.
- Tantalum - Ultimate resistance [20]

3.1.1. Alteration of Environment

Environment alteration is a means of controlling corrosion that has many applications and is very effective. The constraint on altering the environment normally depends on the type of operation that is taking place, but nevertheless is an effective way of reducing corrosion. Changes that are normally applied to the environment are:

- Changing concentration of the solution
- Removing oxygen or oxidizers
- Reducing the velocity of the solution
- Lowering the temperature of the solution [21]

The above provide an effective way of mitigating corrosion but there are exceptions to each of them. For example, Lowering the temperature normally reduces the corrosion rate but for seawater where oxygen solubility is decreased by boiling a higher temperature means lower corrosion rate. For metals that passivate removing oxygen is detrimental to the metal. For metals that are susceptible to erosion-corrosion reducing velocity is efficient but metals that passivate have a better resistance to corrosion to mediums that flow as compared to mediums that are still(stagnant).

3.1.2. Proper System Design

As mentioned before material selection is a very important means of avoiding unnecessary costs in controlling the corrosion of a material. Proper system design is just as important in the controlling of corrosion as the proper selection of material. An allowance for corrosion should be included in design as well as the strength and mechanical requirements. The proper design of systems is also dependent on the materials being used as they differ in their mechanical characteristics [21]. Listed below are some design rules that should be followed to obtain the best corrosion resistance as regards the design:

- Design to exclude air. This rule comes as a result of trying to remove oxygen as it is the cause of most cathodic reactions. Eliminating oxygen reduces the rate of corrosion.
- In corrosive mediums excessive mechanical and stress concentrations should be avoided to avoid problems such as stress corrosion cracking.
- Components of a system that fail often during operations should be placed in such a way that it is easily replaceable.
- Containers that store liquid should be designed in such a way that they drain easily; that is they’re sloped towards the drainage. This is to avoid any liquid lying stagnant within the tank.
• Weld instead of using rivets as riveted joints provide access to crevice corrosion.
• In designs that have piping systems, sharp bends should be avoided. This also includes areas where the direction of fluid changes suddenly. This design flaw promotes erosion-corrosion in design systems.
• Electrical contact should be avoided between metals that are not similar, as this leads to galvanic corrosion. Unless unavoidable it is advisable to use similar metals throughout design and in cases where it is not possible electrical insulation should separate dissimilar metals.
• During design it is advisable to avoid designing places where heat can be concentrated. Heat exchangers and other devices that deal with heat should have a uniform temperature gradient across the structure.

The most important general rule which should be followed is to avoid heterogeneity in design. Uneven stress and heat distributions, dissimilar metals, and other differences between points in a system eventually lead to corrosion damage [22].

3.1.3. Surface Coating
Surface coating is a process of putting a thin layer or layers of a substance as a covering substance on a surface (normally called substrate) as a means to improve its properties and to create a protective barrier against its reaction with a corrosive environment. Surface coats are applied mainly for the purpose of protecting a barrier of corrosion but provide other useful benefits such as:

• Resistance against scratches and abrasions
• Insulation of flow of electric charge
• Provides an improved Physical appearance
• An improved heat resistance etc. [23].

Surface coatings can be generally grouped into two which are coatings that are not metallic, and coatings which are metallic. Non-metallic coatings can be further sub-divided into: organic and inorganic coatings.

3.1.4. Inorganic Coatings
Inorganic coatings are produced by a chemical galvanic or non-galvanic reaction [24]. They fulfill their objective with adding a film which is slim with increased resistivity to corrosion on the substratum. Types coatings that are inorganic are listed as: oxidation, enamelling, phosphating and cementing. Oxidation includes the binding of a metal such as steel with an oxide layer by heating up at elevated temperatures in an electrolyte cell under the presence of water, chemical oxidation procedures of other organic products or anodic oxidation. Phosphating involves an iron phosphate film that coats the plate. Enamelling is the process of coating the metal with a sheet of glass by immersing it in a powdered glass suspension accompanied by my melting of high temperature glass on the surface of the metal. Usually cementing or a cement coating is applied to the interior of steel pipes carrying waste water [25].

3.1.5. Organic Coatings
Organic metal surface coatings are the oldest and most popular corrosion protection method, which is attributed to their make-up. Organic coatings consist of usually carbon-rich materials and their derivatives derived from renewable sources, with properties such as being inert to chemical reactions and possessing a quality of having porosity which is low. Chemical coats include materials such as: binders, pigments, solvents, adhesives and other chemicals, and may be formulated using either physical or electrostatic methods [26]. The principal variable is the binder.
3.1.6. **Metallic Coatings**

Metallic coatings involve using metals, their alloys and their compounds to create a covering on a substrate to prevent corrosion. The methods of depositing metal coatings include:

- **Electroplating:** This involves immersing the substrate in a solution of the coating material and then passing a direct current between the substrate and electrode to coat the substrate.
- **Flame Spraying:** This method consists of feeding into a molten flame a metal or material, such that the metal is separated into finely fragmented liquid particles and then spread across a sheet. The porous coating is a strong foundation for painting, since it creates a strong bond [27].
- **Cladding:** It means bringing together a thin sheet of metal by rolling together two thin sheets of metal.
- **Hot dipping:** The method in metal painting includes immersing a surface in a bath in low melting point powder with painting such as tin and aluminium. This is one of the earliest metal-coating processes [28].
- **Vapor Deposition:** This method is carried out in a high vacuum chamber where the surface metal is electrically heated and the vapor collects on the substrate content [29].
- **Diffusion:** This metal coating method includes heat treatment that induces alloy forming by the diffusion of one product to another [30].

3.1.7. **Electrical and Cathodic Protection**

The electrical protection of a material involves the use of electrons to prevent corrosion of the material. This electrical protection can be divided into 2 main categories: anodic and cathodic protection [31]. Cathodic protection is a way of corrosion protection that simply involves the supply of electrons to the metal to be protected. This supplication of electrons tends to promote cathodic reactions and suppress anodic reactions thereby reducing the rate of corrosion. There are 2 ways to accomplish this: Firstly, this can be accomplished by an appropriate galvanic coupling. Secondly this can be accomplished by an external power supply.

3.1.8. **Galvanic Coupling, Electrical and Anodic Protection**

Galvanic coupling is the process of connecting 2 metals electrically with the intention to protect one of them by the transfer of electrons. The metal which becomes the sacrificial anode is the metal between the 2 metals that is higher in the electrochemical series. This metal is more reactive therefore it transfers electrons to the cathode which is then protected. Electrical power supply is another way of cathodic protection which involves the supply of electrons to the cathode by means of an external power source. Anodic protection is different from cathodic protection as its aim is to form a protective film on the material caused by the externally applied anodic currents. This form of protection applies to materials which passivate. To successfully achieve anodic protection a potentiostat is required. A potentiostat is an electronic device that keeps a metal at a particular potential with a reference electrode.

3.2. **Application of Inhibitors**

An inhibitor is a chemical substance which when applied in little amounts slows down the rate of reactions in processes. These inhibitors in relation to corrosion slow down the corrosion rate [32]. There are different types of inhibitors:

- **Adsorption inhibitors:** Below this class of inhibitors is the inhibitor used in this project. In general, adsorption inhibitors constitute the main classification of
substances used for inhibition. These are compounds of an organic nature that adsorb on the surface of the metal and inhibit anodic-cathodic reactions [33].

- Hydrogen evolution poisons: These reactions specifically retard the hydrogen evolution reactions which occur at the cathode. These substances as a consequence are effective in only acidic environments.
- Oxygen scavengers: These types of inhibitors remove dissolved oxygen from solutions [34].
- Oxidizers: These are like the opposite of scavengers and are applied mainly to metals that exhibit the active-passive transitions
- Vapor Phase Inhibitors: These inhibitors possess a high vapor pressure so they can atmospherically inhibit a substance without being in direct contact with it. They just have to be in the vicinity of the metal they are to protect and by the processes of sublimation and condensation protect the metal. They are similar to adsorption type inhibitors as they are predominantly organic inhibitors [35].

Above listed are the various types of inhibitors used in corrosion.

**Conclusion**

This study has successfully looked into the overview perspectives of the electrochemical corrosion phenomena and the prospect of materials selection in curtailing the ranging challenges. The corrosion challenges were seen to have been caused by several factors ranging from materials inclusion, environmental subjection, dissimilar coupling, etc., Corrosion evolution takes under several vibrational influences. A practical method was posed through material selection and application of design responses in retarding consistence occurrences.

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